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TEXT-BOOK OF

ANATOMY

EDITED BY

JAMES COUPER BRASH

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PROFESSOR OF ANATOMY, UNIVERSITY OF EDINBURGH

NINTH EDITION

ILLUSTRATED BY 1252 TEXT FIGURES,
699 OF WHICH ARE PRINTED IN COLOURS,
AND 88 PLATES INCLUDING
145 RADIOGRAPHS

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TO

Sir William Turner, K.C.B.

LL.D., D.C.L., M.B., D.Sc., F.R.S.

PROFESSOR OF ANATOMY, UNIVERSITY OF EDINBURGH, 1867–1903
VICE-CHANCELLOR AND PRINCIPAL, 1903–1916

IN RECOGNITION OF

HIS EMINENCE AS AN ANATOMIST

AND HIS INFLUENCE AS A TEACHER

THE FIRST EDITION

OF

THIS VOLUME

WAS DEDICATED

BY THOSE OF HIS FORMER PUPILS AND ASSISTANTS

WHO CONTRIBUTED

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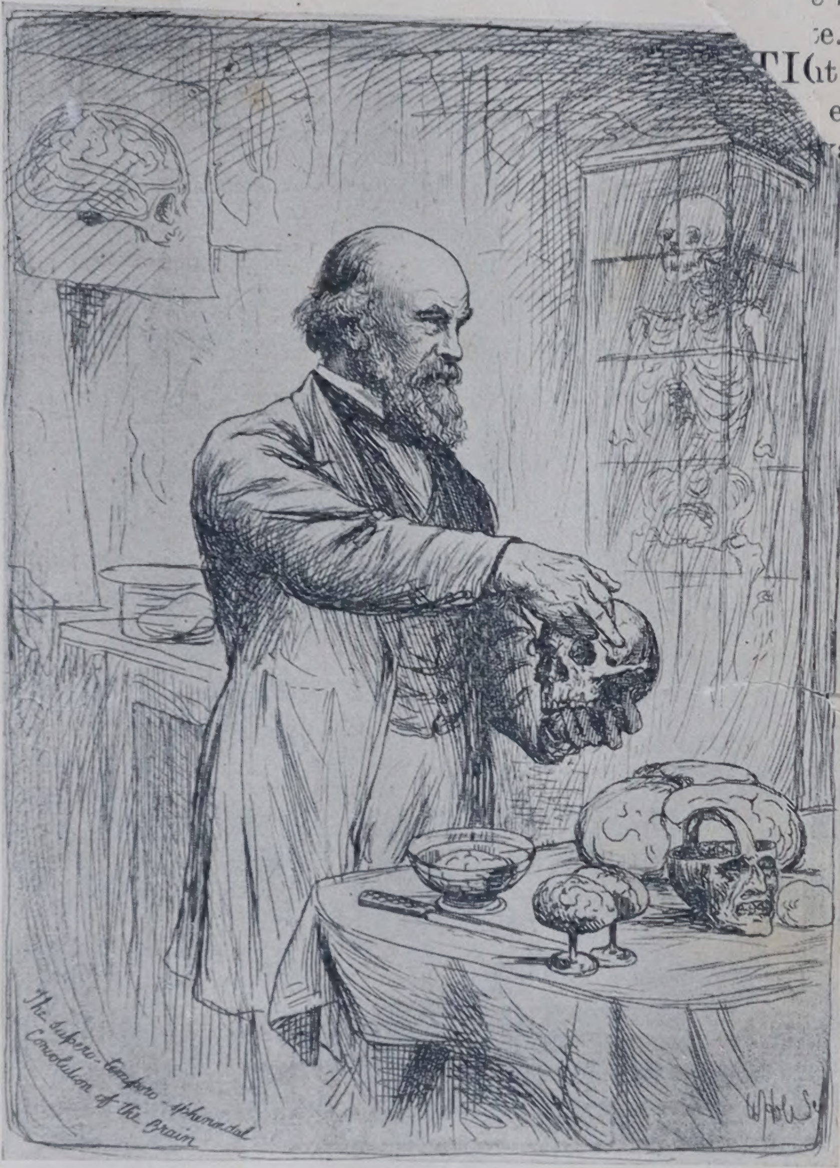

From a drawing by] [William Hole in 1884

WILLIAM TURNER
ANATOMIST

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FIRST EDITION . . .	*1902*	D. J. CUNNING
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PREFACE TO THE NINTH EDITI

THE interval of seven years since the publication of the eighth edition of
Text-Book of Anatomy has brought some changes in the authorship o
Dr. E. B. Jamieson, who had been responsible for the *Osteology* Secti
and co-editor since 1937, has retired; and the present editor desires
grateful appreciation of a harmonious co-operation that has proved
him personally and in the maintenance of the reputation of the Text-B

The Section on *Osteology* has been taken over by Dr. R. G. Inkste
the University of Edinburgh, and he has revised in particular the ac
development and growth of bone with some new illustrations.

The untimely death of Professor D. M. Blair has caused a vacancy i
ship of the Section on *Arthrology*. This has been filled by Profe
Walmsley, University of St. Andrews, who has amplified and illustrated th
on the development of joints.

The Text-Book has suffered another severe loss by the death of Sir
not long after his appointment as Principal of the University of Edinbur
intimated that he would be unable to retain charge of the Section on
Surgical Anatomy, and his place has been taken by his successor in the R
of Clinical Surgery, Sir James Learmonth. The editor feels sure that th
association of the Section, originally contributed by the late Sir Harold
this famous Chair will be very gratifying to all former readers of the Text
in particular to graduates of the University of Edinburgh. Sir James
has revised the Section in detail, with some reduction in its length, and he h
useful Tables of the segmental innervation of the limb-muscles.

The editor, with a sense of personal loss of a friend and colleague, rec
the death of one of the contributors, Emeritus Professor Arthur B. Applet
the preparation of this edition was nearing completion. He had revised t
less Glands before his fatal illness overtook him, and his name therefore sta
author of that Section for which he had been responsible in the two previous

The editor records also with regret the death at an advanced age in
Emeritus Professor Arthur Robinson, the last surviving original contrib
editor of the fourth, fifth and sixth editions. The time has now come, t
for an alteration in the form of the Sectional headings which hitherto have
the name of the original contributor and in some instances the names of su
revisers; in this edition the name of the present contributor alone appears.

Apart from the items already mentioned, the text of this edition has ag
thoroughly revised by all the contributors and broug up to date by the in
of numerous references to new work in their several su ts. The editor
to record his appreciation of their unfailing co-operation t this has e
Special note may be made of the new material bearing the earliest st
human development incorporated in the Section on *Embryology*, Professor (
revised and illustrated account of the broncho-pulmonary segments, and t
arrangement of Professor West's Section with its w title, *The Skin and the S*
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portant innovation in this edition of the Text-Book is the provision erences at the end of each Section. Previous editions had included ımber of references to recent work, either in the text or as occasional it has been suggested that it would be much more convenient and ;o have these gathered together and amplified into brief biblio- ;ical references have not been omitted; but in general the several ; including recent scientific papers and monographs, have endeavoured ; sources which themselves provide more complete bibliographies. de also references to the sources of all borrowed illustrations, old ıddition to its character as a student's text-book, it is hoped that by ıningham's Anatomy may serve also as an up-to-date work of reference ents and others. Every endeavour has been made to ensure accuracy ;nces, both in the text and in the lists, which have been printed in th standard practice.

ıtions have again been extensively revised, and the increase of twenty- al number of text-figures does not indicate the extent of that revision. ıstrations have been omitted, some replaced and some repetitions hers, as in previous editions, have been improved by alteration, by by the addition of colour; and many have been replaced by entirely s. The number of new or altered illustrations is actually one hundred ɔne, of which fifty-five have been specially prepared, eighteen altered by addition of colour, and forty-eight borrowed or adapted from other . Special mention may perhaps be made of the new series illustrating ı development and the external form of the embryo.

jority of the new drawings have been prepared in the Department of edical Illustration Division) of the University of Edinburgh—a few of r. Clifford Shepley, but most by Miss Ann Brown, to both of whom the eatly indebted for the care and artistic skill they have brought to bear ɛ. His thanks are due also to Mrs. Yvonne Hill for a considerable number matic figures which also witness her skill as an artist. Fig. 606 has been Miss Nancy Joy of the Department of Anatomy, Toronto; Fig. 391 is . of Mr. William Cruickshank, Department of Anatomy, Aberdeen; and : M. R. Drennan, University of Cape Town, has provided Figs. 533 and e editor acknowledges also the provision of photomicrographs by Professor ısley for the Section on Arthrology, and the preparation by Dr. J. W. A. cth, of this Department, of the new photomicrographs of blood-vessels for ;ular System.

;ditor desires to thank most cordially the various authors and publishers ; so courteously granted permission to use illustrations borrowed or adapted publications. In addition to the statement of authorship and source orded with each figure and in the lists of References, acknowledgment is ;he following publishers and editors for the use of the figures mentioned: ıerican College of Chest Physicians (604, 1215); Messrs. Baillière, Tindall (827); The Blakiston Company (108 B.C.D., 109 B., 110 B.); Chicago ity Press (989); The Clarendon Press (124, 126); Edinburgh University ;, 28); MM. Hermann et Cie (1072); MM. Masson et Cie (127); and the ; and Proprietors of the *American Heart Journal* (1066); the *Anatomical* (718); *Brain* (8[illegible]; the *British Journal of Surgery* (1224); the *Bulletin of ns Hopkins Hos*[illegible]*l* (713); and the *Journal of Anatomy* (46, 733).

;cial thanks are due to Dr. George W. Corner, Director of the Department of ;ology (Carnegie Institution of Washington), Baltimore, for his very cordial ;sion, on behalf of the Department and the various authors concerned, to uce a considerable number [illegible]f illustrations from the Contributions to Embry- (Figs. 37-40, 42-44, 47,[illegible]5, 72, 112-116, 118, 119) and in particular for

providing original photographic prints for Figs. 39, 40, 42 and 43. In addition, the editor is deeply indebted to Dr. Arthur T. Hertig for his personal permission to reproduce his illustrations of the 2-cell and free blastula stages of human development (not fully published at the time), and to Dr. Corner for providing photographic prints of these beautiful specimens (Figs. A & B, p. 16) and of the perfect chorionic vesicle, with embryo in its amnion, reproduced as Fig. 121 A.

The series of Radiographic Plates, which has been a feature of the seventh and eighth editions, has again been revised and made still more complete. The total number of Plates has been increased from eighty-four to eighty-eight; and they have been rearranged and all duplicates eliminated. Twenty-three entirely new radiographs have been added and five others replaced by better examples. In addition, three Plates, reproducing, by kind permission of Messrs Faber & Faber, Ltd., nine illustrations from Professor R. D. Lockhart's *Living Anatomy*, have been added; and a classical figure from William Harvey has been included (Pl. LXXIX).

As in previous editions, the great majority of the radiographs appear in negative reproduction, only those illustrating arterial injections (Pls. LXXXI-LXXXVII) being shown as positives. Radiographs are examined clinically as negatives, and the contrast presented by these positives may enable the student to appreciate the points made in the Appendix on the technique and principles of radiography. In this connection, mention may be made also of the addition there of two simple diagrams illustrating these principles.

The editor is indebted to several colleagues for the provision of new radiographs. Dr. D. R. Maitland and Dr. J. D. Recordon of the Radiological Department, Royal Infirmary of Edinburgh, have assisted him in this way while acting as Demonstrators of Radiography in the University Department of Anatomy; and the new radiographs illustrating the paranasal sinuses were prepared by Dr. Peter Aitken. Dr. R. G. W. Ollerenshaw, Manchester Royal Infirmary, kindly prepared negative prints of his parotid and submandibular sialographs (Pl. XLIX), and Professor Norman M. Dott (through Dr. C. A. Gleadhill, Senior Registrar, Neuro-surgical Department of the Royal Infirmary) has again placed the editor in his debt by providing new ventriculographs (Pls. LXXIV, LXXVI) and cerebral arteriographs (Pl. LXXX). With the exception just mentioned (Pl. XLIX), all the prints, negative and positive, for the reproduction of the new radiographs have been prepared by Mr. John Borthwick of this Department.

With regard to nomenclature, the Birmingham Revision (B.R.) continues to be used, and the policy of eliminating synonyms in a students' text-book has been carried to its conclusion; but in a few instances latin terms have been retained (in brackets), where these may help the student to appreciate the derivation of related words.

In addition to the cordial co-operation of all the contributors, the editor h received valuable assistance in the reading of page-proofs from Dr. Helen Barret who has made numerous useful suggestions, and from Dr. R. G. Inkster who ha been responsible also for the preparation of the Index.

Lastly, the editor takes pleasure in recording that he prepares this Preface in the centenary year of his own teacher and the original editor, Daniel John Cunningham (1850–1909), and in pointing out that this ninth edition may serve, during its currency, to celebrate the Jubilee of Cunningham's *Text-Book of Anatomy*, first published in 1902.

J. C. Brash.

Department of Anatomy,
University of Edinburgh,
June 1950.

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INTRODUCTION

TO

HUMAN EMBRYOLOGY

by J. C. Brash, *M.C.*, M.A., M.D., D.Sc., F.R.C.S.Ed., F.R.S.E.
Professor of Anatomy, University of Edinburgh

Human Embryology—the study of the human embryo and its development—treats of the phenomena of the intra-uterine period of life, from the fertilization of the ovum to the birth of the child. But there is a cycle of events in the relation of succeeding generations; and so it is necessary first to consider the life-history of the germ-cells which link one generation to the next.

It has been explained in the General Introduction that all the cells of the body are the descendants of a single cell which is the starting point of each individual. The innumerable cells derived from the fertilized ovum are separable into two main groups, a larger group—the **soma-cells**—from which the body of the individual is developed, and a much smaller group—the **germ-cells**—upon which

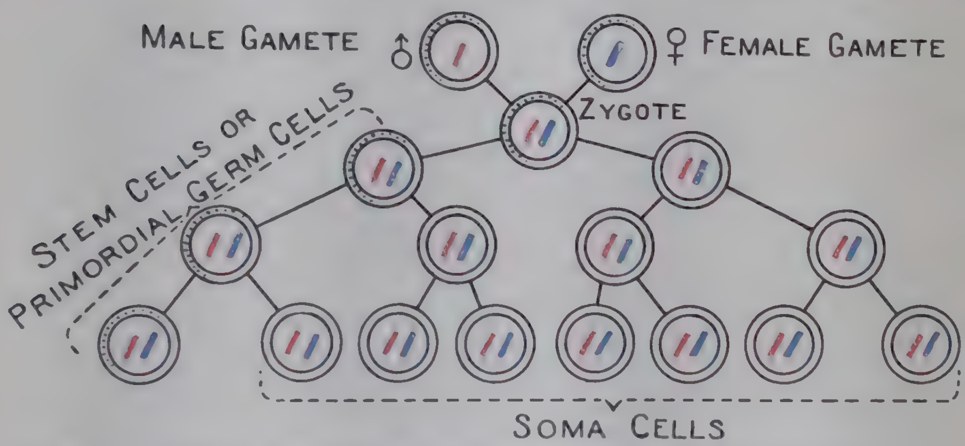


Fig. 9.—Diagram showing the Descent of Germ-cells and Soma-cells.

the life of the species depends (Fig. 9). The germ-cells are lodged in the body of the individual in the **sex-glands**—**ovaries** in the female, **testes** in the male.

The germ-cells undergo a process of ripening, known as *maturation*; and when mature they are called **gametes**. A new individual is initiated by the union of two gametes—a male gamete, or **spermatozoon**, and a female gamete, or **mature ovum.** The new cell thus formed is a **fertilized ovum** and is known as a **zygote**—a term conveniently indicating that it is formed by the yoking together of two individuals and that it contains therefore the potentialities of both (Fig. 9).

The human zygote is about 150 μ in diameter and of scarcely measurable weight. From it are produced not only a new individual and the germ-cells of the next generation, but also a series of membranes and appendages necessary for growth and development during intra-uterine life.

The **ontogenetic** or **developmental history** of the individual is usually considered to extend from the formation of the zygote to the attainment of full adult growth. The **period of development** thus defined is divided into an **intra-uterine** or **pre-natal** period and an **extra-uterine** or **post-natal** period.

The intra-uterine life of human beings lasts for about nine months, and is itself divided into three secondary periods:—(1) The **pre-embryonic period**, during which the growing zygote is *implanted* in the mucous membrane of the uterus (*endometrium*), and is differentiated into embryonic and non-embryonic portions; this period lasts rather less than two weeks. (2) The **embryonic period**, in which the rudiments of all the main organs of the adult are developed, although the embryonic part has not yet assumed a definitely human form; this period runs to the end of the second month. (3) The **fœtal period**, from the end of the second month, when the embryo begins to assume a definitely human appearance and is called, thenceforth, a **fœtus.** The fœtal period ends at birth, when the fœtus becomes a child and passes into the stage of *post-natal development.*

During the fœtal period growth proceeds rapidly. It is especially rapid during the ninth month; and at birth the child usually weighs about seven pounds.

During the first-stages of the post-natal period—**infancy, childhood, adolescence**—growth and development still proceed until the adult condition is attained; then follows a period of **maturity**, which passes insensibly into the last stage of all—**senescence**—which ends in natural death. In the following pages it is the intra-uterine period of life which will be considered and more especially the phenomena of the first two months—the pre-embryonic and embryonic periods.

The aim of this Section is to provide the student with a general account of the formation of the embryo—*embryogeny*—so that he may be in a position to understand the more detailed paragraphs on the development of organs—*organogeny*—which he will find throughout the text-book. Some account will be given also of those important extra-embryonic organs peculiar to intra-uterine life—the **fœtal membranes**—which are responsible for the protection of the embryo and fœtus and provide, by the connexion established between one of them and the uterus, for its physiological needs (Barcroft, 1946).

For further information on human development the student should consult the special works on the subject included in the list of References at the end of this Section.

Growth and Differentiation.—In the development of the embryo two main processes go hand in hand, but **growth**—increase in size by cell-division—must be carefully distinguished from **differentiation**—the specialization of cells in the formation of tissues and the rudiments of organs. Growth in general depends upon a proper supply of nutriment, and the growth of some parts of the body depends further upon special chemical factors, either derived from food-material or secreted into the blood by organs of the body itself. The differentiation of a group of cells to form the rudiment of an organ may be due to inherited potentialities located in that particular group—such rudiments of organs are said to be 'self-differentiating'; or it may depend on the situation of the group of cells and the influence of neighbouring cells and rudiments upon them. Experiments have been made by the simple excision, or the transplantation into other regions, of portions of embryos, and by the cultivation of excised portions, either as grafts on other growing tissues (such as the chorio-allantoic membrane of the chick) or inserted in suitable nutritive media (tissue-culture). It has thus been shown that the power to form parts and organs may be more widespread in the cells of an embryonic layer than is apparent, and that their development in a particular place depends on the influence of other parts already differentiated. Such 'dependent differentiation' of parts may be illustrated by two classical examples of the results obtained by the methods of *Experimental Embryology.*

The formation, and therefore the situation, of the axial structures in the embryonic area depends upon an influence, known to be chemical, exerted by the tissues in the primitive streak: these are believed to correspond with the dorsal lip of the blastopore in lower forms which, because it has this power, has been called the "Organizer" (Spemann & Mangold, 1924). The formation of the lens-vesicle of the eye from the ectoderm depends, in some species, on the presence of the underlying optic cup—a self-differentiating structure which grows out from the fore-brain; if the optic cup is removed the lens does not appear, but a lens-vesicle may be induced to form from another part of the ectoderm by transplanting the cup (Lewis, 1904).

Progressive differentiation of the cells of a region is illustrated by experiments on limb-buds. Part of a limb-bud which, if left *in situ*, would form a particular part of the limb may, if transplanted soon enough, 'regulate' so as to form a complete limb. After a time, however, the cells of the limb-bud are differentiated, chemically if not morphologically, to form a 'mosaic', any part of which has its particular destiny fixed and is incapable of 'regulating' to form a whole limb; yet, for a time, it may still be capable of producing the whole of one segment of the limb. Thus, a portion of the thigh-region of a chick-embryo, transplanted (Murray & Huxley, 1925) or grown by tissue-culture methods (Fell & Robison, 1929), will produce not a complete limb but a femur only.

For further information on the control of development see the works of Huxley & De Beer (1934), Spemann (1938) and Waddington (1935, 1940).

There are also many general chemical problems in the development of the embryo, and for information on this aspect of the subject and on the history of Embryology the student should consult Needham (1931; 1934; 1942).

GERM-CELLS

The majority of the multitudinous descendants derived from a zygote are soma-cells, which form the tissues of the body; but a minority, which inherit all the potentialities of their parents, remain as **primordial germ-cells** or stem-cells. Fresh evidence has recently been brought forward to show that the primordial germ-cells are segregated from the soma-cells at a quite early period (Fig. 9), and that they migrate from the wall of the yolk-sac to the genital ridge of the embryo (Witschi, 1948). There are three main stages in the life-history of germ-cells—multiplication, a growth-period, and maturation. Though the functions and the life-histories of germ-cells are quite different from those of soma-cells, nevertheless the structural characters of the two groups of cells are very similar; in particular they both multiply by the same process of mitotic division (p. 8). Each primordial germ-cell thus produces many descendants which are lodged in the sex-glands—female sex-cells or **oogonia** in the ovaries, male sex-cells or **spermatogonia** in the testes—where they undergo further

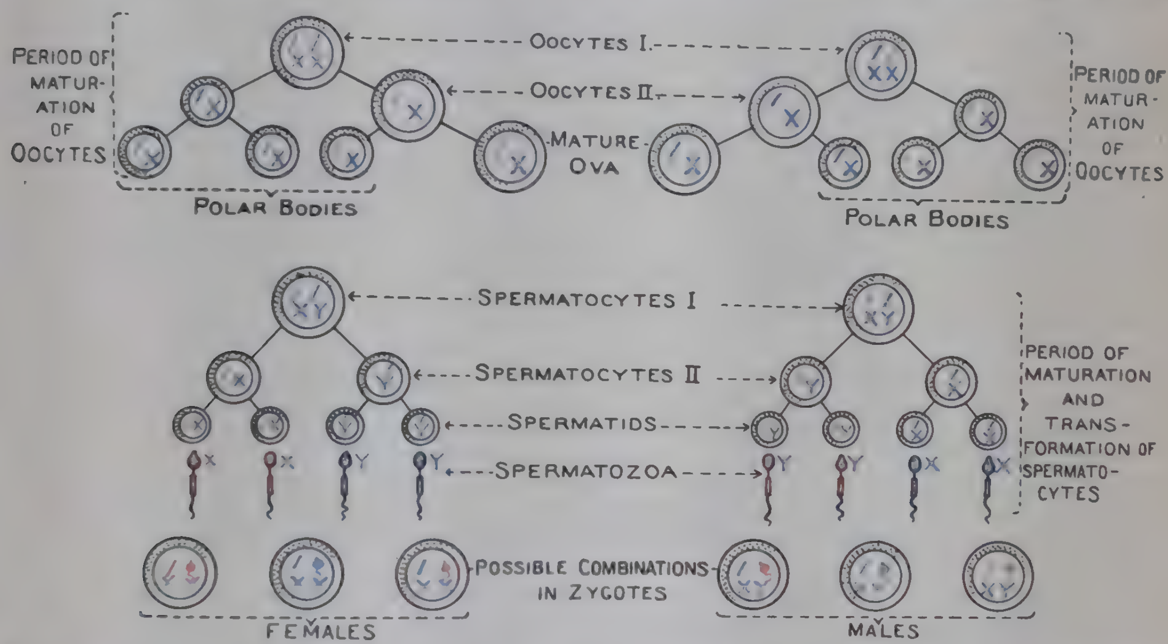


FIG. 10.—DIAGRAM OF THE BEHAVIOUR OF THE CHROMOSOMES DURING MATURATION OF THE GERM-CELLS, INCLUDING THE XY MECHANISM OF SEX-DETERMINATION.

multiplication. Eventually they cease to multiply and enter upon a period of growth; the female cells are then known as **oocytes** and the male cells as **spermatocytes.** When the growth-period is attained the power of division is not altogether lost; but each oocyte or spermatocyte is then capable of producing only four descendants by two final divisions—the **maturation-divisions.** The four descendants of an oocyte are a **mature ovum** and three small cells called *polar bodies*: the four descendants of a spermatocyte are four *spermatids* which undergo metamorphosis into **spermatozoa** (Fig. 10).

The first maturation division is *heterotypical* because the chromosomes do not split in the process, or *meiotic* [μειοῦν (meioun) = to lessen] because the result is a reduction of their number.

Heterotype Mitosis and **Meiosis.**—It has already been pointed out (p. 8) that the number of chromosomes in the dividing cells of any species of animal is always the same; the number varies greatly in different species, but is characteristically constant in each. The same number of chromosomes is found in the soma-cells and primordial germ-cells; and it is believed that they are arranged in pairs of *homologous chromosomes*, one member of each pair being derived from the male parent and the other from the female parent.

In one of the maturation divisions of the germ-cells the homologous chromosomes are separated, one of them going to one daughter-cell and the other to the other daughter-cell: this is the essence of **heterotype mitosis**; and **meiosis**, or the reduction of the number of chromosomes to half, is the result.

In Man and other mammals meiosis occurs in the first of the two maturation divisions.

During the early prophase of the reduction-division the chromatin of the nucleus passes through a special series of changes in form to which various terms have been applied. These changes, which are related to the intricate mechanism of inheritance, occur in the spermatocyte immediately before the reduction-division; but in the oocyte they may occur long before, and are then followed by a long period of rest. In other words, the prophase of the reduction-division in the spermatocyte is short, but in the oocyte it may be very prolonged. Finally, the chromosomes appear and lie side by side (Fig. 17), each pair of homologous chromosomes forming a twin-chromosome—a stage also known as *conjugation of the chromosomes*. Thus, the apparent number of chromosomes is reduced to half the original number of the ordinary chromosomes present in soma-cells and in non-maturing germ-cells.

At the end of the prophase of the heterotype division the twin-chromosomes are assembled at the equator of the spindle, where they are attached to the achromatic fibrils (see p. 8).

There is no true metaphase, since the chromosomes do not split longitudinally as in ordinary mitosis, and the anaphase begins when the homologous chromosomes separate from each other. They thus pass undivided to the opposite ends of the achromatic spindle; therefore, in the telophase, when the cell divides, each daughter-cell contains one group of chromosomes which are the homologues of the chromosomes in the other daughter-cell, and each daughter-cell has only half the number of chromosomes which were present in the mother-cell.

In other words, the heterotype division is a reduction-division by means of which homologous chromosomes are separated from one another, with the result that the mother-cell's inheritance of chromosomes is equally divided between the two daughter-cells.

Mechanism of Inheritance and Determination of Sex.—Reference has already been made to the chromosome theory of inheritance (p. 10), and the student will now realise that a reduction-division in maturation is not only necessary in order that the characteristic number of chromosomes may be maintained in each generation after fertilization, but that it is part of the mechanism for that "shuffle and deal" of the parental chromosomes upon which, according to the theory of chance, the inheritance of the offspring depends.

In Fig. 10 the behaviour of *one pair* of homologous chromosomes (paternal, red; maternal blue) in the maturation of germ-cells is represented. But in studying this diagram the student should remember that in human oocytes and spermatocytes there are 23 such pairs, in addition to a special pair in each (oocyte, XX : spermatocyte, XY) which has special relation to the inheritance of sex. The statistical study of the mode of inheritance of pairs of characters, of which one may be *dominant* and the other *recessive*—**Mendelism**—is in accord with the behaviour of the chromosomes. As it appears to be a matter of chance which daughter-cell will receive any single chromosome, it may be calculated that in the maturation and union in fertilization of any two human germ-cells there are over 281 *billions* of different possible combinations *of the chromosomes alone.*

Add to this that interchange of genes (p. 10) or groups of genes—*crossing-over*—is known to occur during the conjugation of the chromosomes in the prophase of the reduction-division, and it is abundantly clear that the chromosome theory of inheritance is consistent with the infinite variety of individual characterization.

Every normal individual must be either male or female; and there is now conclusive evidence that sex is a heritable character, that it is determined at the time of the union of the gametes and that it is dependent upon special chromosomes, which, although they bear other genes than those that determine sex, are known for that reason as *sex-chromosomes*. The relation of the behaviour of these special chromosomes to the sex of the offspring has been traced in many species of invertebrates and vertebrates. Although there are many variations of the mechanism in detail, the general principle disclosed is that one sex is characterized by the presence of a pair of similar sex-chromosomes distinguished as X-chromosomes, and the other by the presence of only one X-chromosome, which may or may not be paired with another of dissimilar form known as the Y-chromosome. The determining factor is the formation by one sex of two kinds of gametes of different chromosome-constitution. That sex (usually the male, but the female in

many invertebrates and in birds) is therefore said to be *digametic*; while the other is said to be *monogametic* since the gametes it produces are all alike.

In the determination of human sex, it is the male that is digametic. The human oocyte has 23 pairs of ordinary chromosomes and one pair of X-chromosomes—48 in all. Its chromosome-constitution may thus be written 46XX: and every mature ovum therefore possesses an X-chromosome. Its formula is 23X. The formula of the spermatocyte, on the other hand, is 46XY; when the reduction division occurs the X-chromosome passes into one spermatocyte II, the Y-chromosome to the other spermatocyte II. Therefore, of the four spermatids two will have an X-chromosome and two will have a Y-chromosome. There are thus two kinds of spermatozoa, of 23X and 23Y constitution respectively. If an X-bearing spermatozoon unites with an ovum a female results, and if a Y-bearing spermatozoon unites with an ovum a male results (Fig. 10).

The chromosome-constitution of human sex-cells stated above, including the presence of a Y-chromosome in the male, is now generally accepted on the evidence of Painter (1923) and of Evans & Swezy (1929); but the presence or absence of a Y-chromosome in the male (King & Beams, 1936) does not affect the principle of sex-determination. Male sex depends on the absence of a second X rather than on the presence of a Y-chromosome, the physiological activity of which is in some doubt.

Moreover, the student should understand, although sex is said to be 'determined' at fertilization by the chromosome-constitution of the nucleus of the zygote, that sex has to be 'developed' in the individual. The rudiments of the organs of both sexes are formed in every embryo, and the actual sex depends upon physiological factors believed to be controlled by the chromosomes. But there is evidence, experimental and otherwise, to show that the normal mechanism may be deranged, with the production of the phenomena of inter-sex and sex-reversal, by changes in the environment either external or internal.

The cytological and other evidence upon which the chromosome-theory of sex is based is confirmed by the observation that uni-ovular twins, *i.e.*, twins developed from a single ovum, are always of the same sex, whilst bi-ovular twins may be of the same or of opposite sex. It is also strikingly confirmed by the phenomena of 'sex-linkage' in inheritance. The sex-chromosomes are not solely concerned with sex; they bear genes which control other heritable characters; and these characters are linked to sex in their transmission from generation to generation. Sex-linked characters are of some importance in human inheritance, the best-known example being the condition called *hæmophilia*, in which there is an abnormal tendency to spontaneous or excessive bleeding. It is believed that the determining factor of this condition is carried on the X-chromosome, which explains its characteristic mode of inheritance; it is not transmitted from an affected father to his son, but only to a grandson through a 'carrier' daughter who remains herself unaffected (see Fig. 10).

For further information on these interesting questions, the student is advised to consult Wilson (1925); Crew (1927); Waddington (1939); and Roberts (1940).

Gametogenesis.—Gametes are the final descendants of a line of germ-cells which pass through successive stages of specialization and are finally transformed into mature ova and spermatozoa by means of the two maturation-divisions; the whole process is known as **gametogenesis** (Figs. 9 and 10).

Both ovum and spermatozoon are specialized cells, inasmuch as each possesses only half the number of chromosomes present in its grandparent; moreover, each is incapable, under ordinary circumstances, of undergoing cell-division, and must either die or unite with the other to produce a new, rejuvenated cell—the zygote.

The ovum and the spermatozoon have their own special characteristics. The phenomena of **oogenesis** and **spermatogenesis** must, therefore, be considered **separately**.

Oögenesis and the Ovum

The structure of the ovary and the relation of the oocytes to the 'germinal epithelium' are described with the Urogenital System (p. 772).

Each **oocyte** lies at first in the cortical part of the ovary, surrounded by a single layer of cells known as the stratum granulosum; and the oocyte and the stratum granulosum constitute, together, a **primary ovarian follicle** (Fig. 11).

Gradually the oocyte increases in size until it attains a diameter of 100 μ to 200 μ, and so becomes a relatively large cell. During the growth-period changes occur both in the surroundings and in the contents of the oocyte.

The changes in the surroundings include increase in number of the cells of the stratum granulosum, changes in their form, division of them into two groups

by the appearance of a cavity amidst them, and the formation of a new envelope, called the *oolemma*, around the oocyte.

At first the cells of the stratum granulosum are flat plates. Then they become cubical and increase in number by mitosis until they form several layers. Thereafter, a cavity filled with a fluid called the *primary liquor folliculi* appears amidst the cells. It increases rapidly in size and separates the cells into two multicellular parts. One part forms the boundary of the cavity and is still called the *stratum granulosum.* The other projects into the cavity; it is called the *cumulus ovaricus,* and in it the oocyte is embedded. The primary ovarian follicle is thus converted into a *vesicular ovarian follicle* (Figs. 13, 14).

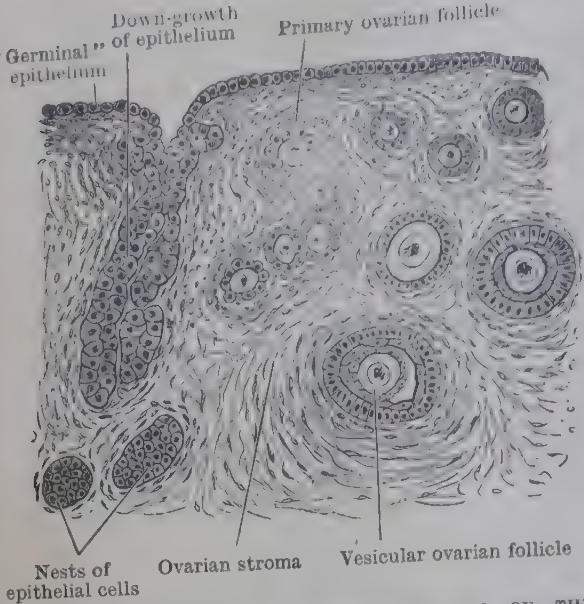


FIG. 11.—DIAGRAMMATIC REPRESENTATION OF THE MANNER IN WHICH VESICULAR FOLLICLES DEVELOP IN THE OVARY.

When the cells of the stratum granulosum have formed two layers, the **oolemma** begins to appear around the oocyte, separating it from the cells of the cumulus. It increases in thickness until the maturation of the oocyte begins, when it is an elastic, pellucid membrane (zona pellucida), sometimes faintly striated (zona striata), varying from 7 μ to 10 μ in thickness.

The oolemma is formed by the oocyte, and it appears to be traversed by processes of the surrounding cells of the cumulus, which gradually assume an elongated columnar form and constitute the *corona radiata* (Figs. 15 and 24).

It is the fine prolongations of the cells of the corona, passing through the

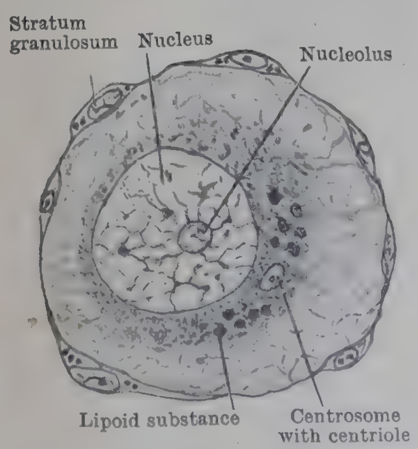


FIG. 12.—HUMAN OOCYTE AT BEGINNING OF GROWTH-PERIOD. Diameters 38 $\mu \times$ 33 μ. The small black granules in the granulosa-cells are lipoid granules.

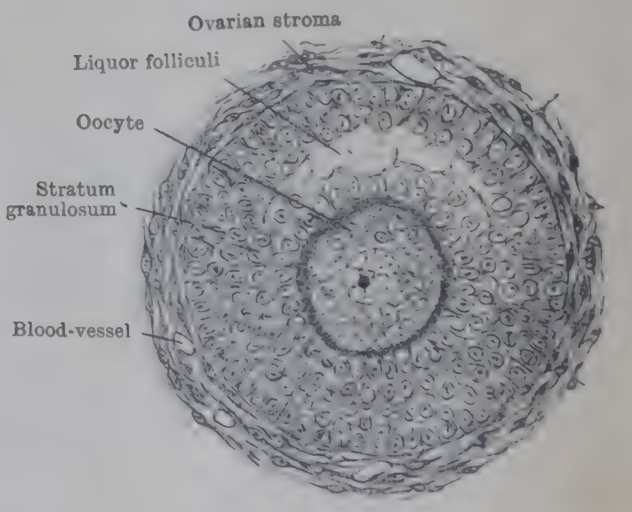


FIG. 13.—HUMAN OVARIAN FOLLICLE AT BEGINNING OF VESICULAR STAGE. Diameters of follicle 155 $\mu \times$ 155 $\mu \times$ 120 μ.

oolemma to the surface of the oocyte, which give rise to the striated appearance which has already been noted.

The changes which take place in the oocyte itself during the growth-period concern the contents of the cytoplasm, and the position and relative size of the nucleus.

At the beginning of the growth-period the oocyte (called *oocyte I* to avoid confusion with its two immediate descendants) is an almost spherical cell; but it soon becomes ovoid and it retains its ovoid form in all subsequent periods. The

cell-body contains a relatively large, eccentrically placed nucleus and a centrosome. The centrosome lies near the central pole of the nucleus and contains one or two centrioles (Fig. 12).

The nucleus possesses one or two nucleoli, and its chromatic substance is dispersed through the linin-reticulum.

Metaplasmic substance is already present in the oocyte; it lies in the cytoplasm around the nucleus, and it is most abundant at the central pole of the nucleus around the centrosome (Fig. 12). As growth proceeds, the metaplasmic substance becomes more diffused, but it is always most abundant around the nucleus in the central part of the cytoplasm.

The nucleus gradually attains a central position in the oocyte (Fig. 14), but afterwards it migrates to the periphery of the oocyte, and the centrosome may disappear before the process of maturation begins.

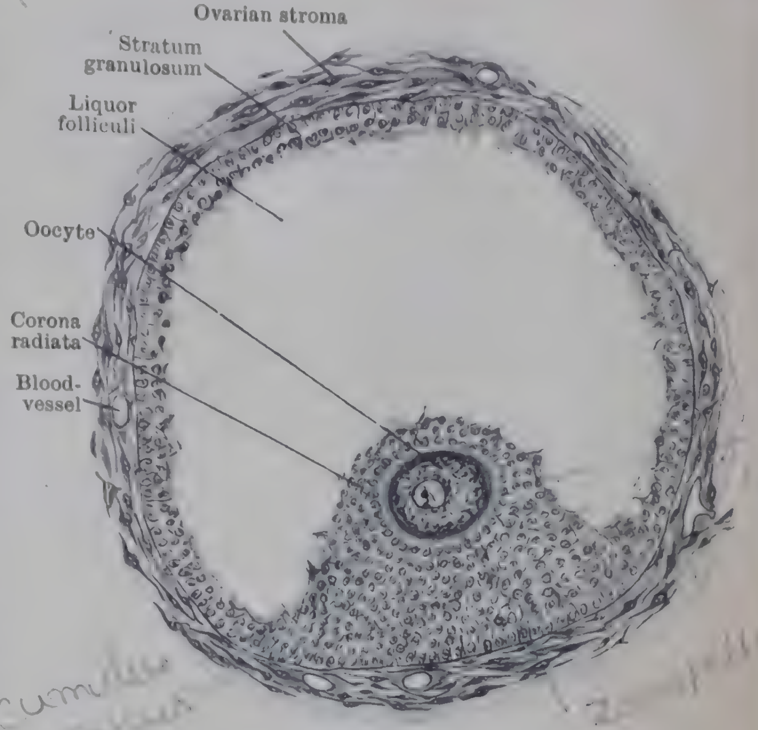


FIG. 14.—HUMAN VESICULAR OVARIAN FOLLICLE. Diameters of follicle 620 $\mu \times 465\ \mu \times 465\ \mu$.

During the period of growth the body of the oocyte grows more rapidly than the nucleus; and therefore at the end of the period the nucleus, though actually larger than it was at the beginning, is relatively smaller.

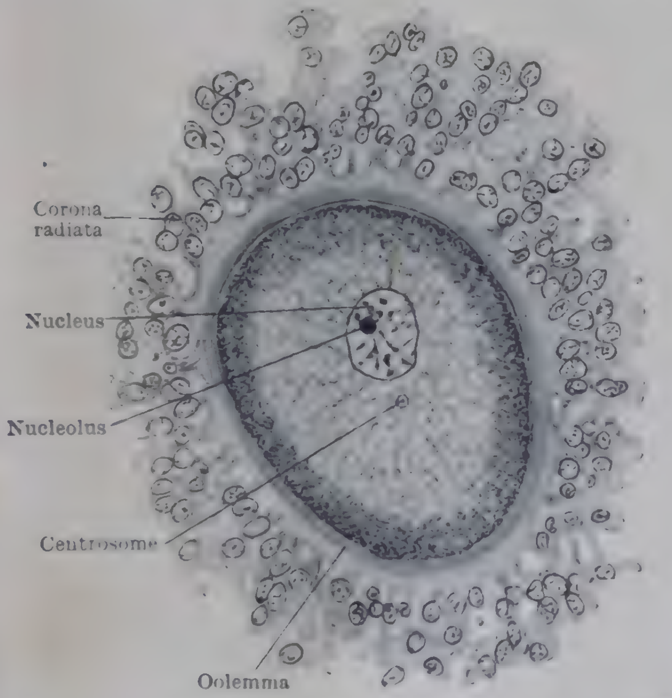


FIG. 15.—HUMAN OOCYTE NEAR THE END OF THE GROWTH-PERIOD. Diameters of oocyte exclusive of oolemma 140 $\mu \times 110\ \mu \times 84\ \mu$. Average thickness of oolemma 5 μ.

When growth is completed the full-grown oocyte I, enclosed in the oolemma, lies in the cumulus of a vesicular follicle in the cortical part of the ovary. It consists of a cell-body which contains a nucleus, mitochondria and numerous highly refractive yolk-granules; but during maturation a centrosome may not be apparent.

The diameter of the cell-body, measured along its major axis, varies from 100 μ to 200 μ, for full-grown oocytes are not all of the same size; the average diameter is 130-140 μ (Hartman, 1929). The diameter of the nucleus varies from 25 μ to 50 μ.

The amount of metaplasm or yolk-substance in human and most mammalian ova is relatively small compared with those of fishes, amphibians, reptiles, and birds. The amount of yolk determines whether the segmentation of the fertilized ovum is complete or incomplete, and special terms are employed in Comparative Embryology to denote differences in the amount and distribution of the yolk. It is sufficient here to note that the amount of yolk in the human ovum is so small that it does not in the least interfere with its complete division in segmentation.

The metaplasmic granules serve as a store of nutritive material which is utilized

during the early stages of the growth of the zygote in mammals, and until the time of hatching in oviparous vertebrates.

There is great variation in the amount of unsaturated fat (lipoid) in the ova of different mammals, as shown by osmic acid staining. It is almost absent in human ova and the ova of rats and mice; a slight but variable amount is found in the ova of rabbits; it is definitely present, as spherules of relatively large size, in the ova of guinea-pigs and cats; and there is a large amount in the ova of dogs and ferrets, in which indeed it constitutes the greater part of the volume of the ova. In the ferret it has been traced into the cells of the trophoblast, of the inner cell-mass and the ectoderm, but not into the entoderm (Robinson, 1925).

Apart from the question whether any new ova are produced in the human ovary after birth—as is apparently the case in some animals—there is evidence that a large number of developing follicles atrophy and disappear so that " radical selective elimination of ova occurs in human ovaries " (Allen *et al.*, 1930a).

Maturation of the Ovum.—Maturation is the term applied to the pheno-

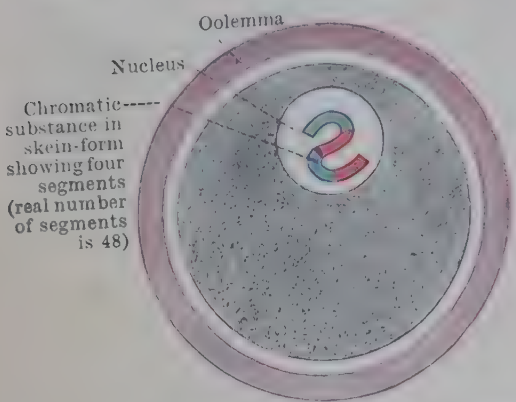


Fig. 16.—Schema of Maturation of Ovum. Early Part of Prophase of First Division.

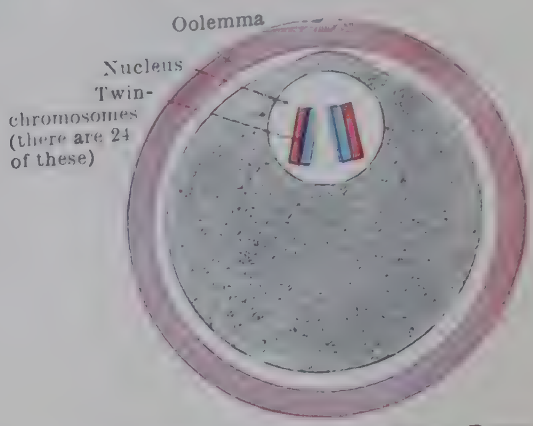


Fig. 17.—Later Prophase of First Division. The chromatic thread has divided into twin-chromosomes. Each twin may be assumed to consist of a maternal and a paternal part.

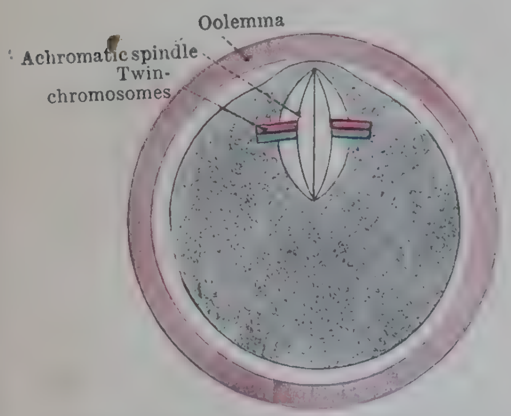


Fig. 18.—End of Prophase of First Division. The twin-chromosomes lie at the equator of the achromatic spindle.

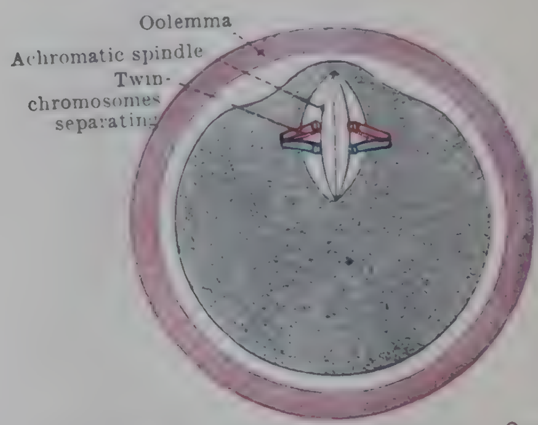


Fig. 19.—Metaphase of First Division. One pole of the spindle projects into the first polar bud, and the maternal and paternal parts of the chromosomes are separating from each other.

mena of the two cell-divisions which take place after the oocyte has attained its full growth.

Knowledge of the phenomena of maturation in human oocytes is not yet complete; but there can be no doubt that they are the same as those which have been clearly demonstrated in many other mammals.

The first of the two divisions is heterotypical and meiotic. During its progress the nuclear membrane and the nucleolus or nucleoli disappear, and an achromatic spindle appears at one pole of the oocyte, in the situation previously occupied by the nucleus.

The chromosomes are aggregated together in pairs as twin-chromosomes. They appear therefore to be only half the number of the chromosomes originally present in the oocyte; at the end of the prophase they lie at the periphery of the equator of the spindle. When this condition is attained the

spindle rotates on its transverse axis, and one pole, carrying a little cytoplasm around it, projects beyond the general surface of the oocyte, forming the *first polar projection* (Fig. 19).

During the metaphase the two halves of each twin-chromosome separate from each other, the two chromosomes thus formed being each equivalent to a whole chromosome of an ordinary cell.

In the anaphase the halves of each twin-chromosome travel to the opposite poles of the achromatic spindle, and those which travel to the peripheral pole enter the first polar projection (Figs. 19, 20).

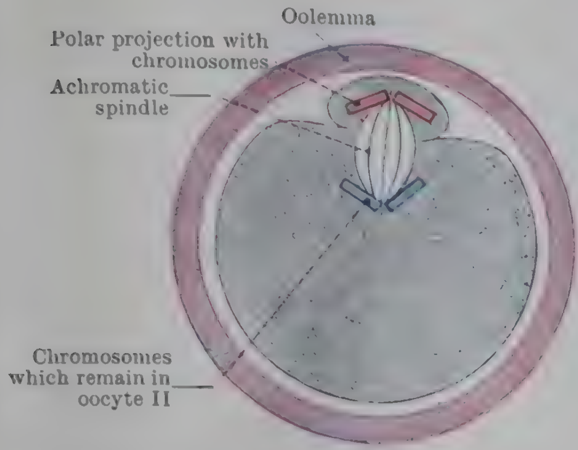


FIG. 20. — END OF ANAPHASE OF FIRST DIVISION. Two chromosomes (paternal or maternal) lie in the first polar bud and two in the larger part of the ovum which becomes oocyte II.

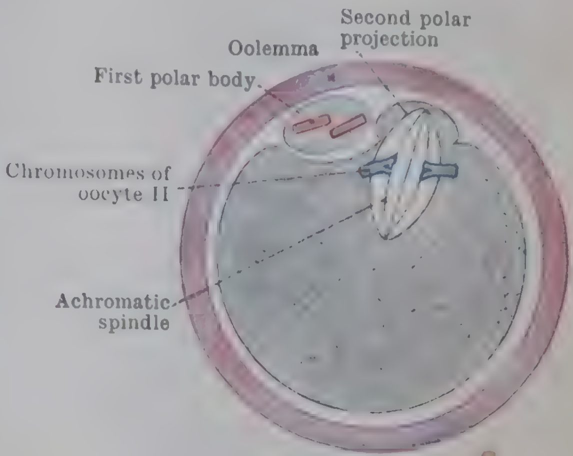


FIG. 21.—BEGINNING OF METAPHASE OF SECOND DIVISION. The chromosomes of oocyte II are dividing.

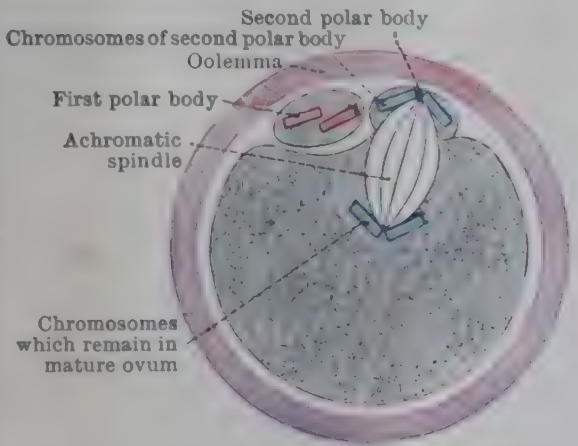


FIG. 22. — END OF ANAPHASE OF SECOND DIVISION. The chromosomes of oocyte II have separated into equal parts which have passed to the opposite poles of the spindle.

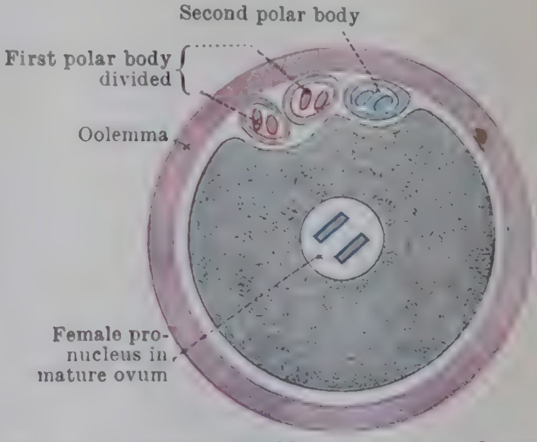


FIG. 23.—SCHEMA OF MATURATION OF OVUM. END OF TELOPHASE OF SECOND DIVISION. The four descendants of oocyte I are the mature ovum, with half the original number of chromosomes, and three polar bodies.

During the telophase the first polar projection, with its included chromosomes and a minute portion of cytoplasm, is cut off from the main part of the oocyte. The first maturation division is then completed; **oocyte *I*** being divided into a large segment (**oocyte *II***) and a small segment called the *first polar body*, both of which lie inside the oolemma and each of which contains half the number of chromosomes originally present in oocyte I (Figs. 20-26). Human ova which have attained this stage of maturation have been seen (Rock & Hertig, 1942).

After the first maturation-division is completed a nucleus may appear in the first polar body and a new achromatic spindle is formed in oocyte II. The new achromatic spindle lies at the periphery of oocyte II near the first polar body, and the chromosomes become grouped at its equator (Figs. 21, 25).

When the condition described is attained the ovarian follicle ruptures, and the liquor folliculi (which has meanwhile increased in amount by the formation of *secondary liquor folliculi* (Robinson, 1918) in spaces in the cumulus), carrying with

it the oocyte surrounded by its corona radiata, is forced through the breach in the surface of the ovary and is swept into the uterine tube. This process is known as *ovulation*; and it is now known to have a definite relation to the menstrual cycle (p. 80).

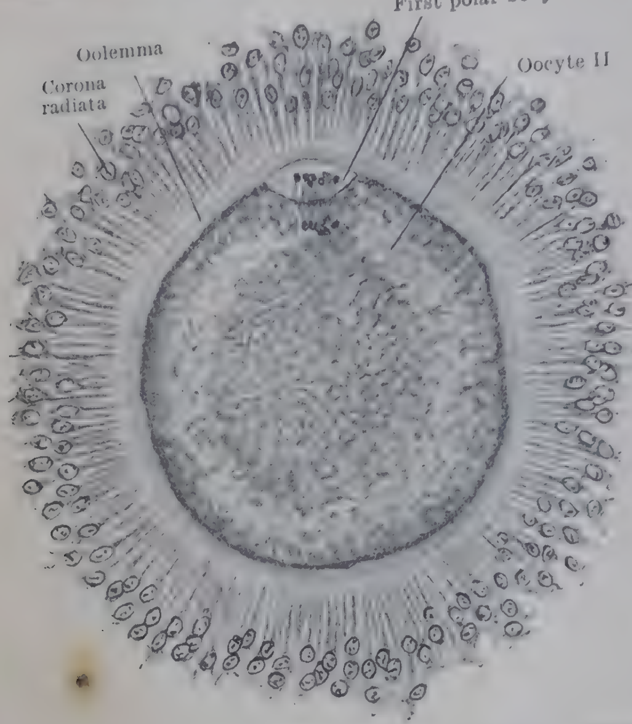


FIG. 24.—OOCYTE OF A FERRET IN THE TELOPHASE OF THE FIRST MATURATION-DIVISION. Diameters of oocyte, exclusive of oolemma, 150 $\mu \times 125\ \mu \times 110\ \mu$.

If the oocyte is penetrated by a spermatozoon it then undergoes the second maturation-division; but it is possible that the second maturation-division of the human oocyte may occur before it leaves the ovary, and therefore before the entry of the spermatozoon.

There are a few observations on record of human oocytes thought to be undergoing the second maturation-division while still in ovarian follicles (Thomson, 1919; Dixon, 1927 (Fig. 26); Hoadley & Simons, 1928; Allen *et al.*, 1930a). But other oocytes in that stage have been found in the uterine tubes (Allen *et al.*, 1930b; Lewis, 1931; Pincus & Saunders, 1937; Hamilton, 1944.); and, owing to the difficulty of obtaining such specimens, the relation of the completion of maturation to ovulation and to fertilization remains in doubt. Thomson described specimens in which he believed he had observed mature human ova in ovarian follicles (Fig. 27.)

The phenomena of the second maturation-division are those of **homotype mitosis**. One pole of the achromatic spindle, already present in oocyte II, projects beyond the surface of the oocyte, carrying with it a small amount of cytoplasm and so forming the *second polar projection* (Fig. 21). Thereafter, each of the chromosomes (which, it must be remembered, are only half as numerous as those originally present in oocyte I) splits longitudinally into equal parts. The opposite halves of the divided chromosomes then travel to the ends of the achromatic spindle; consequently, one group enters the second polar projection and the other remains in the body of the oocyte (Fig. 22).

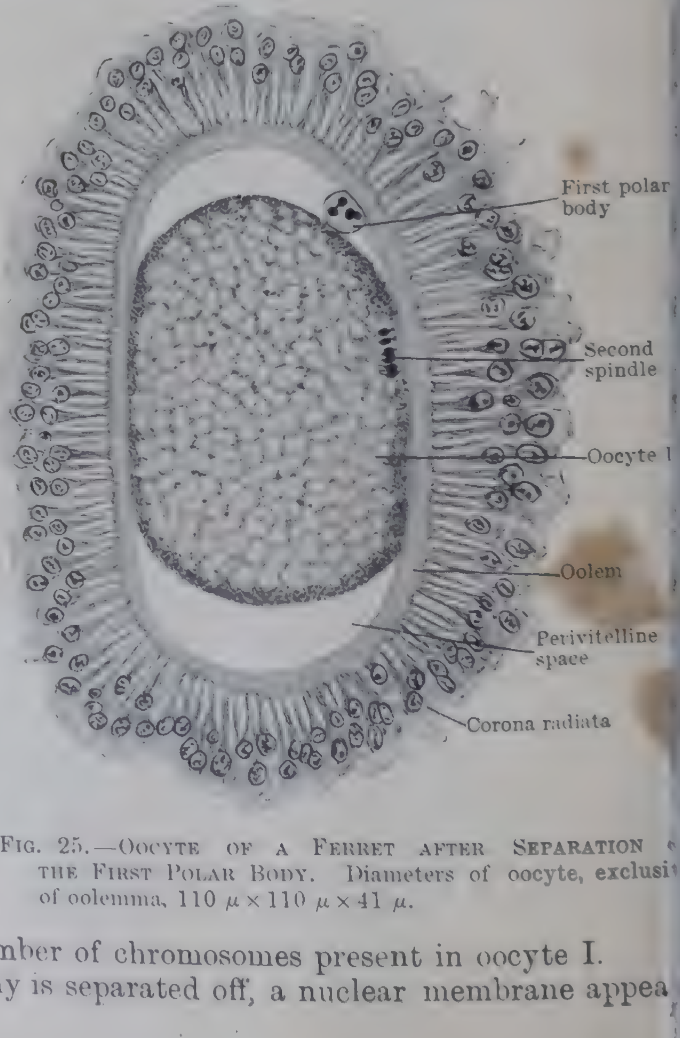


FIG. 25.—OOCYTE OF A FERRET AFTER SEPARATION OF THE FIRST POLAR BODY. Diameters of oocyte, exclusive of oolemma, 110 $\mu \times 110\ \mu \times 41\ \mu$.

When the chromosomes reach the ends of the achromatic spindle, the second polar projection is cut off from the body of the oocyte to form the *second polar body*. Thus, in the second maturation-division, oocyte II is segmented into a larger part and a smaller part (the second polar body), each of which contains half the number of chromosomes present in oocyte I.

As soon as the second polar body is separated off, a nuclear membrane appea

around the chromosomes in the body of the oocyte; a linin-reticulum is formed within the membrane, and the particles of the chromosomes are distributed along the reticulum; a nucleolus also is developed, and the maturation is completed (Fig. 27).

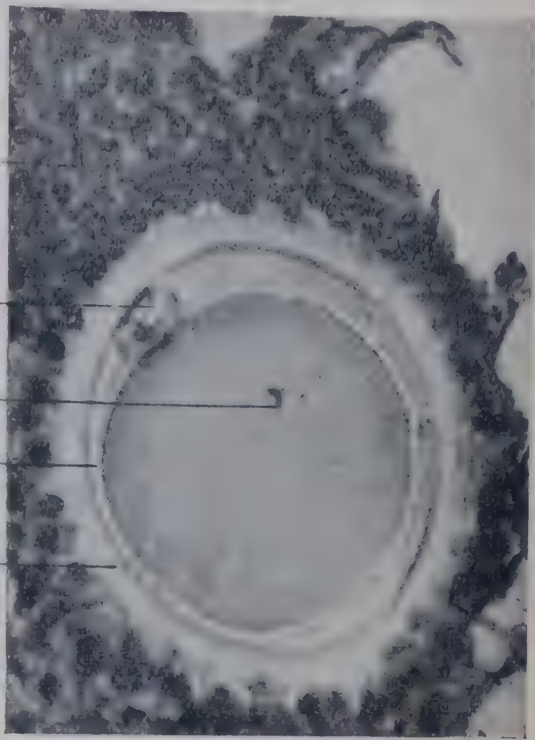


Fig. 26.—Section of a Human Ovum after the First Maturation-Division. (Dixon, 1927.)

The **mature ovum,** like the full-grown oocyte, differs from a typical animal-cell on account of its large size, and also because it is surrounded by a special protective envelope—the oolemma. An additional and important difference is the fact that the mature ovum under ordinary circumstances is incapable of further cell-division because it possesses no centrosome—a deficiency which is supplied by the spermatozoon if fertilization occurs.

The **nucleus** is frequently called the *germinal vesicle,* and the nucleolus the *germinal spot,* whilst the protoplasm of the cell-body is spoken of as the *vitellus* or *yolk.* Consequently the fine surface-layer, which appears as the polar bodies are given off (Fig. 24) and corresponds to an ordinary cell-membrane, has been termed the vitelline membrane. The space, between the body of the oocyte and the oolemma, into which the polar bodies are discharged, is called the *perivitelline space*; in fixed specimens it may appear greatly increased by retraction of the cell-body (Fig. 25).

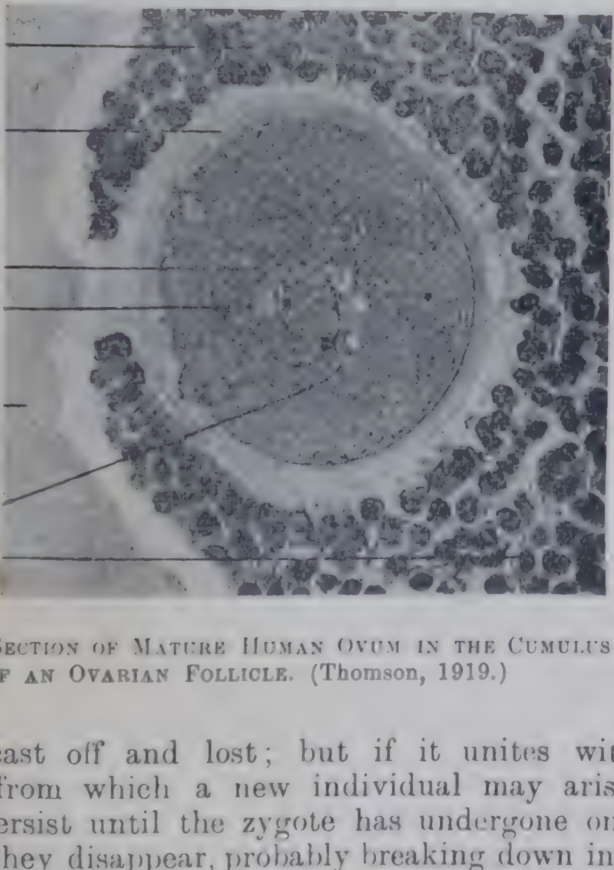


Fig. 27.—Section of Mature Human Ovum in the Cumulus of an Ovarian Follicle. (Thomson, 1919.)

As the second polar body is separated off, the first polar body not uncommonly divides into two parts. When that occurs, the result of the two maturation-divisions of the oocyte is the formation of one large cell (the mature ovum) and three polar bodies, all of which are enclosed within the oolemma (Fig. 23).

If the oocyte II does not meet with a spermatozoon it breaks down or it passes through the genital passages and is cast off and lost; but if it unites with a spermatozoon a **zygote** is formed, from which a new individual may arise, and in that case the polar bodies persist until the zygote has undergone one or two divisions; but sooner or later they disappear, probably breaking down into fragments which are absorbed by the cells of the zygote.

The polar bodies were originally so named in the belief that they indicate the line along which the first segmentation of the fertilized ovum will take place; but their exact position does not appear to be of any significance in the mammalian ovum.

Spermatogenesis and the Spermatozoon

When the male germ-cells reach the period of growth they are called **spermatocytes** I, which correspond morphologically with oocytes I (Fig. 10). The spermatogonia and the spermatocytes lie in the walls of the seminiferous tubules of the testes. There, their descendants become converted into spermatozoa (Fig. 28).

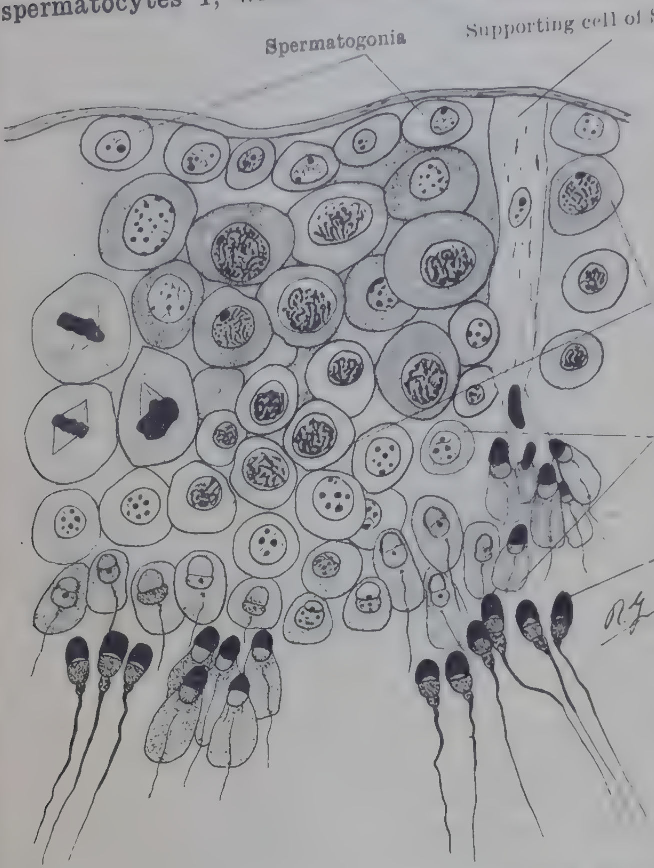


Fig. 28.—Drawing of Small Part of Transverse Section of Seminiferous Tubule of Mammal to show Stages of Spermatogenesis. (Gresson, 1948.)

Spermatocytes differ from oocytes in three important respects: (1) they have no protective membrane corresponding with the oolemma of the oocyte; (2) they are not enclosed in follicles; (3) they are not surrounded by definite encircling layers of cells similar to the cells of the stratum granulosum.

In the tubules of the testes the spermatocytes are intermingled with *supporting cells* (cells of Sertoli), amidst which they undergo their maturation-divisions; their descendants become embedded in the supporting cells, where they are converted into spermatozoa. To a certain extent, therefore, the supporting cells may be looked upon as corresponding with the cells of the cumulus ovaricus which surround the growing oocyte.

After it has reached its full growth each spermatocyte I, like each oocyte I, can produce only four descendants; the descendants, as in the case of the oocyte I, are formed by two successive mitotic divisions, of which the first is heterotypical and produces reduction of the chromosomes, and the second is homotypical.

These divisions differ from the corresponding divisions of the oocyte in the important respect that the four grand-daughter-cells are of equal size and of equal value, so that they are all capable of uniting with an ovum to form a zygote.

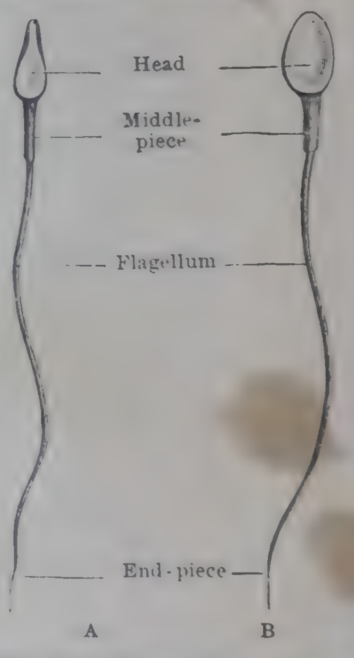


Fig. 29.—Human Spermatozoa (After Retzius.)
A, Side view; B, Front view.

In the prophase of the first or *heterotype* division the nucleus and nucleolus disappear in the ordinary way. The centrosome divides, and an achromatic spindle appears, which has the daughter-centrosomes at its poles and apparently half the typical number of chromosomes at its equator. But the chromosomes are twin-chromosomes, and during the metaphase the two segments of each twin-chromosome separate from each other. In the anaphase they travel to the opposite poles of the achromatic spindle, and consequently, when the cell divides in the telophase, each daughter-cell or **spermatocyte** II contains a centrosome and half the typical number of chromosomes (Fig. 10).

The second maturation-division, which takes place without the intervention of a resting stage, is of the *homotype* form. The centrosome divides, a new achromatic spindle appears, and the chromosomes gather at its equator. In the metaphase the chromosomes divide into equal parts, which travel to the opposite poles of the spindle during the anaphase, and when the telophase is completed each granddaughter-cell, now called a **spermatid**, possesses a centrosome and half the typical number of chromosomes (Fig. 10). In the resting stage which follows, the chromatic particles become enclosed in a new-formed nucleus, and the centriole passes to the surface of the cell and divides into two equal parts (Fig. 31 (1)). The Golgi material (p. 7), which has been scattered, reassembles close to the opposite side of the nucleus. In addition to numerous mitochondria, other particles, known as Y-granules, which may represent abortive yolk, are present, and there is also an *accessory body* which later is concerned in the formation of the neck of the spermatozoon.

The Spermatozoon.—The reader will have noted that the ova become ready for conjugation with spermatozoa directly after the first maturation-division is completed. In the case of the male germ-cells, however, the spermatids which result from the second maturation-division have still to undergo a complicated process of transformation before they become converted to spermatozoa. The process of transformation takes place in association with the supporting cells in which the developing spermatozoa become embedded.

The details of the process of transformation are difficult to follow, and knowledge regarding them has been until recently rather indefinite. Gatenby & Beams (1935), however, have provided us with an authentic account of human spermatogenesis, including very clear details of the metamorphosis of the spermatid (Fig. 31); but before these details are considered it is necessary that the student should be acquainted with the anatomy of an adult spermatozoon.

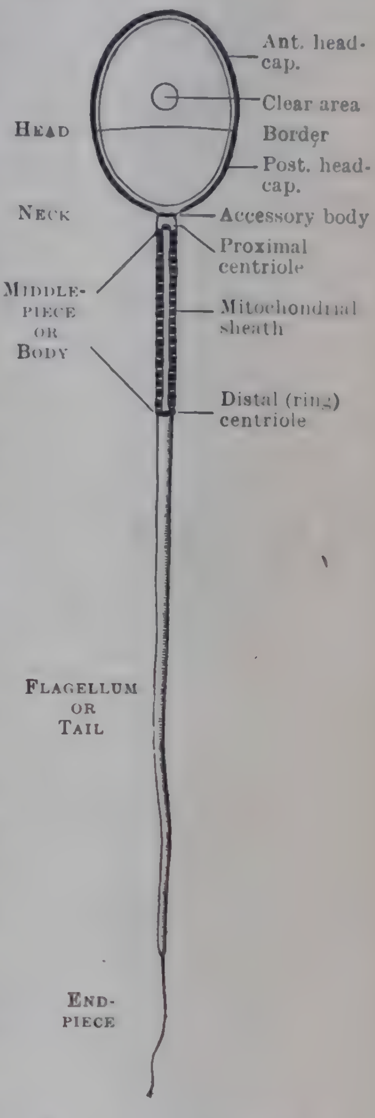


FIG. 30. — STRUCTURE OF HUMAN SPERMATOZOON. (Gatenby & Beams, 1935.)

A spermatozoon is a minute organism possessing a head, a neck, a middle-piece or body, and a flagellum or tail. Its total length is about 50 μ, that is, its length is about the same as the diameter of the nucleus of the ovum.

The **head** has the form of a compressed ovoid. It contains the nucleus of the spermatid and is completely covered by a **head-cap** which consists of two parts—an anterior part, the head-cap proper, and a posterior part, the post-nuclear cap. The length of the head is about 4·5 μ.

The **neck** is an extremely short constricted region between the head and the middle-piece. It contains a deeply staining *neck body* or *accessory body*, which may consist of Golgi material. The **middle-piece** is about the same length as the head, and its constituent parts are: (1) the proximal centriole; (2) a portion of the axial filament with its sheath; (3) the mitochondrial sheath; and (4) the distal centriole.

The **axial sheath** is a thin layer of protoplasm immediately surrounding the **axial filament**, which extends from the **proximal centriole** through the middle-piece into the flagellum. The **mitochondrial sheath** surrounds the axial sheath, and is formed by numerous fused mitochondria. The **distal centriole** is ring-shaped, and through it the axial filament and its sheath pass from the middle-piece into the flagellum.

The **flagellum** or tail is long. It consists of prolongations of the axial filament

and its sheath, and it terminates in a short thin *end-piece*, in which the axial filament appears free from the sheath.

Metamorphosis of Spermatid into Spermatozoon.—The **head** of the spermatozoon is formed from the nucleus of the spermatid, which becomes encased in a special sheath formed in two parts. The Golgi elements, which have been scattered during the maturation-divisions, assemble on the surface of the nucleus as a single apparatus which contains a bead surrounded by a small vacuole. The bead is deposited on the nucleus to form the *acrosome* from which the **head-cap** proper is derived; the vacuole enlarges to form a semilunar space over the acrosome; and the greater part

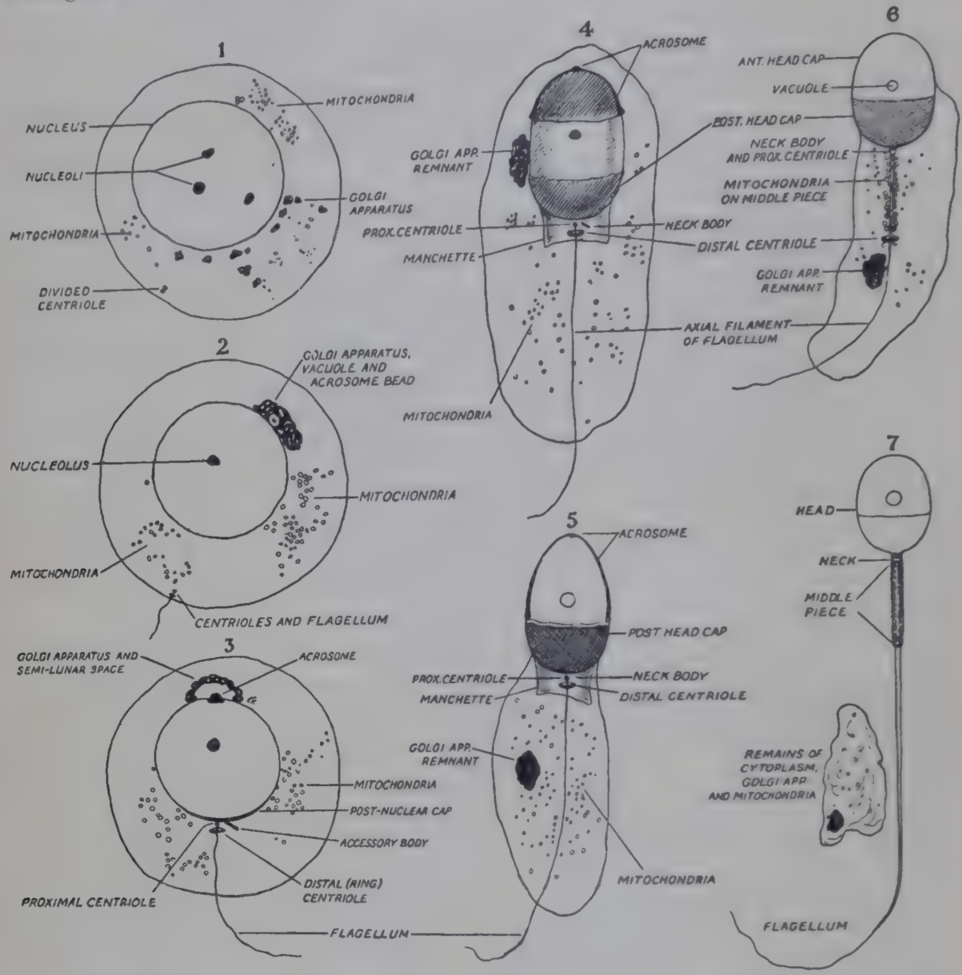


FIG. 31.—METAMORPHOSIS OF SPERMATID INTO SPERMATOZOON. (After Gatenby & Beams, 1935.)

of the Golgi material then detaches itself from the nucleus and flows down into the cytoplasm of the spermatid to be discarded later.

After the second maturation-division the centriole of the spermatid passes towards the cell-wall and divides into two; from the double centriole the **axial filament** then grows out through the surface of the cell. The double centriole moves inwards again, and can then be seen to consist of two separate parts—a **proximal centriole** (nearer the nucleus) which is granular and gives rise to the axial filament of the flagellum, and a **distal centriole** which appears as a *ring* threaded on the filament. The two centrioles continue to move in together and become applied to the nucleus on the side opposite the attachment of the acrosome-bead. The distal centriole grows very considerably and becomes a conspicuous object.

A new membranous structure has meanwhile appeared between the centrioles and the nucleus. This is the rudiment of the **post-nuclear cap**, which begins to grow upwards to meet the down-growing head-cap proper, which is derived from the rapidly spreading acrosome. A clear area or vacuole (probably of nucleolar origin) has meanwhile appeared in the nucleus, and when the two parts of the head-cap meet, the head of the sperm is complete.

While the acrosome and the post-nuclear cap are spreading to form the complete head-cap, and before the separation of the two centrioles, the *accessory body* has been taken

into the neck-region, between the proximal centriole and the head, and becomes the *neck-body*; and a collar-like structure (*manchette*) grows down from the nucleus and encloses the two centrioles. The manchette soon disappears, and its significance, like that of the neck-body, is not known.

The **middle-piece** has still to be formed and the **flagellum** completed. The distal ring-centriole slips down the axial filament for a distance about the length of the head, and leaves a space on to which most of the mitochondria crowd to form the **mitochondrial sheath**. The remains of the cytoplasm of the spermatid, carrying other mitochondria and the remnant of the Golgi material, are then stripped off, and the spermatozoon is complete (Fig. 31 (7)).

Fertilization

The process of union of the male and female gametes to form a zygote is known as *fertilization of the ovum*. It begins when a spermatozoon enters an

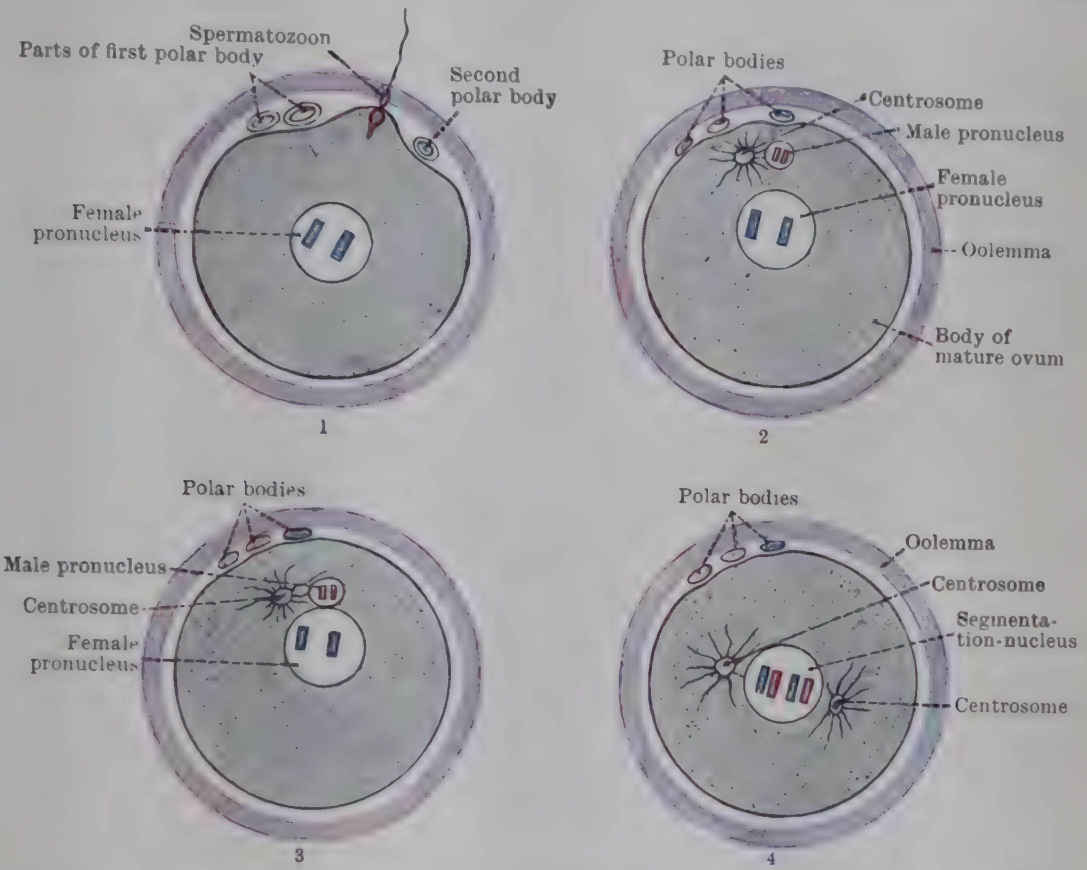


FIG. 32.—SCHEMA OF FERTILIZATION OF MATURE OVUM AND FORMATION OF ZYGOTE.

ovum (either mature or in the last stage of maturation), and it is completed when the nuclear elements of the two have combined.

Fertilization of the human ovum has not been observed, but it is certain that all its essential features are the same as those which have been found to occur in other mammals. The stages of fertilization will probably be observed before long in human ova recovered from the uterine tubes (Hamilton, 1944); but experimental observation of fertilization and segmentation *in vitro* has not so far been very successful, although 2-cell and 3-cell stages have been obtained (Menkin & Rock, 1948). It is believed that fertilization takes place in the ampulla of the uterine tube, and that the entry of one spermatozoon causes some change in the surface of the ovum that prevents the entry of others (Fig. 34).

It has already been pointed out that maturation of the oocyte is usually not completed until after the spermatozoon has entered; thereafter, the second polar body is extruded and the nucleus of the mature ovum, now called the **female pronucleus**, takes up a central position. It contains half the number of chromosomes present in the nucleus of the oocyte before the maturation began. As the female pronucleus forms, the tail of the spermatozoon disappears, the head is transformed into the **male pronucleus**, and two centrosomes arise from the middle-

piece. The male pronucleus is smaller than the female pronucleus, and it also contains only half the number of chromosomes present in the spermatocyte I from which it descended.

As soon as the female and male pronuclei are established they approach each other (Fig. 32), meet, and fuse together to form a single nucleus (Figs. 32, 33) called the *segmentation-nucleus*, which contains the full number of chromosomes.

When fertilization is completed, therefore, a new structure—the **zygote**—is formed. It lies, together with the polar bodies, inside the oolemma, and it consists of a cell-body containing the segmentation-nucleus, and two centrosomes which lie at opposite poles of the nucleus. The only essential difference in appearance between an oocyte I and a zygote is the presence of two centrosomes in the zygote. But oocyte I is a cell almost at the end of its life-period. It can have only one capable descendant and its chances of life are small, whilst the zygote is a rejuvenated cell, endowed with the potentialities of its parents and capable of producing a new member of the species.

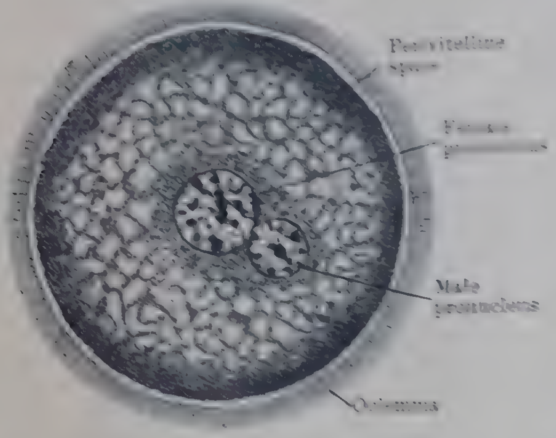


FIG. 33.—ZYGOTE OF A FERRET JUST BEFORE THE FUSION OF THE PRONUCLEI. Diameters of zygote, exclusive of oolemma, 100 μ × 93 μ × 90 μ.

There are therefore two factors in fertilization. The first is the reconstitution in the segmentation-nucleus of the number of chromosomes that is typical for the cells of the species to which the zygote belongs, half of them derived from the female parent and half from the male. The second factor is the stimulus to division which the spermatozoon provides—a stimulus that is due to the physico-chemical influence exerted by the centrioles.

In the phenomena of natural parthenogenesis among invertebrates there are many interesting variations in the chromosome-mechanism. Loeb (1913) and others have also shown experimentally—*artificial parthenogenesis*—that it is possible, in the case of invertebrates like the sea-urchin, and even in the frog, to replace the stimulus normally supplied by the spermatozoon by chemical or mechanical means. Further information on the interesting cytological problems of parthenogenesis will be found in the works of the authors already cited (p. 21).

PRE-EMBRYONIC PERIOD

Segmentation.—Immediately after its formation the zygote segments, by a series of consecutive mitotic divisions, into a large number of cells or blastomeres

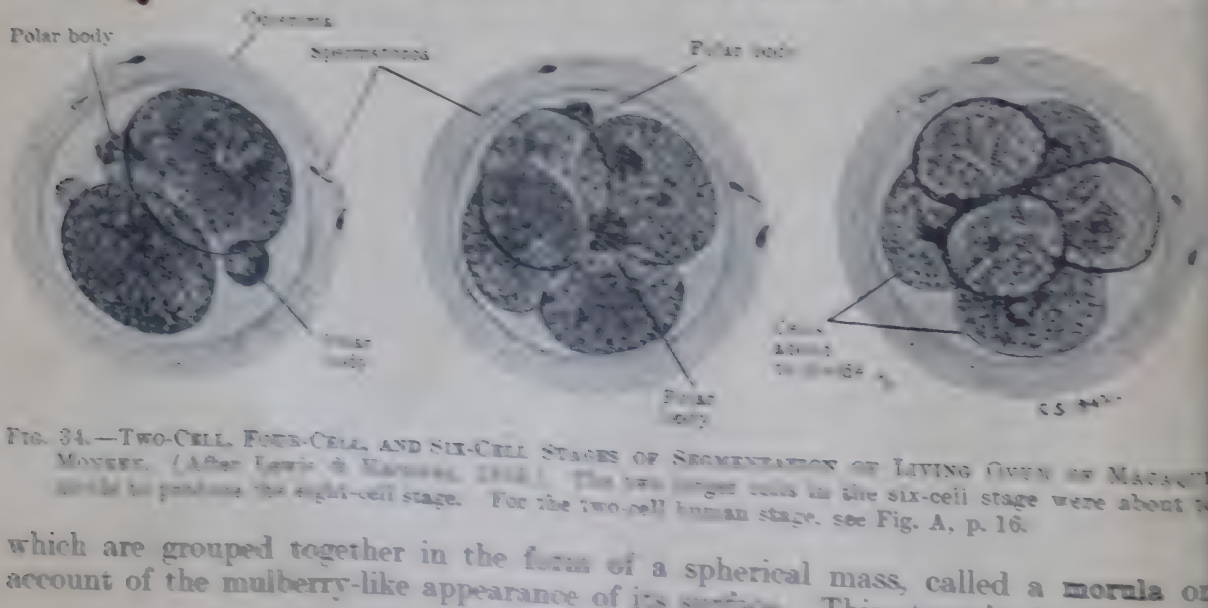


FIG. 34.—TWO-CELL, FOUR-CELL, AND SIX-CELL STAGES OF SEGMENTATION OF LIVING OVA OF MACAQUE MONKEY. (After Lewis & Hartman, 1933.) The two larger cells in the six-cell stage were about to divide to produce the eight-cell stage. For the two-cell human stage, see Fig. A, p. 16.

which are grouped together in the form of a spherical mass, called a **morula** on account of the mulberry-like appearance of its surface. This stage in development

TEXT-BOOK OF ANATOMY

INTRODUCTION

ANATOMY is a comprehensive term, for it includes several closely related branches of knowledge. It originally meant the cutting up of the body [ἀνατομία from ἀνά (ana) = up, τέμνειν (temnein) = to cut] for the purpose of examining the characters and arrangement of its parts; thus, it is primarily equivalent to **dissection** [dis = asunder, secāre = to cut] but comes secondarily to mean knowledge of the form and relations of the parts into which the body may be resolved by that fundamental method of study.

As the body is dissected region by region or is studied by means of sections taken in different planes, and as the knowledge so acquired is formulated in descriptions of all the features of each region taken together, such basic anatomical knowledge is known as *Regional* or *Topographical Anatomy*, which is a kind of "descriptive geography" of the body [τόπος (topos) = a place or locality].

But in the course of dissection it soon becomes evident that all regions of the body are built up of the same kinds of structures (bones, muscles, nerves, blood-vessels, etc.), and that the viscera are related to one another in special ways. The idea of **systems** of structures therefore arises, and the description of the same kinds of structures found throughout the body is known as *Systematic Anatomy*. The observation that there are different kinds of structures in the body inevitably leads to enquiry (speculative at first and then experimental) about what they do; and thus the idea of a community of **function** is inherent in the description of a 'system' of parts or organs. *Functional Anatomy* may therefore be considered in a sense equivalent to Systematic Anatomy; but it has in fact a wider range and merges insensibly into Physiology, which is the study of the normal functions of the body.

Closely related to the study of the functions of the body is the use of the microscope for resolving still further the structure of its parts. The topography of the body as learned by the method of dissection is often referred to as *Gross* or *Macroscopic Anatomy*: the finer structure is, in contrast, known as *Microscopic Anatomy*. It will be easily understood by the student that there is no essential difference between the two—only one of method of study—and that even this difference may be bridged to some extent in the dissecting-room by the habitual use of magnifiers of moderate power, by means of which many important details of the finer structure of organs may be readily observed. Microscopic Anatomy includes not only the minute structure of the organs and parts but also the still finer details of the **tissues** of which they are composed. The study of the minute structure of the tissues is called *Histology* [ἱστός (histos) = a web]; and it includes *Cytology* [κύτος (cytos) = a receptacle, a cell], *i.e.*, the study of the cells which, although far from simple, may be taken as the ultimate units of the body.

But the structure of the body is not the same at all stages of life. All the cells of the body are the descendants of the single cell—formed by the union of ovum and spermatozoon—which is the starting-point of each individual. This single-cell stage is obviously a very different thing from the finished organism represented by the adult; and the series of changes through which the organism passes until its structure is perfected constitute the phenomena of **development** and **growth**.

The general term 'development' is not restricted to the various and striking structural changes which occur during the intra-uterine life of the individual, to the study of which the term *Embryology* is more specially applied; it includes also—in addition to alterations in proportions—many developmental and growth processes which occur after birth, such as the adjustment of the vascular system to its new requirements, the later stages in the ossification and growth of the bones, the eruption of the two sets of teeth, and the changes in the sex-organs and the appearance of secondary sex-characters at puberty. 'Development', indeed, in the wider sense continues throughout the natural span of life, and includes all changes in the body which are due to age.

In the mind of the thoughtful student, the study of Embryology in particular raises questions of the origin of Man and, indeed, helps to answer them. Human Anatomy from this point of view is but part of a larger subject; Man as a vertebrate and a member of the mammalian Order of Primates takes his place in the wider studies of *Comparative Anatomy* and *Comparative Embryology* with all the evidence that they have to offer in support of the theory of evolution. The broader conceptions of anatomy, which are obtained by a general survey of the structural aspects of the vertebrate animal-kingdom, constitute *Vertebrate Morphology*. The morphologist investigates the laws of form and structure, and he gives attention to detail only in so far as this is necessary for his argument.

The knowledge of anatomy which is required by the student of medicine is different. Though his education is incomplete without some appreciation of these wider issues, it is essential for him to be familiar with details of the structure of the human body; and many details that are important from the practical point of view have little or no morphological interest. Moreover, his knowledge is of little value if he is incapable of transferring it from the dissecting-room to the bedside, and of applying it in the examination and treatment of his living patients. Hence the importance of having his attention directed to the study of the anatomy of the living body. This may be done in several ways. One is the consideration of the relation of organs and other structures to the superficial features of the body—*Surface Anatomy*; or the living body may be examined in the revealing light of the X-Rays—*Radiographic Anatomy*. By X-Ray examinations not only may the student's impressions of the form and position of organs obtained from the embalmed cadaver be suitably corrected, but his attention may also be drawn to many interesting observations which are important from the growth and functional points of view.

Finally, it should be understood that what is called *Applied Anatomy* is not a separate division of the subject at all; it is merely the application of every kind of anatomical knowledge to practical problems of diagnosis and treatment in Medicine, Surgery, and other departments of clinical study, as exemplified in the classical work of Hilton (1863). It should, indeed, be the aim of the student of medicine during his anatomical studies to obtain such a knowledge of the anatomy of the living human body that he will find no difficulty in applying it later in practice with understanding and confidence.

Topographical Anatomy

As already explained, Anatomy is primarily a descriptive science founded on observation, and in order that precision and accuracy may be attained it is necessary to have well-defined **descriptive terms**. It is in dissecting-manuals that the regional or topographical method is followed; but such terms are just as necessary in a systematic text-book. It must therefore be clearly understood that all topographical descriptions are framed on the anatomical convention that the body is in the erect position, with the arms by the side and held so that the palms of the hands look forwards. An imaginary plane of section, passing longitudinally through the body and dividing it accurately into a right and a left half, is called the **median plane**, Fig. 1 (M.P.). When the right and left halves of the body are studied it will be found that both are to a large extent formed of similar parts. The right and left limbs are alike; the right and left

Fig. 1.—Horizontal Section through Trunk at Level of First Lumbar Vertebra.
M.P.-M.P.', median plane; S-S', sagittal plane; C-C', coronal plane; A B, points relatively lateral and medial; D E, points relatively ventral and dorsal.

halves of the brain appear the same; there are a right and a left kidney and a right and a left lung; and so on. Many organs are therefore **symmetrically** arranged. But still a large amount of **asymmetry** may be observed. Thus, the chief bulk of the liver lies to the right side of the median plane, and the spleen is an organ which belongs wholly to the left half of the body. Indeed, it is well to state that perfect symmetry never does exist. There always will be, and always must be, a certain want of balance between symmetrically placed parts of the body. Thus, the right upper limb is, as a rule, constructed upon a heavier and more massive plan than the left, and even in those organs where the symmetry appears most perfect, as for instance the brain and spinal cord, it requires only a closer study to reveal many points of difference between the right and left halves.

The line on the front of the body along which the median plane reaches the surface is termed the **anterior median line**; and the corresponding line behind is called the **posterior median line**.

It is convenient to employ other terms to indicate other imaginary planes of section through the body. The term **sagittal** is used to denote any plane which

cuts the body parallel to the median plane (S S′); and the term **coronal** is given to any vertical plane which cuts the median plane at right angles (C C′). These two terms are derived from the names of two of the sutures of the skull. The term **horizontal**, as applied to a plane of section, requires no explanation.

Any structure which lies nearer to the median plane than another is said to be **medial** to that other; and any structure placed farther from the median plane than another is said to lie **lateral** to it. Thus, in Fig. 1, A is lateral to B; and B is medial to A. The term **intermediate** may be employed to indicate the position of a third structure lying between two others that are medial and lateral.

The terms **internal** and **external** express relative distance from the centre of an organ or a cavity; thus, the ribs have external surfaces, that is, surfaces away from the cavity of the thorax, and internal surfaces adjacent to the cavity. The terms **superficial** and **deep** also are used to denote relative distance from the surface of the body, especially in the limbs.

The terms **anterior** and **ventral** are synonymous, and are used to indicate a structure (D) which lies nearer to the front or ventral surface of the body than another structure (E) which is placed nearer to the back or dorsal surface of the body and is thus said to be **posterior** or **dorsal**. The terms 'anterior' and 'posterior' belong strictly to human descriptive anatomy, since they are applicable only to man in the erect attitude and cannot be applied to a four-footed animal; the terms 'ventral' and 'dorsal' belong rather to the language of morphology, as they are independent of habitual position.

Similar pairs of terms are **superior** or **cephalic** and **inferior** or **caudal**, which are employed to indicate the relative levels at which two structures lie with reference to the head or upper end of the trunk, and the lower end or tail.

The term **middle** may be used to indicate the position of a third structure that lies between two others that are either 'superior' and 'inferior' or 'anterior' and 'posterior'.

In the hand we commonly speak of **dorsal** and **palmar** instead of 'posterior' and 'anterior'; and in the foot the corresponding surfaces, though 'superior' and 'inferior' in the anatomical position, are usually called **dorsal** and **plantar**.

The terms **proximal** and **distal** denote relative distance from some central point agreed upon. They are commonly employed only in the description of the limbs, and then denote relative nearness to or distance from the root of the limb. Thus, the hand is distal to the forearm, and the upper arm is proximal to the forearm.

The terms **preaxial** and **postaxial** also are useful in relation to the axis of a limb in considering its development or the distribution of its nerves (see p. 325 and the Section on the Peripheral Nervous System).

Systematic Anatomy

The description of the several systems of organs of which the human body is composed, separately and in logical order, constitutes 'Systematic Anatomy', and is the plan upon which this treatise is based. The several parts of each system not only present a certain similarity of structure but are also associated in specialized functions. As already pointed out, 'Functional Anatomy' merges insensibly into Physiology. It begins with simple ideas, such as that the skeleton has the primary function of a supporting framework of the body, and the muscles the primary function of moving the parts of the framework in relation to each other and the external world: it advances by deductions about the function of parts from their anatomical arrangement (such as Harvey's famous discovery of the Circulation of the Blood (1628), from observations and simple experiments on the

valves of the veins and of the heart): but it is also concerned with the wider field of the interrelations of parts belonging to different systems—for example, the anatomical localization in the Central Nervous System of the origin of nerve-fibres concerned with the regulation and control of the functions of different organs. Anatomy and Physiology are indeed but two different aspects of one subject, separated as a matter of convenience for investigation and study. Structure and function are in reality indissolubly associated; and that is the basis of Systematic Anatomy. Thus there are—

1. The *Locomotor System*, which includes

A. The *Skeletal System*, composed of the bones and certain cartilaginous and membranous parts associated with them, the knowledge of which is known as **osteology**.

B. The *Articulatory System*, which includes the joints or articulations, the knowledge of which is termed **arthrology**.

C. The *Muscular System*, comprising the muscles, the knowledge of which constitutes **myology**. With the muscles are usually included fasciæ, synovial sheaths of tendons, and synovial bursæ.

2. The *Digestive System*, which consists of the alimentary canal and its associated glands, and parts such as the tongue, teeth, liver, pancreas, etc.

3. The *Respiratory System*, in which we place the nasal passages, larynx, windpipe, and lungs.

4. The *Urogenital System*, composed of the urinary organs and the genital organs—the latter differing in the two sexes.

5. The *Ductless Glands*, which, though heterogeneous in their origin, structure, and particular functions, are conveniently grouped together as a 'system', as they share the common functional feature of '**internal secretion**' and together have a profound influence on the functioning of the body as a whole: they include the thyroid and parathyroid glands, the thymus, the hypophysis cerebri and pineal body (these two are attached to the Brain), the suprarenal glands, and the spleen.

The term **splanchnology** denotes the knowledge of the organs included in the digestive, respiratory, and urogenital systems, and the ductless glands.

6. The *Nervous System*, which is divided into—

A. The *Central Nervous System*—the brain and the spinal cord.

B. The *Peripheral Nervous System*—the cranial and the spinal nerves and their ganglia.

C. The *Autonomic Nervous System*, comprising the Sympathetic and Parasympathetic Systems of nerves and ganglia.

The knowledge of all these is included in the term **neurology**.

With the Nervous System may be included

D. The *Organs of the Special Senses* (Sight, Hearing, Smell, Taste) and also

E. The *Common Integument* (skin, nails, hair, etc.), which is also a great sense-organ.

7. The *Blood-Vascular System*, including the heart and blood-vessels (arteries, veins, and capillaries).

8. The *Lymphatic System* of lymph-vessels and lymph-glands.

Microscopic Anatomy and Histology

The organs which form the various systems of the body are themselves built up of **tissues**. Their intimate structure can be resolved only by the use of the microscope and is thus known as *Microscopic Anatomy*. The tissues themselves

are built up of elements comprising **cells** and their products; and the study of these tissues constitutes *Histology*. These two together form an important branch of Anatomy requiring special technical methods for its study; and, since it involves finer description in great detail, special text-books are devoted to it. In a general text-book of Anatomy it is only the outlines of this aspect of the subject that can be presented; and in this text these outlines will be found in relation to the systematic description of the organs in the several Sections. It is, however, necessary to give the student an introduction (1) to the general structure of the ultimate units of the body—the cells—including their methods of reproduction, and (2) to the kinds of tissues which they build up and which in turn form the basis of the microscopic anatomy of the organs.

Structure of the Cell

The human body is an aggregate of innumerable microscopic units called **cells**. The cells vary in size and shape, but all are very minute, the largest—apart from ova (p. 21)—rarely exceeding 80 μ in diameter (a μ = a micron, which is 1/1000 of a millimetre). In some tissues, as will be explained, the cells lie side by side, but in others they are separated from one another by a varying amount of intercellular substance. Each cell is a minute mass of the living substance called **protoplasm**, which is the "physical basis of life".

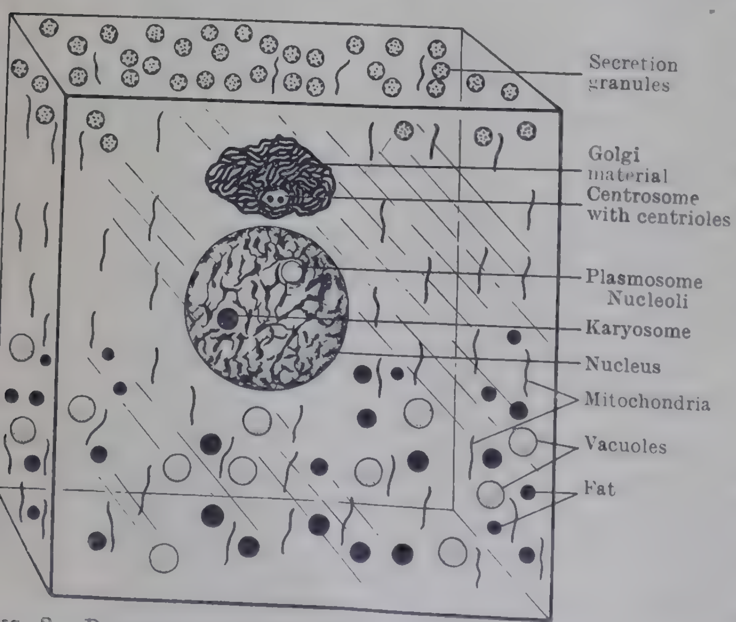
Protoplasm is a colourless, semi-transparent, mobile, irritable substance. It is a colloidal mixture of proteins and nucleo-proteins, with carbohydrates, fats, lipoids, inorganic salts, and water. Different kinds of protoplasm, containing different proportions of these constituents, are recognizable by their reactions to various staining agents.

Every typical animal cell has a **cell-body**, which contains the following structures:—

Nucleus with its **nucleolus** or nucleoli.
Centrosome with its **centriole**.
Mitochondria.
Golgi material.

In addition, the cell-body may contain a number of substances, more or less constant in different cells but not essential parts of their structure. They are products of the activity of the living protoplasm and are known collectively as **metaplasm**. They include:—(1) *Fats* and *Lipoids*, in the form of globules of varying sizes; (2) *Carbohydrates*, including *Glycogen*; (3) *Vacuoles*, filled with fluid; (4) *Secretion granules*; (5) *Pigment granules*; (6) *Protein crystals*, etc.

Much light has recently been thrown on the structure of the cell and the physical nature of its parts by the method of **microdissection** (Chambers, 1940); and microchemical methods also have been applied to the study of the cell.



IG. 2.—Diagram of Animal-Cell. (After Gresson, 1948.)

Cell-Body.—The proto-lasm of the cell-body is called **cytoplasm**. It is probable that the living cytoplasm as no special structural arrangement other than that due to its colloidal nature, and hat the apparent structure, which has been variously described in the dead cell, is ue to the action of fixing and staining chemicals.

The peripheral part of the cytoplasm forms a definite, clear film called the **plasma-membrane**, outside which a definite **cell-membrane** may or may not be present. These act as a semi-permeable membrane through which exchanges take place between the cell and its surroundings.

Nucleus.—The protoplasm of the nucleus is called **nucleoplasm**, and it is surrounded by a *nuclear membrane.* Contained within it there are:—(1) the substance known as *chromatin*; (2) a network of *linin*; and (3) one or more *nucleoli*, which are either (*a*) plasmosomes or (*b*) karyosomes, or both. The nucleus controls the metabolic changes in cells, and it is also concerned with their reproduction by mitotic division.

The **chromatin** is present in the form of granules and owes its name to the fact that it is very readily stained by basic dyes. In fixed cells it generally forms a beaded network, and during cell-division it is aggregated into the specific bodies known as **chromosomes**.

The **linin** or 'thread' material may be seen in fixed cells as a fine reticulum with which the chromatin-network, though independent, may be connected. It has an affinity for acid dyes, but it is not easily stained. It is probably an artifact due to fixation.

The **nucleoli** are small spheres of two kinds. (*a*) The *plasmosomes*, or true nucleoli, lie in the karyoplasm and stain, like cytoplasm, with acid dyes. (*b*) The *karyosomes* appear as knots in the chromatin-network, and they stain, like chromatin, with basic dyes.

The **nuclear membrane** is the outer layer of the nucleus and stains like the chromatin, with which it is connected. It disappears when cell-division begins.

Centrosome.—The essential part of this structure is a minute particle called the **centriole**. It is usually seen densely stained at the centre of a homogeneous sphere, which is different in appearance from the surrounding cytoplasm and placed near the nucleus. The centriole is the structure that appears to initiate cell-division; it is present in all cells that have retained the power of division, and is absent only in those so highly specialized (*e.g.*, nerve-cells) that they have lost that power.

Mitochondria.—These minute bodies are believed to play an important part in cell-function, for example, in the production of *enzymes* (ferments). They occur as minute granules, rods, or filaments, and they may be scattered throughout the cell or collected in groups. When a cell divides, the mitochondria are distributed between the two daughter-cells.

Golgi Material.—This remarkable intracellular 'apparatus' is seldom visible in living cells but is displayed after the cell has been treated by special chemical reagents—silver and osmium. It varies greatly in shape and in size, according to the activity and function of the cell; it often appears beside the nucleus as a network (Figs. 2, 31), but it has no definitely fixed place in the cytoplasm. Like the mitochondria, it seems to be very important in the functioning of the cell and is believed to be concerned with metabolism and the formation of secretions. Like the mitochondria also, the Golgi material is shared between the two daughter-cells when a cell divides.

Life-History of Cells

Necessities for Cell-Life.—In order that an animal-cell may live and perform its work, certain conditions are necessary:—(1) a temperature which varies only within narrow limits; (2) a certain amount of moisture in the form of water; (3) oxygen; and (4) a supply of food from which it can obtain the other chemical elements of its substance, more especially carbohydrates (in the form of sugar), fats, and proteins which contain the necessary nitrogen.

Reproduction of Cells.—Every animal-cell is formed by the division of a pre-existing cell called the *mother-cell*. The mother-cell divides into two equal parts—*the daughter-cells*—each of which, under ordinary conditions, possesses all the capabilities of its mother. Every new cell has a definite life-history. It grows and performs its proper functions; it then ceases to exist either by dividing into two daughter-cells, or by dying and breaking up into fragments which disappear.

Any tissue or organ grows so long as the multiplication-rate of the cells exceeds the death-rate. When the multiplication-rate and the death-rate are equal, the tissue or organ is in a state of equilibrium. As soon as the death-rate exceeds the multiplication-rate, decay and atrophy set in; and, when the decay and atrophy have proceeded to such an extent that an important tissue or organ can no longer perform its proper functions, general death ensues. Cell-division is therefore a vital necessity, and it takes place in two ways—(1) by **amitotic division**, and (2) by **mitotic division.**

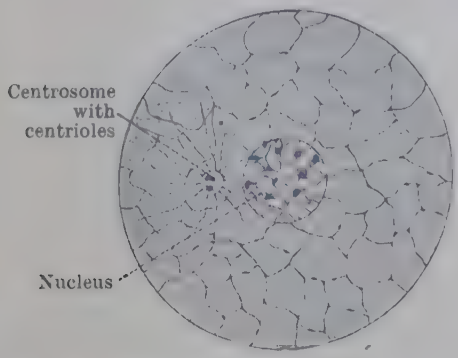


FIG. 3.—SCHEMA OF ANIMAL-CELL IN RESTING STAGE.

Amitotic Division.—The amitotic division of cells is an apparently simple process. First the nucleus is divided by an advancing constriction; thereafter, the cell-body is constricted and divided; and so two similar daughter-cells are produced.

The nucleus of some cells (epithelium of urinary bladder, giant cells of bone-marrow) may divide in this manner, so that the cells become bi-nucleated; but complete amitotic division occurs rarely, if at all, in the human body, and it is not known whether the daughter-cells produced can live and, in their turn, divide. Amitosis may be a degenerative process; and in any case, in comparison with mitosis, it is certainly unimportant.

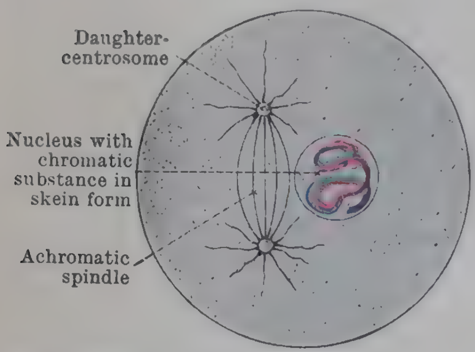


FIG. 4.—SCHEMA OF ANIMAL-CELL IN EARLY PART OF PROPHASE OF MITOSIS.

Mitotic Division.—Mitosis (so-called from the thread-like formation of the chromosomes) or *karyokinesis* (from the activity of the nucleus) is the more common, the more important, and by far the more complicated method of cell-division.

The phenomena of mitosis occur in four phases termed (1) the prophase, (2) the metaphase, (3) the anaphase, and (4) the telophase.

Prophase.—During the prophase the centrosome and the nucleus undergo very obvious changes.

The centrosome divides into two daughter-centrosomes, of which one passes to one side and the other to the opposite side of the nucleus.

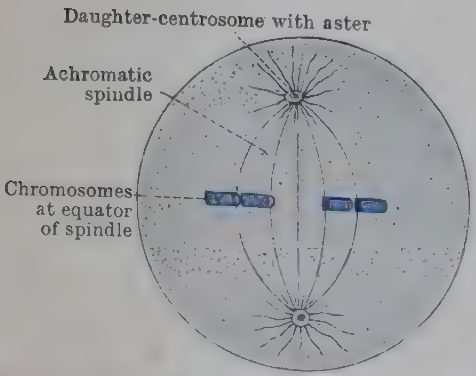


FIG. 5.—SCHEMA OF ANIMAL-CELL AT COMPLETION OF PROPHASE OF MITOSIS.

At the same time a spindle of achromatic fibrils appears and extends from one daughter-centrosome to the other; and fibrils radiate also from each centrosome into the surrounding cytoplasm with star-like figures known as *asters* (Fig. 4). In some cases the *achromatic spindle* is formed entirely outside the nucleus; but more often it passes through the nucleus and may then appear to be derived from the reticulum of linin. It is thought that the fibrils represent a physical change in the cytoplasm, and they appear to guide the movements of the chromosomes in the anaphase of division.

The nuclear transformation affects also the nuclear membrane, the nucleoli, and the chromatin. The nuclear membrane disappears, as also do the nucleoli—sometimes after passing from the nucleus into the cytoplasm, but more commonly without such migration.

The chromatin, during the resting period, is dispersed in the nucleus in an apparently irregular and inconstant manner. As the prophase begins, it is aggregated into small nodules, called *chromomeres*, which are strung together to form a series of nodulated filaments called **chromosomes**. In each species of animal the number of chromosomes

found during cell-division is constant and characteristic. The number of chromosomes in human cells is now definitely known to be 48 (p. 21).

The filamentous chromosomes of the early prophase are bent, twisted, and intimately intermingled, so that, for a time, they simulate a convoluted *skein* (Fig. 4), and, indeed, the individual filaments are sometimes united to one another end to end. Such a condition is, however, but a transitory connexion of the individual chromosomes, and they soon reassert their independence. Gradually the thread-like chromosomes become shorter until the chromomeres are so compressed together that they are no longer distinguishable from one another.

When the shortening is completed the chromosomes appear in the form of rods, hooks, or V-shaped bars, of varying size, which are gathered together at the equator of the achromatic spindle, where they form collectively the *equatorial plate* of the completed prophase (Fig. 5). At this period, each chromosome is attached to one or more of the fibrils of the achromatic spindle.

Metaphase.—During this phase each chromosome divides longitudinally into two equal daughter-chromosomes (Fig. 6).

The division begins at the point where the chromosome is attached to the achromatic spindle; and, as it proceeds, it becomes evident that one daughter-chromosome is attached by one or more of the fibrils of the achromatic spindle to one centrosome and the other to the opposite centrosome.

When the division of the chromosomes is complete the metaphase is ended, two equatorial daughter-plates are present, and the number of chromosomes is doubled.

Anaphase.—In the anaphase the chromosomes of each equatorial daughter-plate move along the fibrils of the achromatic spindle towards the corresponding centrosome. As they approach the centrosome, the body of the cell begins to be divided by a circular constriction which appears at the level of the equator of the achromatic spindle. The appearance of the constriction indicates the end of the anaphase and the commencement of the telophase (Fig. 7).

Telophase.—In the telophase, the terminal period of mitosis, the constriction of the cell-body deepens until the cell is divided into two daughter-cells.

As the division of the cell-body proceeds, the changes which occurred in the chromatin to form the chromosomes are reversed, so that first a skein and then a network are formed. A nuclear membrane is formed again and nucleoli reappear. A new daughter-nucleus is thus formed in each daughter-cell; and as it is formed the greater part of the achromatic figure disappears.

The result of mitotic division is therefore the formation of two daughter-cells from a mother-cell. Each daughter-cell is necessarily smaller than the mother-cell, but has the same constituent parts and the same number of chromosomes in its nucleus as the mother-cell had (Fig. 8).

Heterotypical and Homotypical Mitosis.—The mechanism of mitosis just described applies to all **somatic cells** or **body-cells**; but in the maturation of the **germ-cells** two special cell-divisions occur which are known as 'heterotypical' and 'homotypical'.

In **heterotypical mitosis** the number of chromosomes is reduced to half the characteristic number; in **homotypical mitosis** the ordinary mechanism of cell-division is applied to the daughter-cells with the reduced number of chromosomes (see pp. 19 and 26).

Periods of Growth and Function.—After cell-division there is a variable period during which the daughter-cells grow until they attain the adult size. Thereafter, until division again occurs, they perform the functions of the group of cells to which they belong.

The capability of cells to perform functions depends upon their chromatin contents as well as upon proper nutriment, warmth, and moisture, upon their relative positions in the body of which they form a part, and the provision of means whereby the products of the cell-activity can be removed.

Function of Chromosomes.—As the chromosomes of the mother-cells are split longitudinally during mitosis, each daughter-cell receives exactly the same number of

chromosomes and presumably the same number of chromomeres as the mother-cell from which it was derived, and in the case of cells in fully differentiated tissues it seems probable that the chromosomes carry with them the same possibilities for functional capacity that the mother-cell possessed. This, however, cannot always be the case in the early stages of development before the different tissues of the body are differentiated from one another, for in those stages some cells take part in the formation of one tissue, and others in the formation of other tissues which ultimately perform quite different functions. It must be assumed, whilst the number of the chromosomes in all the cells of the body is the same, that the qualities of their chromomeres may be different.

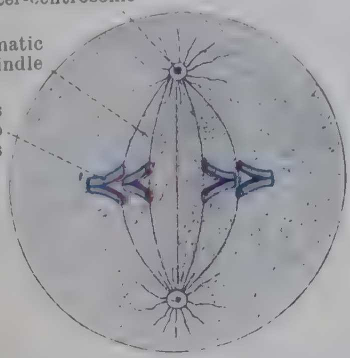


FIG. 6.—SCHEMA OF ANIMAL-CELL IN METAPHASE OF MITOSIS.

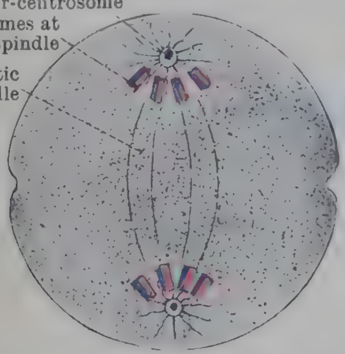


FIG. 7.—SCHEMA OF ANIMAL-CELL AT END OF ANAPHASE OF MITOSIS.

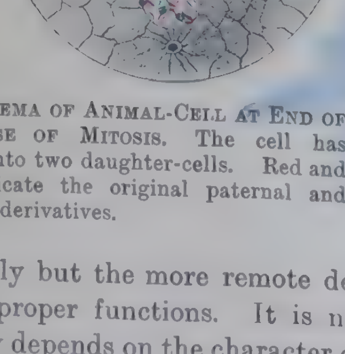


FIG. 8.—SCHEMA OF ANIMAL-CELL AT END OF TELOPHASE OF MITOSIS. The cell has divided into two daughter-cells. Red and blue indicate the original paternal and maternal derivatives.

The function of the chromosomes is therefore to transmit potentialities from one generation of cells to the next. This function has its supreme expression in the transmission through male and female germ-cells of heritable characters from two parents to their offspring. The chromosomes are thus "the material basis of inheritance".

It is believed that the chromomeres of the chromosomes consist of innumerable ultra-microscopic particles, called **genes,** in which, in some manner unknown, determinants of heritable characters are located, and that the capabilities and tendencies of each new individual depend upon the paternal and maternal genes which come together in a new combination in the fertilized ovum.

Further, the evidence available points to the conclusion that the chromomeres and their genes derived from the father never fuse with those derived from the mother, although they lie in close juxtaposition (Fig. 8).

Period of Cell-Life.—As already pointed out, every new cell has a definite life-history. The period of cell-life varies, but it always ends in death; for a time comes when cells no longer transmit to their descendants the power of division, or the capability of growth and function. If it were not so, growth and function, or at least maintenance and function, would continue uninterruptedly, and, in the absence of accident or disease, individual life would continue for ever, and 'old age' would be unknown.

It appears therefore that the ancestors of some cells are capable of producing only a certain number of descendants that can grow to the normal size and perform their proper functions for a more or less fixed period, whilst in other cases the power of division appears to be transmitted continuously but the more remote descendants become less and less capable of performing their proper functions. It is not known how the period of cell-life is fixed; but it probably depends on the character of the genes and their rearrangement in the fertilized ovum. When favourable combinations occur the human individual may live for a hundred years or more. If the combinations of the genes are unfavourable the ova may die immediately after they are fertilized; or they may survive and develop for a time, only to die later at any stage of the intra-uterine period. Eventually all individuals

must die—some killed by accident, others by microbic disease; but most because they have reached the limit originally determined by their inheritance.

There is evidence that the prenatal death-rate is high (Robinson, 1921). For example, it has been shown that about 30 per cent of pig embryos " are abnormal, and that one-third of these are already defective in the phase of segmentation ". In the case of the Hertig-Rock series of early human embryos (p. 38), almost 40 per cent of the twenty-three implanted specimens found in nine years " show some abnormality, often of such a serious nature that it is incompatible with normal continuation of the pregnancy " (Corner, 1947).

Tissues of the Body

There are only four main tissues in the body—**epithelial**, **connective**, **muscular**, **nervous**—and all parts of it are made up of combinations of varieties of these four in different proportions. All the tissues originally consist of cells; and the differences between the tissues are due to (1) changes in the cells in accordance with specialized functions, and (2) the formation of different kinds of extra-cellular materials—**intercellular substance**—which may surround the cells and separate them in varying degree.

The contents of the cells of some tissues are, however, not entirely separate, as in the germinative zone of the epidermis in which protoplasmic bridges pass between contiguous cells. Cell-walls may even be absent so that the 'cells' form a mass of multi-nucleated protoplasm known as a **syncytium** or a **plasmodium**, as in the outer layer of the 'ovum' in early stages of development (p. 81).

In **epithelial tissue**, extra-cellular material is at a minimum, and the varieties of the tissue depend upon the form of the comparatively simple cells according to their situation and function. *Epithelium* provides a covering for the surfaces of the body, external and internal, and is represented also by the secreting cells of glands. It is derived from all three germ-layers of the embryo (p. 55). The epidermis of the skin with its derivatives (skin-glands, hairs, nails) is ectodermal in origin; the epithelium that lines the alimentary and respiratory tracts and composes the secreting parts of the glands associated with them is entodermal; and the epithelial lining of the greater part of the urogenital tract is derived from the mesoderm.

The epithelial cells that line the cavities of the heart, blood-vessels, and lymph-vessels, and of the serous cavities of the body, also are mesodermal in origin. They are specially named *endothelium*; but those that line the serous cavities (pericardium, pleura, and peritoneum) are sometimes distinguished as *mesothelium*.

In **connective tissue**, intercellular substance is at a maximum, and its varieties depend mainly upon the nature of the intercellular substance and the appearance of different kinds of fibres in it. Connective tissues in general form the framework of the body, including the skeleton. The main varieties are areolar, adipose, fibrous, elastic, and reticular tissue, cartilage and bone; they are all derived from the mesoderm or the mesenchyme of the embryo (p. 52). *Areolar tissue* is the most widespread connective tissue in the body, and also the least specialized, as it contains a mixture of the white, collagenous (gelatin-producing) fibres and the yellow elastic fibres, which preponderate respectively in fibrous and elastic tissues. It is a loose tissue which receives its name because spaces or 'areolæ' are easily produced in it; and it is found wherever a slightly elastic connexion that will accommodate itself to movements of parts is required, *e.g.*, in the superficial fascia (p. 410) and in the submucous coat of the alimentary tract.

Adipose tissue is areolar tissue in which the cells are loaded with fat. It is found notably in the superficial fascia, in the mesentery and greater omentum in the abdomen, and around the kidneys, where it acts as a packing-material adapting these organs to the bed in which they lie (p. 728).

Fibrous tissue is composed mainly of bundles of collagenous fibres, and it is the basis of dense, strong structures such as the deep fascia (p. 410), ligaments, and tendons.

Elastic tissue owes its name to the property of the elastic fibres which are its chief constituent. It is found where strong, highly elastic connexions are required by the nature

of the movements that take place, *e.g.*, in the yellowish ligaments (ligamenta flava) of the vertebral column (p. 346), and in the ligamentum nuchæ (p. 345) of quadrupeds which relieves the muscles in the support of the head. Elastic tissue is an important element in the walls of blood-vessels, especially of the larger arteries.

Reticular tissue is a special kind of areolar tissue in which the collagenous fibres are arranged as a fine-meshed framework for the support of the proper substance of various organs. It is typically seen as the supporting element of the lymphoid tissue in lymph-glands, in the tonsils and other lymphoid structures in the alimentary tract, and in the spleen; and it is found also in the liver and the bone-marrow. Associated with reticular tissue there are special phagocytic cells called *macrophages* which are capable of ingesting particles and readily take up certain dyes in the process of vital staining. These cells, with others of similar property in the blood and elsewhere, are collectively known as the *reticulo-endothelial system* (p. 831).

Cartilage is the more or less translucent, resilient tissue that occurs mainly in relation to the skeleton. There are three varieties—hyaline, white fibro-cartilage, yellow or elastic fibro-cartilage—differing in respect of the inclusion of fibres in the ground-substance; they are described on p. 112.

Bone is the highly specialized connective tissue that forms the skeleton. It is described in the Section on Osteology (p. 106).

Bone-marrow (p. 109) and the *blood* and *lymph* (in which the fluid corresponds to inter-cellular substance in other varieties) are usually reckoned also as connective tissues.

Muscular tissue consists of highly specialized cells which have been converted into *muscle-fibres.* Muscle-fibres exhibit a supreme degree of contractility in response to stimulus—a property inherent in all protoplasm—and are of different kinds according to their situation and function and the nature of their control by the nervous system. There are three structural varieties of muscular tissue (p. 403):—(1) *Plain muscle*, the simplest kind, which is the contractile element in the walls of hollow viscera and of blood-vessels. (2) *Striated muscle*, the fibres of which are more specialized and exhibit under the microscope a characteristic cross-striation; the ordinary skeletal muscles are composed of this tissue arranged in bundles. (3) *Cardiac muscle*, which is intermediate in structure and functionally specialized in relation to the rhythmic contraction of the heart. With certain exceptions (plain muscle of sweat-glands and of the iris of the eye, which are ectodermal) all muscular tissue is derived from the mesoderm or the mesenchyme.

Nervous tissue (p. 835), consists of *nerve-cells* and their processes, including *nerve-fibres* which are the essential element in ordinary nerves. A nerve-cell with all its processes constitutes a unit called a *neuron*, and the whole of the nervous system, both central and peripheral, is built up of these units (p. 840); their relation to each other in the central nervous system is extremely complex. Neurons are the most highly specialized cells in the body, exhibiting in supreme degree irritability and conductivity which, like contractility, are inherent properties of protoplasm. Nervous tissue, including most of the elements, known collectively as *neuroglia*, which take the place of ordinary connective tissue in the central nervous system, is derived from the ectoderm of the embryo.

For a general account of the tissues, emphasizing their functions and the parts they play in the building-up of the body, the student is strongly recommended to consult Le Gros Clark (1945).

Embryology and Morphology

The study of the processes by which the parts of the body are gradually formed, and of the structural arrangements by means of which a temporary connexion, for the purpose of an interchange of nutritive and other materials, is established between the ovum and the mother, renders Embryology one of the most interesting of all the branches of Anatomy. Moreover, the early stages in the development of the embryo, and the mode of development of its organs, are of great morphological importance. The term **ontogeny** also is used to denote the

development of the individual. There is, however, another form of development, slower but just as certain in its progress, which has affected all the members of the animal-group to which the individual belongs. The theory of **evolution** leads us to believe that the wide structural gap between Man of the present day and his remote ancestors would, if the geological record were perfect, be completely occupied by long-lost intermediate forms. In the process of descent by evolution, structural changes have gradually taken place which have modified the entire race. The evolutionary phases through which it has passed constitute the ancestral history or **phylogeny** of the race. Ontogeny and phylogeny, moreover, are intertwined in a remarkable manner. The ancestral evolutionary development appears to be so stamped upon an individual that it repeats certain of the phylogenetic stages with more or less clearness during the process of its own ontogenetic development. Thus, at an early period in the development of Man evanescent gill-pouches appear which are comparable with those of a fish, and a study of the development of his heart shows that it passes through transitory structural conditions similar, in many respects, to the permanent conditions of the heart in certain of the lower animals. Thus has arisen the picturesque phrase that every animal during its individual development climbs up its own genealogical tree—a saying which, taking it even in the broadest sense, is only partially true.

Speaking broadly, it may be said that during ontogeny only so much of the phylogenetic history is recapitulated as may be necessary to lay the foundation for further stages of development. Thus, although the embryos of the higher mammals have long since ceased to depend upon the storage of yolk in the egg for their nourishment, even in the human embryo a yolk-sac is well-developed, since it is intimately related to the formation of the alimentary canal and to the early appearance of blood-vessels and blood.

Certain terms employed in morphology require some explanation. The same organ repeated in two different animals is said to present a case of **homology**. But the morphological identity between the two organs must be proved beyond dispute before the homology between them can be allowed. The great and essential test is that the two organs in question should have a similar developmental origin. Thus, the fore-limb of a quadruped is homologous with the human upper limb; the puny collar-bone of a tiger, the fibrous thread which is the only representative of this bone in the horse, and the strongly marked clavicle of the ape or Man are all, strictly speaking, homologous with one another. Homologous organs in different animals usually occupy a similar position and possess a similar structure, but not invariably so. It is not uncommon for a muscle to wander slightly from its original position, and many cases could be quoted in which parts have become completely transformed in structure, either from disuse or for the purpose of meeting some special demand in the animal economy. In the study of the muscles and ligaments instances of this will be brought under the notice of the reader.

The term **homoplasy** is sometimes used to express a form of correspondence between organs in different animals which cannot be included under the term homology. Two animal groups, which originally have sprung from the same stem-form, may exhibit convergence in evolution by developing independently a similar structural character which is altogether absent in the ancestor common to both. Thus, the common ancestor of man and the carnivora in all probability possessed a smooth brain, and yet the human brain and the carnivore brain are both richly convoluted. Correspondence of this kind is included under the term 'homoplasy'. Another example is afforded by the heart of the mammal and that

of the bird. In each of the[illegible] [illegible]ups the ventricular portio[illegible] [illegible]eart consists of a right and a left chamber, and yet the ventricular septum in [illegible] [illegible] not strictly homologous with the corresponding septum in the other, because the common ancestor from which both have sprung possessed a heart with a single ventricular cavity, and the double-chambered condition has been a subsequent and independent development in the two groups.

Often organs which perform totally [illegible] [illegible]unctions are yet perfectly homologous. Thus, the wing of a bat or [illegible] [illegible] a bird, both of which are subservient to flight, are homologous with the human upper limb, the office of which is the different one of prehension. Identity or correspondence in the function performed by two organs in two different animals is not taken into consideration in deciding questions of homology. The gills of a fish and the lungs of a higher vertebrate perform very much the same physiological office, and yet they are not homologous. The term **analogy** is often used to express functional correspondence of this kind.

In the construction of vertebrates and certain other animal groups a series of similar parts are repeated along a longitudinal axis, one after the other. Thus, the series of vertebræ which build up the backbone, the series of ribs which gird round each side of the chest, the series of intercostal muscles which fill up the intervals between the ribs, the series of nerves which arise from the brain and spinal cord, are all examples of this. Parts thus repeated are said to be **serially homologous**. An animal in which similar structures are thus repeated is said to present the **segmental type** of organization. In the early stages of development this segmentation is much more strongly marked, and it is to be seen in parts which subsequently lose all trace of such a division. But there are other instances of serial homology besides those which are manifestly produced by segmentation. The upper limb is serially homologous with the lower limb: each is composed of parts which, to a large extent, are repeated in the other, and the correct adjustment of this comparison between the several parts of the upper and lower limbs constitutes one of the most difficult and yet interesting problems of morphology.

No student of Anatomy can proceed far without becoming aware that the human body, like all living things, is subject to **variation**. Many structural variations are recorded in the following pages. Apart altogether from **malformations**—due to aberrations in the course of the development of parts or organs of the body—most of them can be explained on morphological, genetic, or developmental grounds. But there are other kinds of variations in the human body that are not 'structural' in the usual sense, and that are notably subject to the laws of **inheritance.** Even the chemistry of the body varies, and such variation may be inherited. There are constitutional variations in body-build [illegible] [illegible] habitus which have been described and classified in numerous ways (S[illegible] [illegible] The proportions of the body, the stature, the form of the skull and [illegible] the texture and colour of the hair, the colour of the eyes and of the sl[illegible] [illegible] these and many other variable characters, in the skeleton and soft parts alike, make up in infinite variety the genetic constitution of individuals; and in characteristic combinations they are the hall-marks of the varieties or races of mankind.

Such variations are the subject-matter [illegible] *Physical Anthropology*, which not only deals with comparative racial ana[illegible] [illegible]ut is also concerned with the fascinating problems of the evolutionary origin and the early history of Man.

The appended list of References [illegible] [illegible]udes special works on the different aspects of Anatomy mentioned in this Introd[illegible] [illegible], and also books on the history of Medicine from which the enquiring student ca[illegible] [illegible] information on the history of Anatomy

itself. A list … ces will be found … of each Section of the Text Book for the … of those who may wish to st…y any topic more fully. These references include some classical books and papers; but in general they have been selected from recent papers which themselves provide lists that will lead the senior student to all the original sources.

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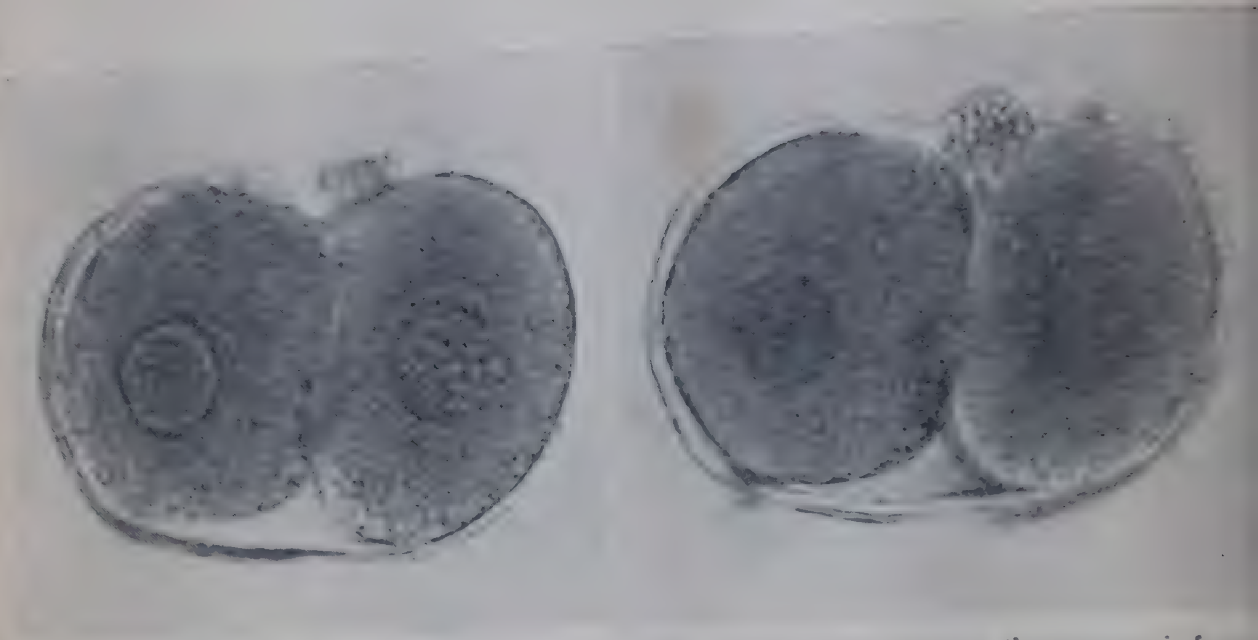
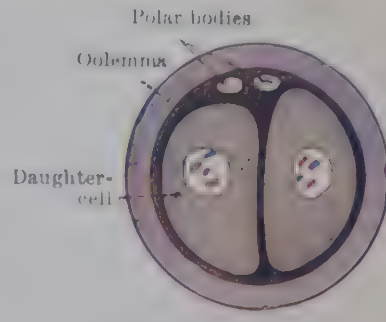


(a) The nuclei are in focus. (b) The two polar bodies are seen, the upper one in focus.

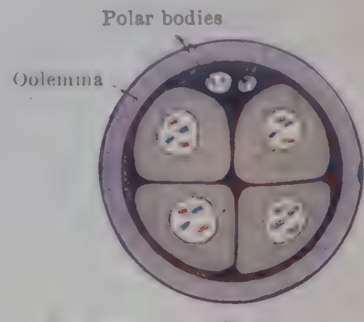
FIG. A.—TWO SECTIONS OF TWO-CELL STAGE OF SEGMENTATION OF HUMAN OVUM, FROM UTERINE TUBE. Photomicrographs × 500. (Carnegie No. 8698; by special permission of Dr. Arthur T. Hertig.)

FIG. B.—SECTION OF FREE HUMAN BLASTULA, 5-6 DAYS OLD, FROM UTERINE CAVITY. Photomicrograph × 600. Note the arrangement of the inner cell-mass in relation to the expanding trophoblastic wall and the segmentation cavity. (Carnegie No. 8663; by special permission of Dr. Arthur T. Hertig.)

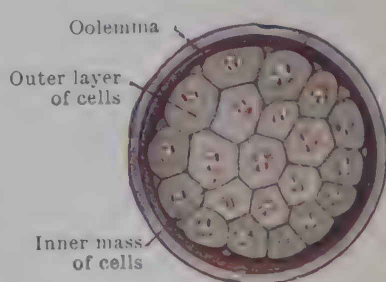
s *the period of segmentation* (Figs. 34, 35). The segmentation of the human ovum has
not yet been followed in detail, but again there can be no doubt that it occurs in
he same manner as the segmentation of the ova of
other mammals (Fig. 34); a perfect 2-cell stage (Fig. A,
p. 16) and at least three other segmenting human ova,
with 8, 9, and 12 blastomeres respectively (Corner,
1947) have been obtained, and the 8-cell stage has
been figured (Rock & Hertig, 1948).



A. Two-Cell Stage.



B. Four-Cell Stage.



C. Morula Stage.

Fig. 35.—Diagrams of Segmentation of Zygote.

The morula is formed inside the oolemma, so that its total size does not exceed that of the mature ovum; consequently, the proportion of cytoplasm to nucleus in the individual cells becomes progressively reduced during segmentation. That proportion is very high in the ovum, and its reduction within the normal range of the soma-cells appears to be an essential preliminary to the next stage of development. Before the segmentation-divisions are completed the polar bodies disappear, and at the end of segmentation the oolemma itself disintegrates as the zygote enlarges with the intake of fluid and structural differentiation begins.

There is evidence which tends to the conclusion that the earliest segmentation-divisions, by which the zygote is divided first into two and then into four parts are qualitatively equal. After a time, however, the divisions result in the formation of cells of different sizes and different capabilities, definite and circumscribed functions being allocated to certain groups of cells and their descendants, according to the position they assume in the morula; that is, the divisions become qualitative as well as quantitative. Some of the cells retain all the potentialities derived from their male and female ancestors and become stem-cells—that is, primordial germ-cells; and there is some evidence that they migrate in the developing embryo to the site of formation of the sex-glands (Witschi, 1948). To others only parts of the chromatic inheritance are transferred, and they become the soma-cells whose descendants become the tissue-cells of the body (Fig. 9).

Trophoblast and Inner Cell-Mass.—The first structural change that occurs in the morula is the differentiation of its cells into an outer layer and an inner cell-mass (Fig. 35 C).

The cells of the outer layer constitute the **trophoblast** or trophoblastic ectoderm, which, by its active proliferation (Figs. 39-48), plays a most important part in the implantation of the ovum in the mucous coat of the uterus and in the nutrition of the embryo and fœtus. It enters into the formation of the **chorion** or outermost envelope of the growing zygote. The chorion, part of which later forms the placenta, serves, in the first instance, as both a protective and a nutritive covering. The relation of the trophoblast to the site of implantation and its differentiation into outer syncytial and inner cellular layers—*plasmoditrophoblast* and *cytotrophoblast*—will be described with the fœtal membranes and placenta (p. 81).

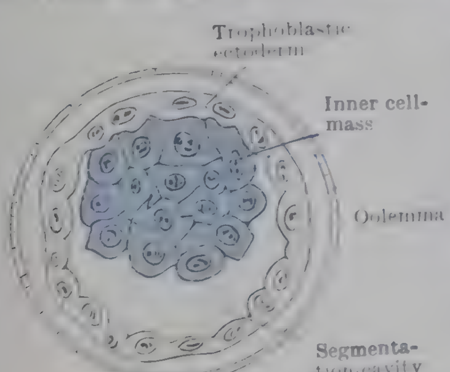


Fig. 36.—Diagram of Mammalian Blastula as Segmentation-Cavity begins to form.

The **inner cell-mass** contains the cells from which the embryo itself will be developed; but it is concerned also with the formation of the other extra-embryonic organs—amnion, yolk-sac, and allantois—which, with the chorion, constitute the fœtal membranes.

In all mammals—it is now known that human development is no exception (Figs. B, p. 16, 39)—a cavity appears in the zygote before the differentiation of the inner cell-mass takes place. As soon as this **segmentation-cavity** appears, the zygote becomes a **blastula** or **blastocyst**. The segmentation-cavity fills with

fluid and enlarges until it separates the inner cell-mass from the outer layer except at one pole of the zygote, where the inner cell-mass and the outer layer remain in contact (Fig. 36). By this time the oolemma has disintegrated and the blastula is free to expand with the further intake of fluid so that the trophoblastic cells are flattened out into a thin membrane, except where the inner cell-mass is attached (Figs. B, p. 16, 37). At this stage—the zygote having entered the uterus as a morula, probably on the 4th or 5th day from ovulation—the blastula becomes attached to the uterine epithelium (Fig. 38) and implantation begins. It is probable that this occurs on the 6th or 7th day, as the earliest implanting human zygote yet observed (Fig. 39) was recovered 7½ days after the presumed date of fertilization; it is still in the blastula stage.

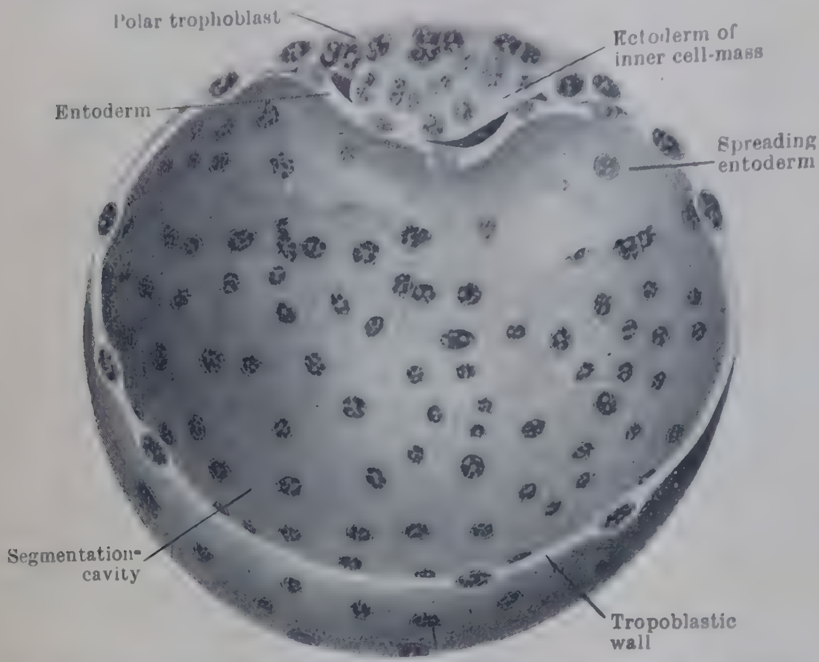


FIG. 37.—RECONSTRUCTION OF 9-DAY OLD BLASTULA OF MACAQUE MONKEY. The entodermal part of the inner cell-mass is flattened and its cells are spreading over the inner surface of the trophoblast. × 280. (After Heuser & Streeter 1941.)

Differentiation of Inner Cell-Mass.—As the blastula begins to attach itself to the endometrium and to be implanted, the fate of the cells of the inner cell-mass is already indicated by the relative positions they occupy (Figs. 39, 40, 51). The group that adheres for a time to the trophoblast, itself of ectodermal origin (p. 76), produce the **ectoderm**, destined to take part in the formation of both the embryo and its amnion; the remainder, projecting at first into the segmentation cavity but rapidly flattening out into a plate of single cells, constitute the **entoderm**, which takes part, too, in the formation of the embryo, and, in addition, of its yolk-sac. The appearance of the inner cell-mass in the blastocysts of the macaque monkey—in which the whole process has been observed (Heuser & Streeter, 1941)—makes it probable that the cells destined to form extra-embryonic parts are segregated at a very early stage from others which remain relatively large and will form the embryo itself.

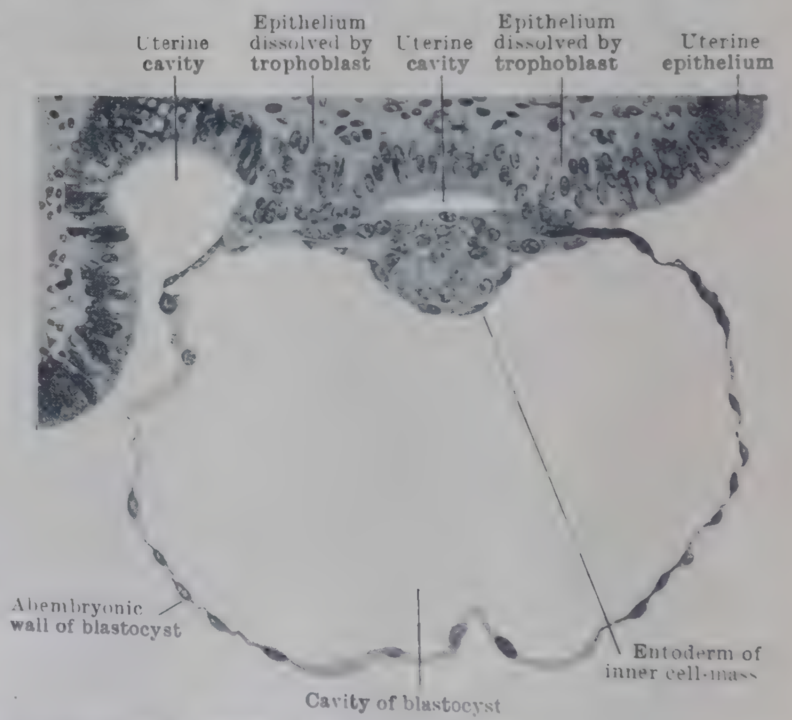
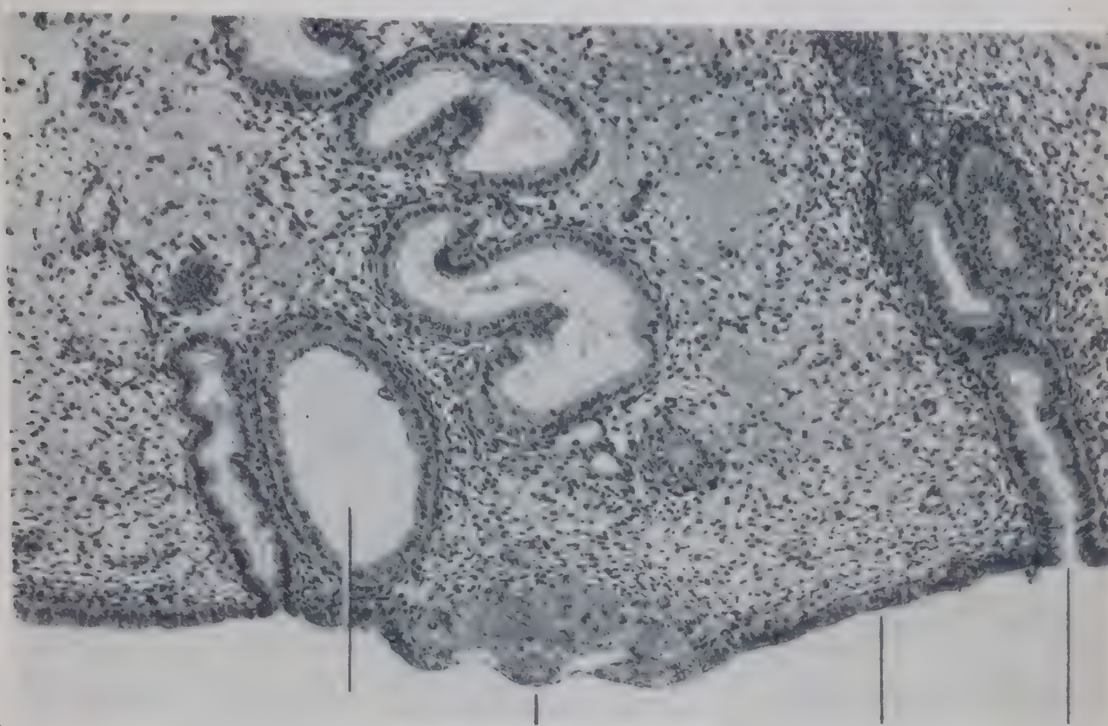
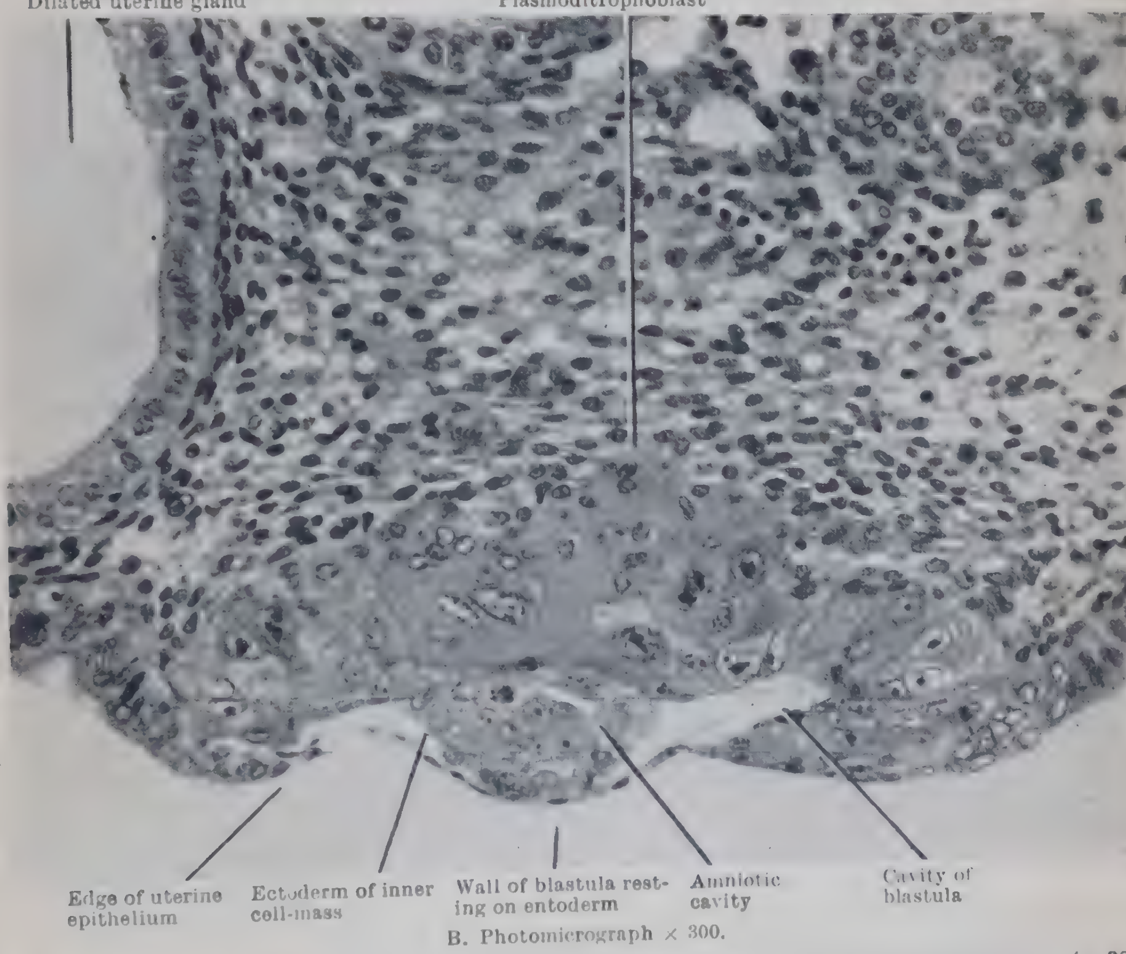


FIG. 38.—EARLY STAGE OF ATTACHMENT OF MACAQUE BLASTULA (ABOUT 9 DAYS) TO THE UTERINE EPITHELIUM. Note the dissolution of the endometrial cells in contact with the trophoblast and the spread of the entoderm from the inner cell-mass. Photomicrograph × 185. (After Heuser & Streeter, 1941.)

The delimitation of the ectodermal and entodermal elements of the inner cell-mass is followed by the formation of two vesicles, one from each group of cells.



A. Photomicrograph × 100.

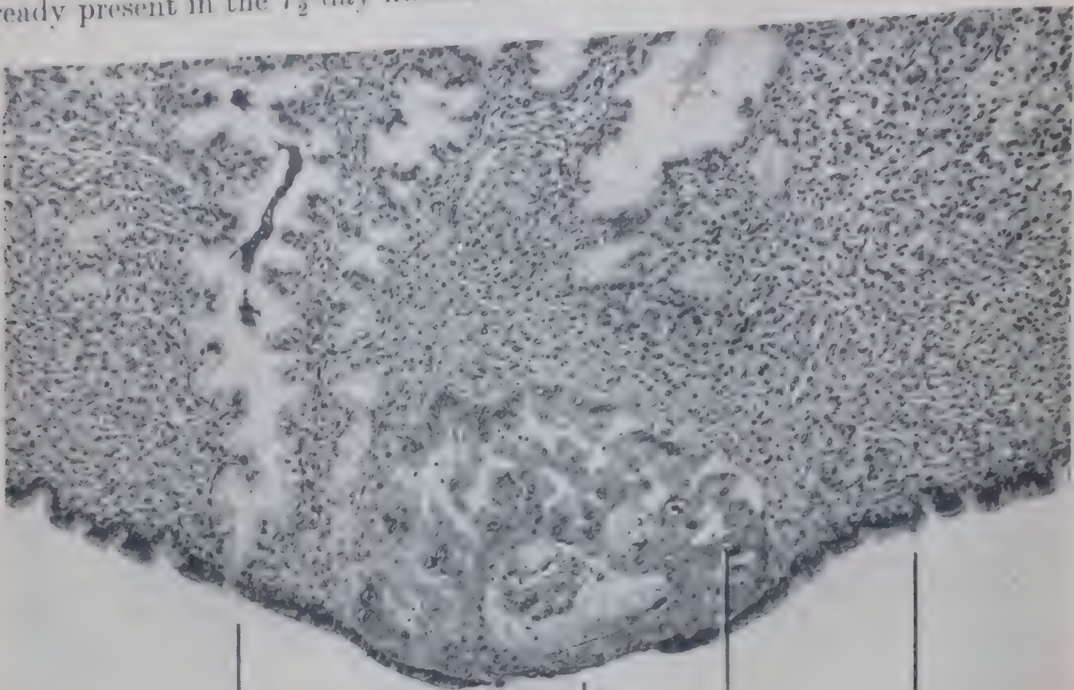


B. Photomicrograph × 300.

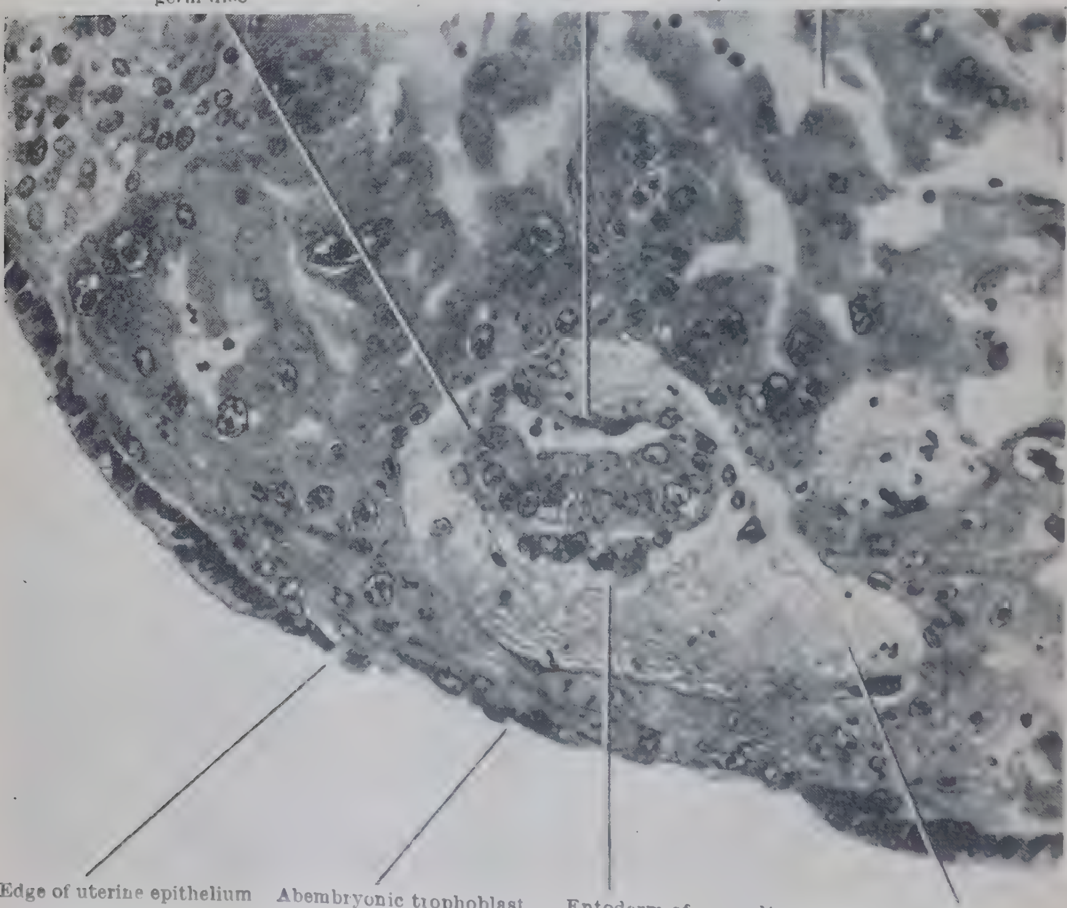
FIG. 39.—SECTION OF HUMAN ZYGOTE, 7½ DAYS OLD, IN EARLY, SUPERFICIAL STAGE OF IMPLANTATION (p. 38). The trophoblast is proliferating wherever it is in contact with the endometrium, and the thin, abembryonic wall of the blastula, still exposed to the uterine cavity, is collapsed on the inner cell-mass. (Hertig & Rock, 1945.)

There is some doubt whether the cavity in the ectodermal group is formed by a loosening of the cells in the middle of the group or by the partial separation of a layer of 'amniogenic' cells from the overlying trophoblast; but in either case the layer of 'amniogenic' cells from the overlying trophoblast ; but in either case the

cells are re-oriented around a space in which fluid accumulates. This *amniotic cavity* is already present in the 7½-day human blastula (Fig. 39).



A. Photomicrograph × 100.



B. Photomicrograph × 300.

FIG. 40.—SECTION OF HUMAN ZYGOTE, 9½ DAYS OLD (p. 38), MORE DEEPLY IMPLANTED THAN THE 7½-DAY SPECIMEN SHOWN IN FIG. 39.

Only a small portion of the trophoblastic wall is still exposed and the uterine epithelium is beginning to regenerate over it. There are numerous anastomosing lacunae in the plasmoditrophoblast. (Hertig & Rock, 1945.)

The precise mode of formation of the entodermal vesicle also is not quite certain. It is at first very much larger than the ectodermal vesicle and the question of its origin is complicated by the simultaneous appearance of the loose, semi-fluid tissue known as the *primary mesoderm*.

The entodermal portion of the inner cell-mass appears in the $7\frac{1}{2}$-day human blastula as a simple layer of cells (Fig. 39), and in a $9\frac{1}{2}$-day specimen (Fig. 40) there is little change in this layer beyond a possibly significant appearance of extending at its edges, although the ectodermal plate has grown thicker, the amniotic cavity is better defined and the implantation of the whole zygote has advanced considerably. Yet in quite a number of slightly older specimens recently described (p. 38) a complete 'entodermal' vesicle is present, larger than the ectodermal vesicle with its amniotic cavity, and occupying a varying but considerable part of the original cavity of the blastula itself now filled with 'primary mesoderm' (Figs. 41-44, 51). In mammals in general, the entoderm grows round the inside of the trophoblastic shell before any mesoderm—which arises later from the primitive streak of the embryonic disc—is present. It is known that the entoderm spreads in this way in the blastula of the macaque monkey (Fig. 37), (Heuser & Streeter, 1941); and it seems highly probable that this happens in human development also.

There is however an obvious difference between the cuboidal cells that form the 'roof' of the vesicle in contact with the ectodermal plate and the extremely tenuous remaining part of the wall of the vesicle. The thin, drawn-out cells that form it are of mesothelial character and are indeed indistinguishable from the cells of the primary mesoderm that now lines the trophoblastic shell and occupies the rest of the cavity in wisps of mesenchymatous tissue. For this reason, on the view that the thin part of the wall of the vesicle is derived from the primary mesoderm, the cavity was originally considered to be the first indication of the *extra-embryonic cœlom* (p. 42) and its wall was named the *exocœlomic membrane* (Heuser, 1932*b*, 1938). But, apart from any doubt as to the origin of the vesicle, its subsequent relation to the formation of the 'yolk-sac' (see below) suggested that it should be named the 'primary yolk-sac' (Heuser & Streeter, 1941), a designation now generally adopted (Figs. 41-44).

Origin of Yolk-Sac.—The vesicle known as the primary yolk-sac is the characteristic feature of the remarkable series of young human zygotes recently described (p. 38). Its origin has given rise to much discussion, but the balance of opinion is that the whole of the wall is of entodermal origin, in spite of the fact that the greater part—the so-called exocœlomic membrane—is composed of cells which appear to be derived from those of the primary mesoderm. But the whole of this vesicle does not participate in the formation of the 'yolk-sac' of later stages. The primary yolk-sac reaches its final state of development about the 12th day, when it is much larger than the ectodermal vesicle (Figs. 43, 44): thereafter, it is quite rapidly reduced in size—actual, not relative size—so that in a $13\frac{1}{2}$-day embryo (Fig. 47) it is not much larger than the ectodermal vesicle and soon, by the growth of that vesicle, the yolk-sac appears about the same size or even for a time relatively smaller (Fig. 48-50). It may now be called the **secondary yolk-sac.**[1]

There is some doubt, moreover, about the process by which the reduction is effected; but again it seems probable that the entodermal plate in the roof of the primary yolk-sac either delaminates with the formation of a cavity or extends at its edges to enclose the upper part of that vesicle. There is no doubt, however, that a considerable portion of the primary yolk-sac is cut off and disintegrates. In several young specimens small detached vesicles, sometimes connected by strands, can be recognized as degenerating portions of the primary yolk-sac (Figs. 46, 47). The earliest record of the stage of constriction of the primary yolk-sac, with a suggestion of its evolutionary significance, is in the description of the "Teacher-Bryce II" embryo by Bryce (1924). Stieve (1931) figured hypothetical stages in the reduction in size of the yolk-sac; and his interpretation is borne out by the 14-day specimen (Fig. 46) recently described by Morton (1949). The primary yolk-sac appears to correspond to the yolk-sac of lower mammals, and its replacement by the secondary yolk-sac is a specialized developmental process in Man and other Primates.

[1] The term *definitive yolk-sac* is better retained for the yolk-sac after separation from the alimentary canal, when it is known also as the 'umbilical vesicle' (p. 77).

Pre-Villous Human Embryos.—In the last edition of this text-book it was possible to make only preliminary reference to the accumulating wealth of new material that has revolutionized our knowledge of early human development. Some of these numerous specimens of recently implanted zygotes—they have been called " a perfect galaxy of new stars in the uterine firmament "—are now illustrated; and it may be well to summarize the features exhibited by this remarkable series, with references to the original descriptions.

No fewer than *eight* specimens in the pre-villous stage of development, i.e., before the formation of chorionic villi (p. 81), have been recorded since 1939. Five of them belong to the beautiful Hertig-Rock series (from the Carnegie Department of Embryology in Baltimore) which includes a number of other early human zygotes, all likewise embedded in the endometrium but described as " abnormal in respect of the state of the trophoblast and thought to have been destined to abort " (Hertig & Rock, 1944). Four of these 'abnormal' specimens, ranging in age from 11½ to 13½ days, show the same essential features of the embryonic rudiment as the eight normal zygotes.

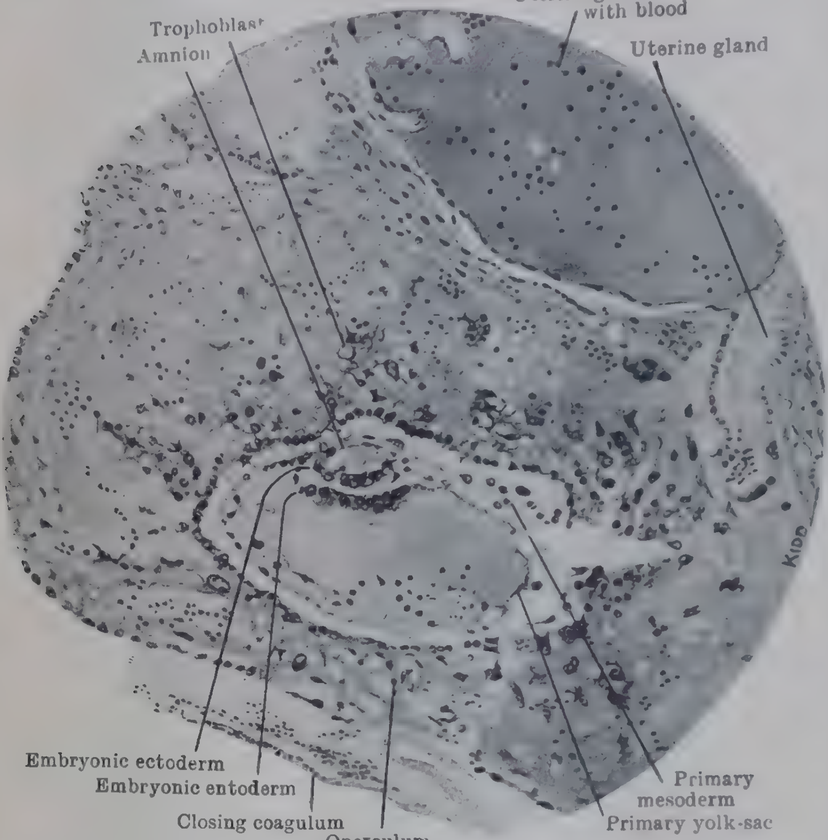


FIG. 41.—SECTION OF DIBLE-WEST EMBRYO TO SHOW THE EMBRYONIC RUDIMENT AND ITS RELATION TO THE PRIMARY MESODERM. × 75. (Dible & West, 1941.)

Carnegie No. 8020 (7½ days).—This is the earliest implanting human zygote yet recorded (Fig. 39). Its striking feature is the proliferation of the trophoblast wherever it is in contact with uterine tissues (p. 81). The implantation is quite shallow; the uterine epithelium shows a wide gap through which the thin abembryonic wall of the blastocyst, though collapsed on to the inner cell-mass, still projects into the uterine cavity. The inner cell-mass, attached to the advancing portion of the trophoblastic wall, shows a commencing amniotic cavity and a flattened plate of entodermal cells. There is no primary mesoderm in the segmentation - cavity; and this specimen provided the first proof—see Fig. B, p. 16—that there is a true blastula stage in human development (Hertig & Rock, 1945).

Carnegie No. 8004 (9½ days). This specimen (Fig. 40) shows the same general features but it is more deeply implanted, there are numerous *lacunae* in the plasmoditrophoblast (p. 81). the abembryonic pole of the trophoblastic shell has begun to proliferate and the uterine epithelium to regenerate over it. The embryonic rudiment is slightly more advanced with a better-defined amniotic cavity, and the entodermal plate shows signs of extending at its edges—an indication possibly of commencing formation of the primary yolk-sac. But there is as yet no primary mesoderm and the cavity appears to be filled with coagulum only (Hertig & Rock, 1945).

" *Davies-Harding* " (9-10 days).—The implantation is similar to the preceding, but there is no regeneration of the uterine epithelium and the aperture is plugged by a 'closing coagulum' (p. 80). The embryonic rudiment is in a definitely more advanced stage; although there is not much difference in the amniotic cavity, a complete primary yolk-sac is present, much larger than the ectodermal vesicle. It occupies a considerable part of the cavity and the rest of the cavity is filled with primary mesoderm. This is the important feature (see p. 37) which is characteristic also of the remaining specimens in this series. (Davies, 1944.)

" *Barnes* " (10-11 days).—Implantation appears to be more superficial than in the preceding specimen—the abembryonic trophoblast is quite thin and there is no regeneration of the uterine epithelium—but the embryonic rudiment is more advanced. The ectodermal plate projects with a convex surface into a well-defined amniotic cavity, the primary yolk-sac is smaller in proportion, and the cavity is filled with primary mesoderm and coagulum. (Hamilton, Barnes & Dodds, 1943.)

" *Dible-West* " (11½ days).—The descriptions of this specimen (Fig. 41) and of the next two were published in the same year, and they share the distinction of demonstrating the now well-known 'primary yolk-sac stage' of human development. The features are very similar to those of the " Davies-Harding " specimen, but the primary yolk-sac occupies a rather larger part of

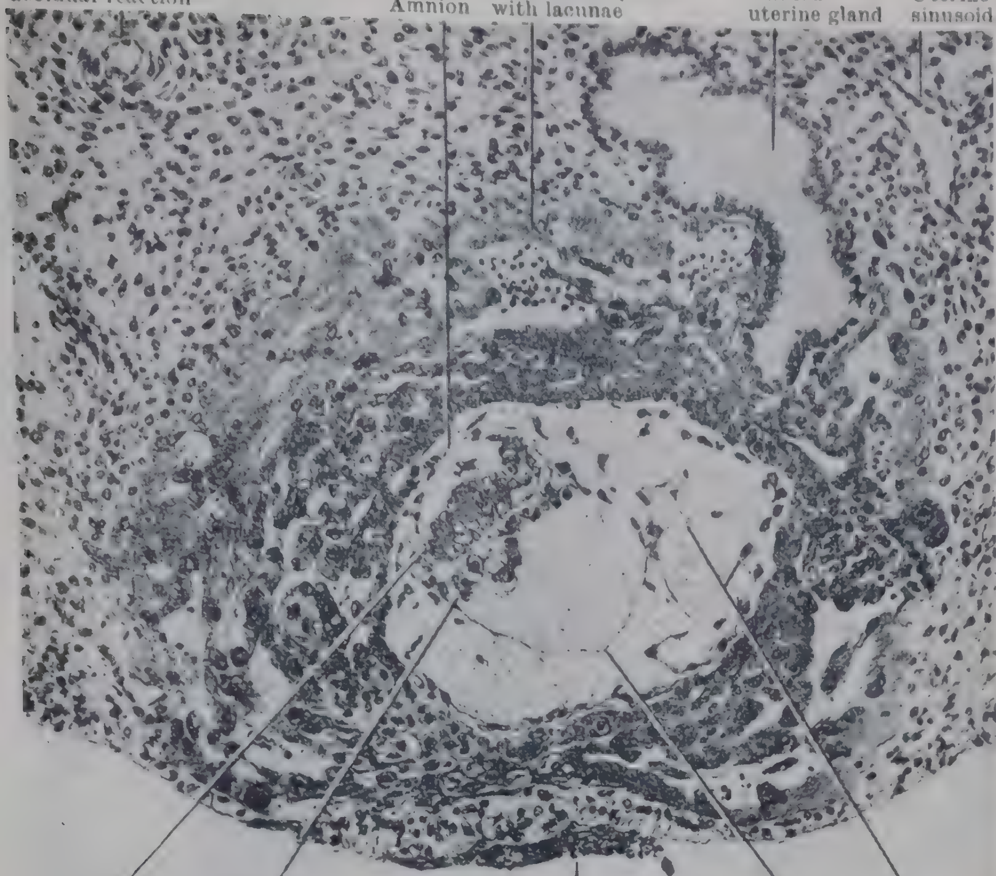


FIG. 42.—SECTION OF HUMAN ZYGOTE, 11½ DAYS OLD (p. 40).

The implantation is advanced to the stage of regeneration of the uterine epithelium, and the abembryonic trophoblast is proliferating. The 'germ-disc' is clearly defined; and the amniotic cavity, the primary yolk-sac and primary mesoderm are evident. Photomicrograph × 125. (Hertig & Rock, 1941.)

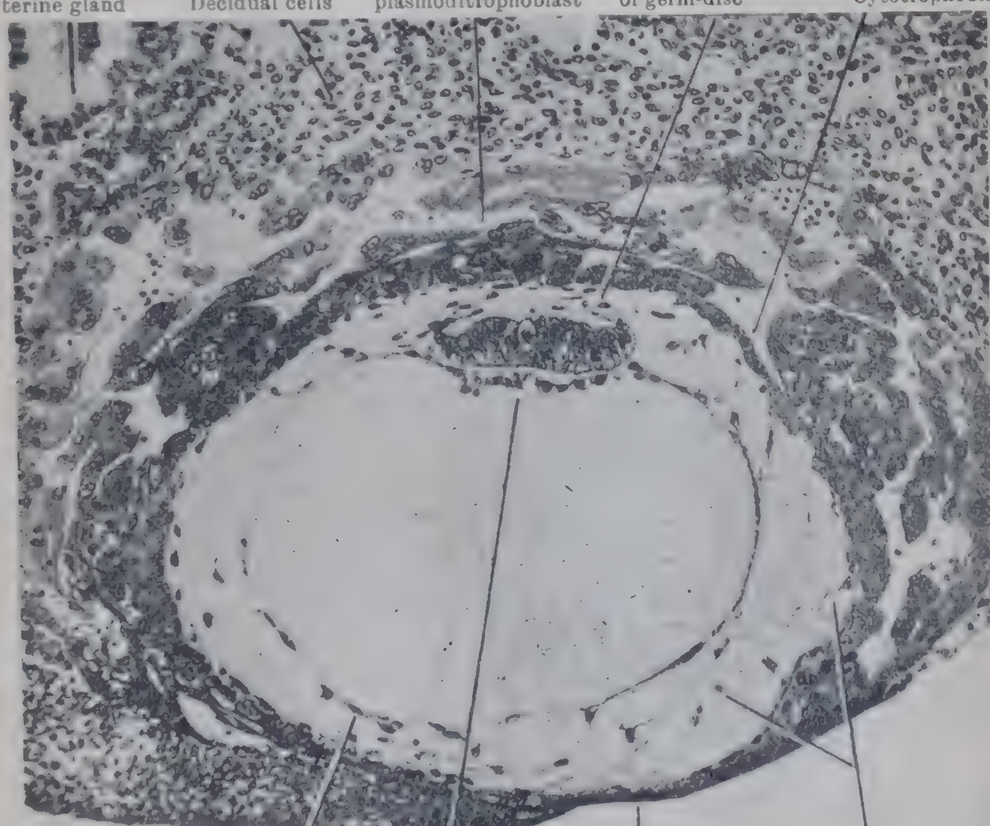


FIG. 43.—SECTION OF HUMAN ZYGOTE, 12½ DAYS OLD (p. 40).

The general features are the same as in the 11½-day specimen (Fig. 42); but the primary yolk-sac is much larger and the 'germ-disc' more advanced. The implantation, however, is more superficial. Photomicrograph × 125. (Hertig & Rock, 1941.)

the cavity, and there is a trophoblastic 'operculum' (p. 80) as well as a closing coagulum. (Dible & West, 1941.)

Carnegie Nos. 7699 ($11\frac{1}{2}$ days) and *7700* ($12\frac{1}{2}$ days).—These two specimens, described together

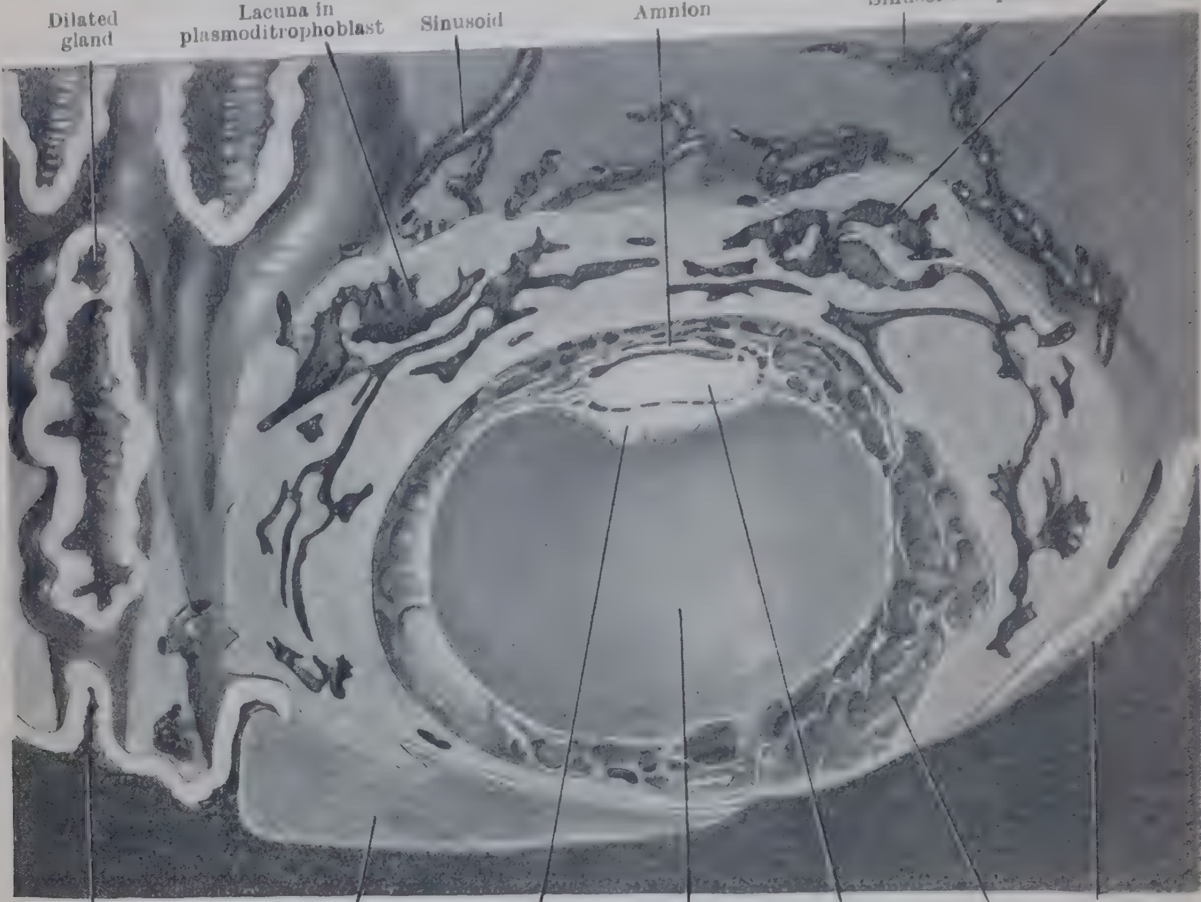


FIG. 44.—SECTIONAL RECONSTRUCTION OF THE $12\frac{1}{2}$-DAY HUMAN ZYGOTE IN FIG. 43.
The reconstruction shows the main features of the embryonic rudiment and of the trophoblast, in particular its relation to the endometrium. ×125. (After Hertig & Rock, 1941, from a drawing by James F. Didusch.)

in the same publication, are the most beautiful examples of the primary yolk-sac stage. They exhibit all the characteristic features and differ, like the others, in detail only, notably in the size of the primary yolk-sac. The ectodermal plates and the amniotic cavities are very similar but the primary yolk-sac is very much larger in the older specimen and indeed occupies nearly the whole of the chorionic cavity (Figs. 42-44). The younger specimen is more deeply implanted with regenerated uterine epithelium and a small closing coagulum (Fig. 42); the older one is more superficial and not so completely covered by abembryonic trophoblast and regenerating epithelium (Figs. 43, 44). (Hertig & Rock, 1941.)

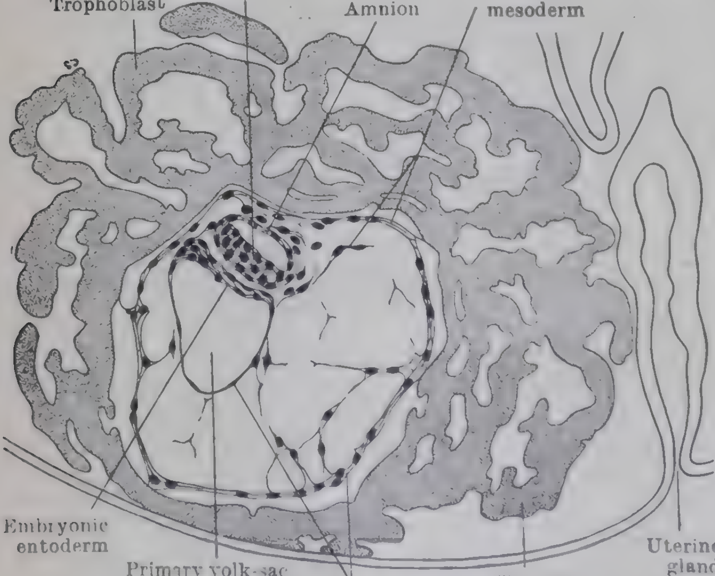


FIG. 45.—RECONSTRUCTED SECTION OF THE MILLER EMBRYO TO SHOW THE EMBRYONIC RUDIMENT AND ITS RELATION TO THE PRIMARY MESODERM AND THE TROPHOBLAST. × 100. (After G. L. Streeter, 1939.)

Carnegie No. 7950 (12 days).—This specimen is very similar to No. 7700 both in respect of the more superficial implantation and the size of the primary yolk-sac. The main difference is the slightly asymmetrical development of the ectodermal plate (Hertig & Rock, 1944).

To this account of these recent pre-villous specimens there should be added a note on two others previously described and now recognized to be examples of the primary yolk-sac stage.

"*Miller*" (11 days).—Originally described by J. W. Miller (1913) and re-described by G. L. Streeter (1926), it was reconstructed by Streeter (1939) (Fig. 45). The "Miller Ovum" supplanted, as the youngest-known human zygote, the well-known 12-13 day "Teacher-Bryce I Embryo" (Bryce & Teacher, 1908; Bryce, 1924), now recognized to be abnormal.

"*Werner*" (11½ days).—Described by Stieve (1931, 1936), it is the first on record to illustrate the 'primary yolk-sac', and the author put forward the proposition, now known to be true, that the 'yolk-sac', as previously understood, is secondarily derived from the larger vesicle.

It may be added that a 10½-day chimpanzee embryo demonstrates an essential similarity to the young human specimens now available in the method of implantation, in the differentiation of the inner cell-mass and in the proliferation of primary mesoderm (Elder, Hartman & Heuser, 1938; Heuser, 1940).

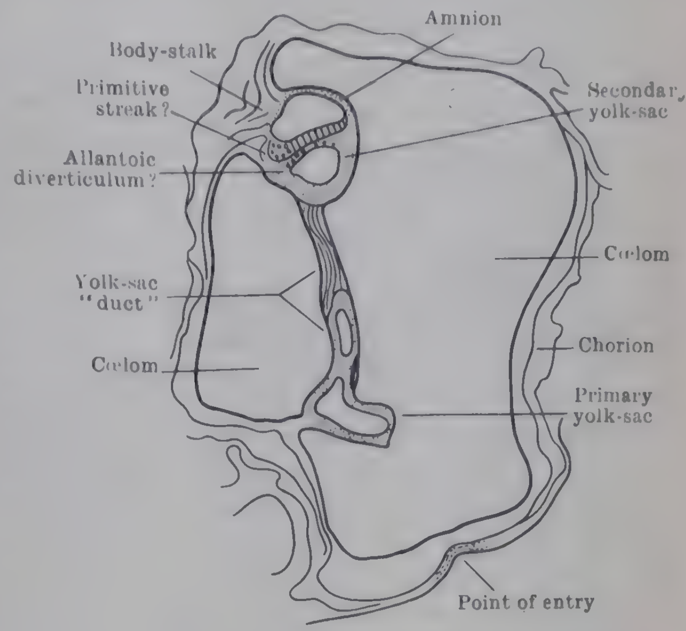


FIG. 46.—DIAGRAMMATIC RECONSTRUCTION OF HUMAN EMBRYO ABOUT 14 DAYS OLD.

This embryo is in the stage of reduction of the yolk-sac; the secondary yolk-sac is still connected by a tubular stalk to a degenerating portion of the primary yolk-sac. × 70. (After Morton, 1949.)

Primary Mesoderm, Extra-Embryonic Cœlom and Body-Stalk.—The mesoderm is one of the three *germ-layers* (p. 52) which co-operate in the building of the tissues and organs of the embryo, and most of it—in the majority of mammals, the whole of it—is formed at a later stage within the developing embryo itself. The *primary mesoderm* of human and other primate zygotes is precocious in its appearance, and this is probably to be associated with early implantation and the mode

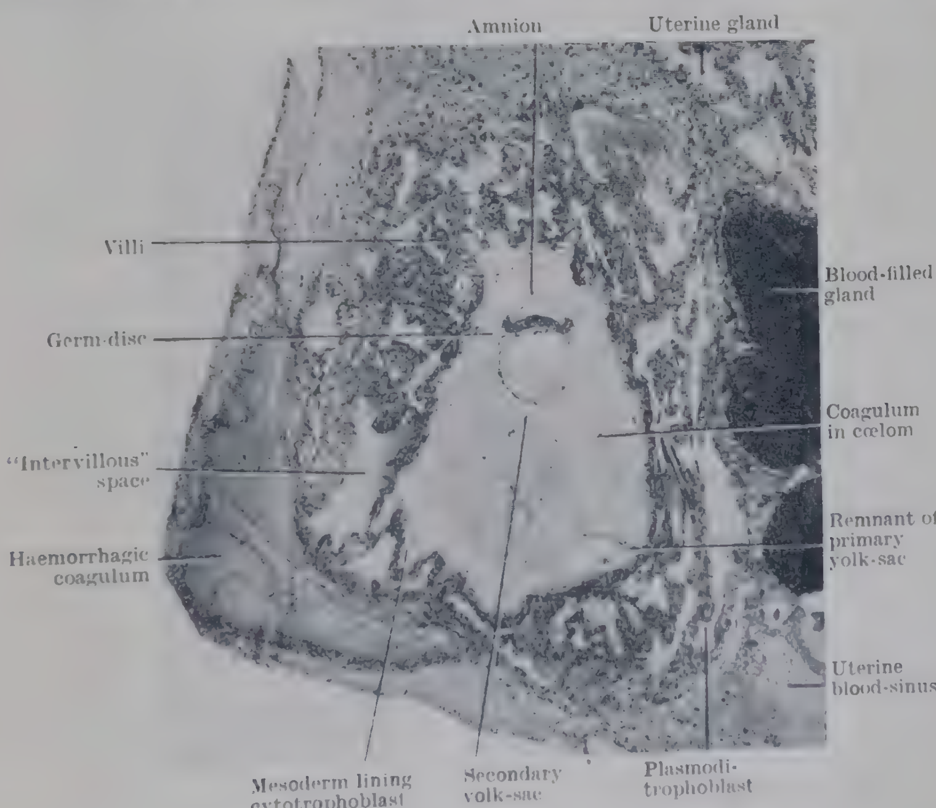


FIG. 47.—SECTION OF HUMAN ZYGOTE, 13½ DAYS OLD.

The embryonic rudiment is clearly defined with amnion and secondary yolk-sac, and a remnant of the primary yolk-sac is seen. There is an unusually large 'closing coagulum', and chorionic villi have begun to form. Photomicrograph × 30. (Heuser, Rock & Hertig, 1945.)

of formation of the ectodermal and entodermal vesicles. The primary mesoderm is extra-embryonic in origin, and indeed it is concerned with the formation of the foetal

membranes which, as already noted, are extra-embryonic organs. It is akin to the special kind of mesoderm formed later within the embryo and known as *mesenchyme* (p. 52).

It is probable that the primary mesoderm, which appears simultaneously with the primary yolk-sac, is derived from the inner surface of the trophoblastic shell. It soon lines the trophoblast as a distinctive layer, fills the space between the trophoblast and the primary yolk-sac in a loose, semi-fluid reticulum and attaches the ectodermal vesicle to the region of the trophoblast from which the 'amniogenic cells' (p. 35) may be derived (Figs. 40, 41, 45).

When the secondary yolk-sac is formed and the remnants of the primary yolk-sac disintegrate, clefts begin to appear in the primary mesoderm and presently run together to form a new cavity. That cavity expands rapidly until the mesoderm is reduced to two thin layers, one of which lines the inner surface of the trophoblast while the other covers the outer surface of the ectodermal and yolk-sac vesicles (Figs. 48-50). This space is the **extra-embryonic cœlom.**

The extra-embryonic cœlom, however, never completely separates the amnio - embryonic and yolk-sac vesicles from the inner surface of the trophoblast; it is obvious that continuity must be maintained at some point to provide a pathway for blood-vessels between the placental area of the chorion and the embryo. The basis of that pathway is provided by the primary mesoderm, which continues to connect the inner surface of the trophoblast with the vesicles in the region that will become the caudal end of the embryonic area. This mesodermal connecting-link is called the **body-stalk** (Figs. 50, 59, 61, 69, 71); the *allantois* grows into it from the yolk-sac; and it takes part, as will be seen later, in the formation of the umbilical cord which connects the fœtus with the placenta (p. 79).

FIG. 48.—SECTION OF HUMAN ZYGOTE, 16½ DAYS OLD. The secondary yolk-sac is fully formed with an outer covering of primary mesoderm. The 'germ-disc' is more advanced than in the 13½-day specimen (Fig. 47) with a primitive streak, early formation of intra-embryonic mesoderm, and a head-process. There is an indication of an 'amnion-stalk' in the condensation of mesoderm that attaches amnion to chorion, and an allantoic diverticulum was present. The chorionic villi with their mesodermal cores are branching freely. Photomicrograph × 30. (Heuser, Rock & Hertig, 1945.)

The word 'cœlom' means 'body-cavity'; and the apparent paradox that part of the body-cavity should be outside the body of the embryo and at one stage should even surround it (Fig 62)—is explained by its relation to the evolution and development of the fœtal membranes (Fig. 89). The *intra-embryonic* part of the cœlom—the body-cavity proper—is developed independently (p. 49) and becomes continuous for a time with the extra-embryonic part at the margin of the embryonic area and the umbilical orifice (Figs. 64 B, 65 B).

Embryonic Area.—When the extra-embryonic cœlom is developed, the zygote then consists of three vesicles, one large and two small. The large **chorionic vesicle** is bounded by the trophoblast lined with primary mesoderm; it contains the two small vesicles projecting into the cœlom and connected to the part of the chorion farthest from the uterine cavity by the mesodermic stalk only. The **ectodermal** or **amnio-embryonic vesicle** and the **entodermal** or **yolk-sac vesicle** remain in contact where the primary mesoderm has not penetrated between the original ectodermal

and entodermal elements of the inner cell-mass; and they form a bilaminar plate known as the **embryonic area** or **germ-disc**—the rudiment of the embryo itself. The ectodermal lamina is *embryonic ectoderm*—it will take part in the formation of the embryo; the *amniotic ectoderm* completes the ectodermal vesicle. Similarly, the entodermal vesicle consists of a lamina of *embryonic entoderm* and extra-embryonic or *yolk-sac entoderm* (Figs. 48, 51 F). The embryonic area is indicated as soon as the amniotic cavity is formed; it is well-defined in the classical Peters embryo of 13 days (Fig. 49), and is clearly demarcated in all young embryos in which the secondary yolk-sac is formed, for example, the 13½-day embryo (Fig. 47), and the embryos of 15 ays (Fig. 50) and 16½ days (Fig. 48) in which the primitive streak (see below) is already in evidence.

FIG. 49.—SECTION OF PETERS EMBRYO SHOWING THE EMBRYONIC AREA BETWEEN THE CAVITIES OF AMNION AND SECONDARY YOLK-SAC. (After Peters, 1899.)

With the formation and spread of the intra-embryonic mesoderm from the primitive streak (p. 48), the embryonic area becomes trilaminar.

Differentiation of Embryonic Area and Formation of Primary Axial Structures.—As the embryonic area is the area of contact between the ectodermal and the entodermal vesicles it is, at first, circular in outline. As growth continues the area becomes oval, and a linear thickening of the ectoderm, called the **primitive streak**, appears in that part of the oval which becomes the caudal part of the area (Figs. 53, 58, 63, 111). Bilateral symmetry is thus impressed upon the embryonic area and the line of the axial structures of the developing embryo is laid down. From this point in development we can speak of **cephalic** and **caudal** ends of the embryonic area. The growth of the area is most rapid at the caudal end so that it becomes elongated and for a time assumes a pear-shaped outline (Figs. 53, 111).

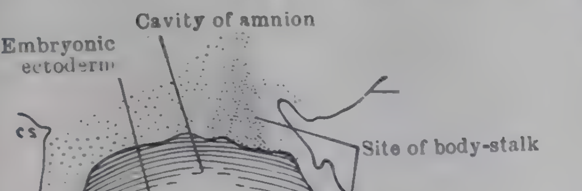


FIG. 50.—MEDIAN SECTION OF 15-DAY HUMAN EMBRYO (RECONSTRUCTION) TO SHOW THE EARLIEST STAGE OF THE PRIMITIVE STREAK AT THE CAUDAL END OF THE EMBRYONIC AREA. (After Brewer, 1938.)

The primitive streak is produced by a downgrowth of the ectoderm which projects as an inverted ridge against the entoderm in the caudal part of the embryonic area, pushing aside any primary mesoderm which may have intervened between the adjacent parts of the walls of the two vesicles. The deeper cells of the ridge adhere to the entoderm, and, by proliferation laterally into the interval between the ectoderm and entoderm of the embryonic area, they form the **intra-embryonic** or **secondary mesoderm**; they also give rise, after a series of remarkable developmental events, to the **notochord**—an axial structure characteristic of all vertebrates.

Immediately after the formation of the primitive streak a groove, called the

neural groove, appears in the cephalic part of the embryonic area (Figs. 60, 62, 68, 113). It is formed by the longitudinal folding of a thickened plate of ectoderm—

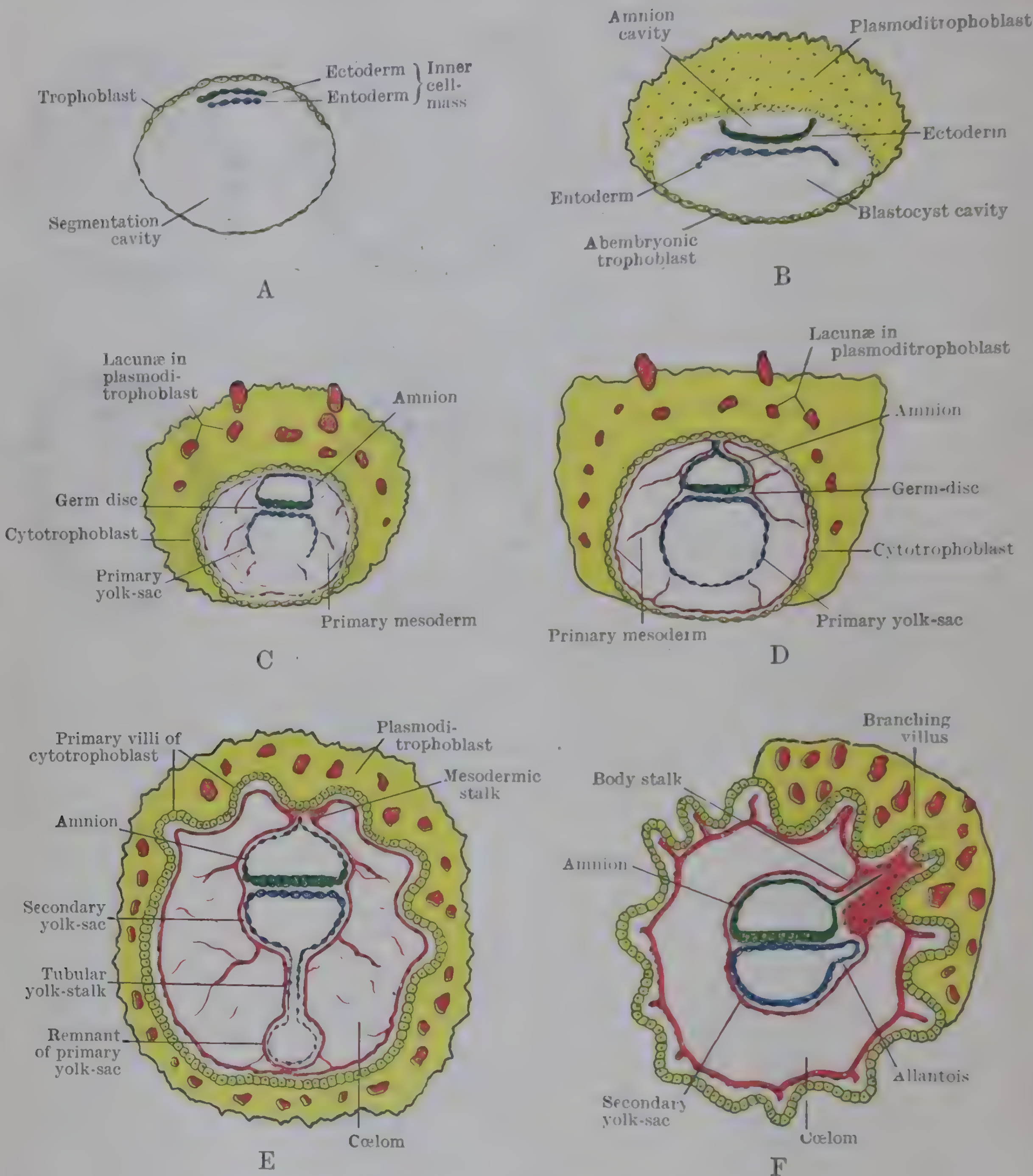


Fig. 51.—Schematic Stages of Early Human Development.

A. Blastula (Fig. 37).

B. Differentiation of inner cell-mass, growth of entodermal plate, and proliferation of plasmoditrophoblast (Figs. 39, 40).

C. Formation of amnion, germ-disc defined, primary yolk-sac developing, primary mesoderm spreading, lacunæ with maternal blood in plasmoditrophoblast.

D. Amnion and primary yolk-sac fully formed, primary mesoderm lines the trophoblastic shell and anchors the yolk-sac. There may be an amnion-stalk (Figs. 41-44).

E. Secondary yolk-sac is forming but still connected with degenerating remains of primary yolk-sac by tubular stalk. Chorionic villi are forming from cytotrophoblast (Figs. 46, 47).

F. The secondary yolk-sac is fully formed; the primary mesoderm lines the trophoblast, extends into the branching chorionic villi and forms the body-stalk which supports the embryonic vesicles in the cœlom (Figs. 48-50).

the **neural plate**—which is the rudiment of almost the whole nervous system, the only exceptions being the olfactory nerves, some parts of the ganglia of the cranial

nerves, and the end-organs of the sensory nerves. From it also are derived the cells of the primitive sheaths of the nerve-fibres and the chromaffin cells of the suprarenal glands and other chromaffin structures. The side-walls of the neural groove form the **neural folds.** Almost from the first the cephalic ends of the neural folds are united together a short distance behind the head-end of the embryonic area. Their caudal ends, which remain separate for a time, embrace the cephalic part of the primitive streak. For the further development of the neural groove and the central nervous system, see p. 59.

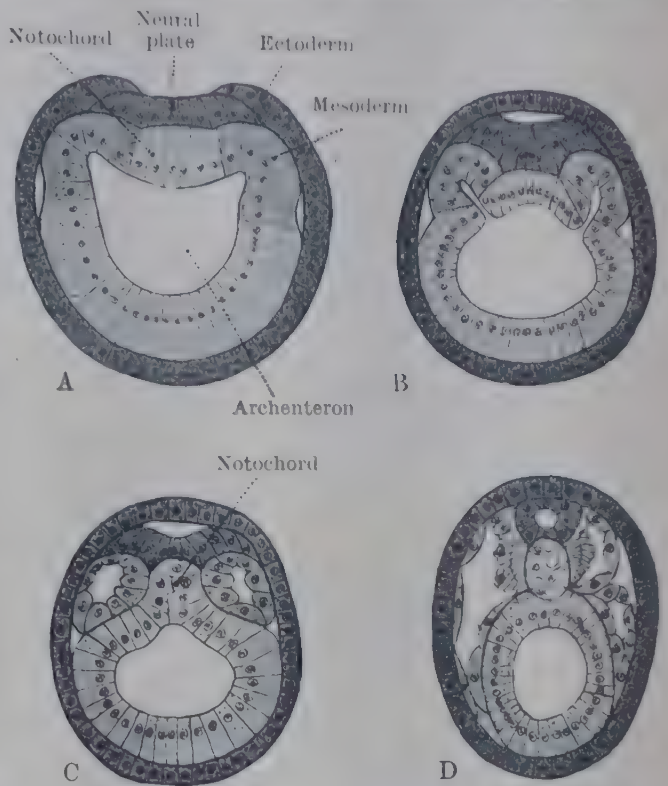


FIG. 52.—TRANSVERSE SECTIONS OF YOUNG *AMPHIOXUS* ILLUSTRATING THE ORIGIN OF THE NOTOCHORD AND THE MESODERM FROM THE ENTODERMIC LAYER OF THE GASTRULA. (After Hatschek.) (J. Graham Kerr, *Text-Book of Embryology: Vertebrata.* Macmillan & Co.)

In the meantime, however, a depression—the **primitive groove**—has appeared on the surface of the primitive streak. The headward end of the primitive groove deepens, until it forms a perforation which passes through the cephalic end of the streak and the subjacent entoderm into the cavity of the entodermal vesicle. As this perforation passes from the floor of the caudal part of the neural groove into that part of the entodermal vesicle which afterwards becomes the primitive alimentary canal or enteron, it is called the **neurenteric canal** (Figs. 59-61). The explanation of this remarkable phenomenon must be deferred until the formation of the notochord

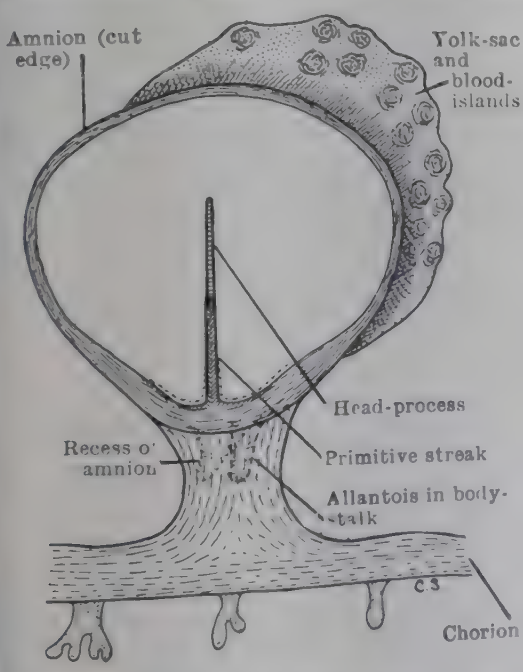


FIG. 53.—RECONSTRUCTED SURFACE VIEW OF EMBRYONIC AREA OF YOUNG HUMAN EMBRYO OF 18 DAYS TO SHOW POSITION OF HEAD-PROCESS AND ITS RELATION TO PRIMITIVE STREAK. × 50.

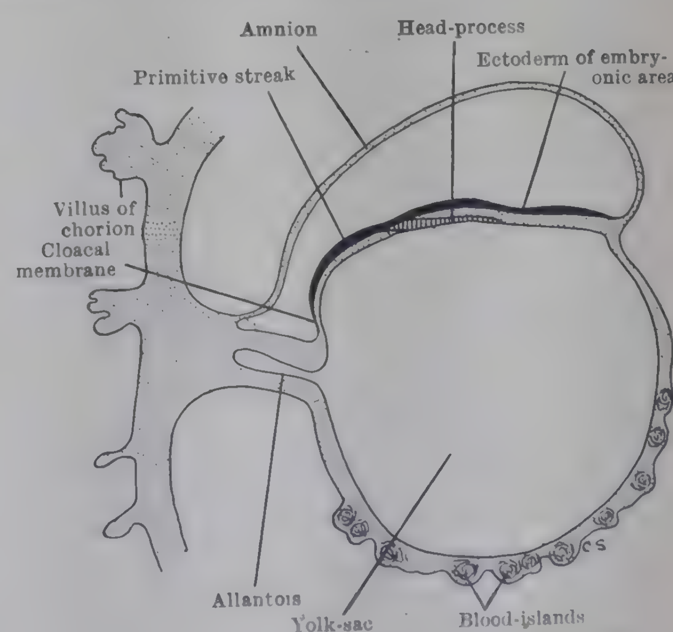


FIG. 54.—RECONSTRUCTED MEDIAN SECTION OF SAME YOUNG HUMAN EMBRYO AS IN FIG. 53. × 50. (Thompson & Brash, 1923.)

is considered; the neurenteric canal as such is but a transitory passage, and it disappears in Man and other mammals before the neural groove is converted into a closed neural tube.

After the appearance of the primitive groove and the neurenteric canal, the caudal ends of the neural folds converge across the cephalic part of the primitive streak and fuse together caudal to the neurenteric canal. The primitive streak is thus divided into two portions: (1) A cephalic portion, which lies at first in the floor of the neural groove, and later in the floor or ventral wall of the caudal end of the spinal cord; and (2) a caudal portion, which remains on the surface and takes part in the formation of the median portion of the tail-end of the body, forming the perineum and the median part of the ventral wall of the body from the perineum to the umbilicus. It is through the perineal section of the caudal part of the primitive streak at a later period of embryonic life, when it is known as the *cloacal membrane* (Figs. 54, 70, 71) that the anal and uro-genital orifices of the body are formed.

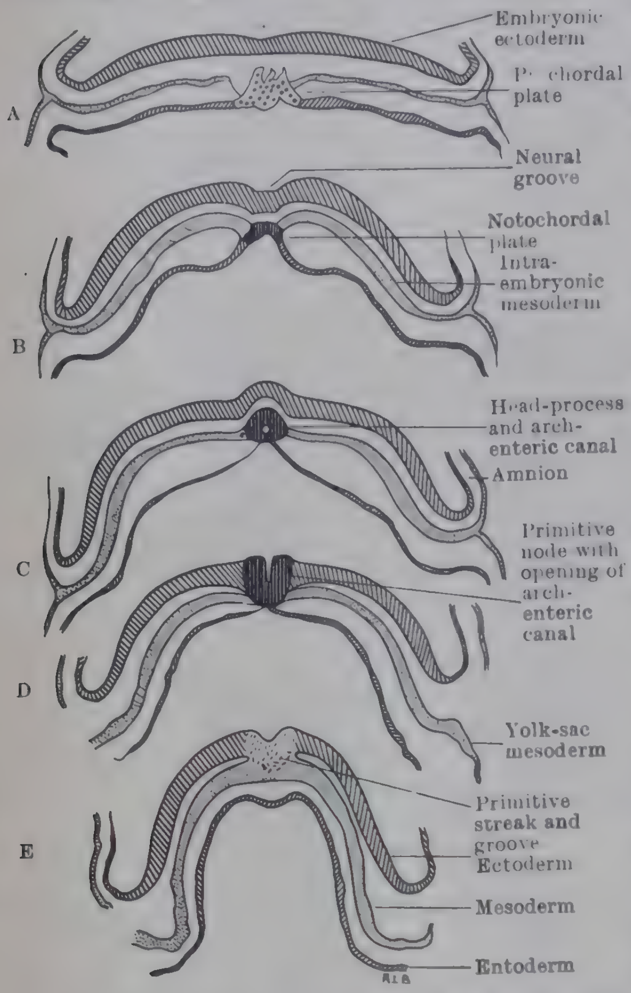


FIG. 55.—TRANSVERSE SECTIONS OF 18-DAY PRESOMITE EMBRYO, TO SHOW RELATION OF HEAD-PROCESS TO PRIMITIVE STREAK AND PROCHORDAL PLATE. × 70. (After Heuser, 1932 *a*.) For the position of the sections, see Fig. 112, p. 96.

Formation of Notochord and Embryonic Mesoderm. — The notochord and the embryonic mesoderm are formed from the primitive streak—the notochord from its cephalic end, and the embryonic mesoderm from its lateral margins and caudal end.

In the primitive vertebrate *Amphioxus*, in which a complete *gastrula* is formed, both the notochord and the mesoderm are derived from the inner layer of the wall of the gastrula, *i.e.*, from the entoderm (Fig. 52). Their connection with the primitive streak in higher vertebrates is explained by the morphological interpretation that the primitive streak represents the fused and elongated lips of the *blastopore*, or opening into the entodermal cavity of the gastrula. As an essential preliminary to the formation of the notochord, there appears a structure which corresponds, though remotely, to the part of the wall of a simple blastula that is invaginated to form the entodermal lining of the gastrula; this is the *head-process*, to which further reference is made below. Although the nature of this event in human development is greatly obscured by the precocious formation of other parts, and especially of a complete entodermal sac from the inner cell-mass, and can be clarified only by extensive comparative studies, nevertheless it is an excellent example of that recapitulation with a purpose to which reference has been made in the General Introduction (p. 13).

As soon as the primitive streak is established its cephalic end becomes a node or centre of growth—the *primitive node*—by means of which the length and, to a certain extent, the breadth of the body are increased. The portion of the body formed by the activity of the primitive node is the dorsal portion, from the back part of the roof of the nose to the caudal end of the trunk. The perineum and the ventral wall of the body, from the perineum to the umbilicus, are formed from the caudal part of the primitive streak. Nevertheless, the primitive streak undergoes little or no increase in length; indeed, as growth continues, it becomes relatively shorter compared with the total length of the embryonic region; for the new material, formed by its borders and its cephalic extremity, is transformed into the tissues of the embryo as rapidly as it is created.

Notochord.—The notochord, or primitive skeletal axis, is formed indirectly by the proliferation of cells from the cephalic end of the primitive streak. It appears first as a narrow rod of cells, called the **head-process**, which projects headwards from the primitive node between the ectoderm and the entoderm (Figs. 53, 54, 62).

The head process then wedges its way among the entodermal cells, and so comes to form part of the wall of the primary entodermal cavity. From that period onwards, as its more caudal parts are formed by continued proliferation from the primitive node, they also are at once intercalated in the dorsal wall of the entodermal sac (Fig. 62).

The head-process is at first solid, but presently a cavity appears in the rod of cells and tunnels it from the ectodermal surface of the primitive node headwards, though not quite to its cephalic end (Figs 55, 56). The floor of the tunnel, *i.e.*, the cells next the cavity of the entodermal vesicle, then breaks down, the roof flattens out, and the head-process is then represented by a plate of cells intercalated in the dorsal wall of the vesicle—the *notochordal plate* (Figs. 57, 64 A, 68). As the tunnel in the head-process breaks down, its caudal end is necessarily

Fig. 56.—Transverse Section through 'Tail-fold' of Young Embryo enclosed in Amnion. The archenteric canal in the head-process is seen beneath the neural plate on the upper surface, the primitive streak and groove on the lower (reversed) surface. Between them is the caudal cul-de-sac of the yolk-sac, separated from the ectoderm by the secondary mesoderm spreading from the primitive streak; below is the body-stalk with the allantois and umbilical vessels.

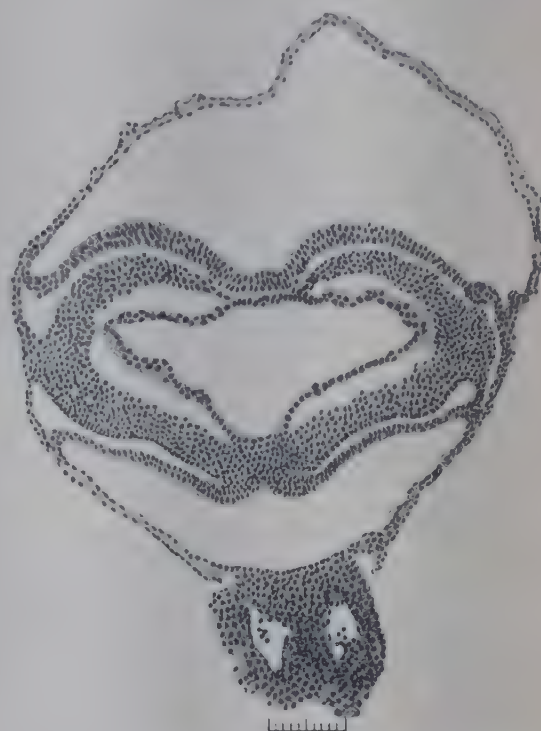


Fig. 57.—Transverse Section of Same Embryo six sections nearer the Head-End. The notochordal plate lies beneath the neural plate on the upper surface; the primitive groove is on the lower surface; the amnion cavity is divided into two parts as the primitive streak mesoderm is continuous with the mesoderm of the amnion. (Embryo M'Intyre. Bryce, 1924.)

left as a passage from the cavity of the amnio-embryonic vesicle through the primitive node to the cavity of the entodermal vesicle—the *neurenteric canal.*

The tunnel which is formed in the head-process is known as the *archenteric canal*, because it is thought to be homologous with the archenteron (entodermal cavity) of *Amphioxus*; from its relation to the formation of the notochord, it is called also the *notochordal canal*. The story of the head-process seems to indicate that the entodermal vesicle is a precocious and specialized formation which does not contain the inherited potentiality of notochord formation. This resides in the primitive node, and before a notochord can be formed it is necessary that it should express itself in the formation of a more 'primitive entoderm' which is carried forward into the roof of the 'entodermal vesicle' by a modified process of gastrulation. When that has been accomplished, then the notochord is formed exactly as in *Amphioxus*.

At a later period the notochordal cells are excalated from the entoderm, and they again form a cylindrical rod of cells in the median plane between the floor of the ectodermal neural groove and the re-formed entodermal roof of the primitive alimentary canal, which, in the meantime, has been more or less moulded off from the dorsal part of the entodermal sac (Fig. 65 B). The neurenteric canal disappears, but for a time the caudal end of the notochord

remains connected with the cephalic end of the primitive streak. The cephalic end of the notochord is continuous with the entoderm of a small portion of the embryonic area which lies immediately beyond the cephalic end of the neural groove. This part of the entoderm, indicated at an earlier date by enlargement of its cells, has been named the *prochordal plate* (Fig. 55); it may give rise directly to the anterior end of the notochord and to mesoderm of the head (Hill & Florian, 1931; Heuser, 1932a). But there is no mesoderm between it and the ectoderm, and this bilaminar region, because it afterwards forms the boundary membrane between the cephalic end of the primitive entodermal canal and the primitive buccal cavity or oral pit, is called the **bucco-pharyngeal membrane** (Fig. 71). It disappears in the fourth week of embryonic life, and immediately afterwards the cephalic part of the notochord separates from the entoderm, but the caudal end remains continuous with the primitive streak until the formation of the neural tube is completed.

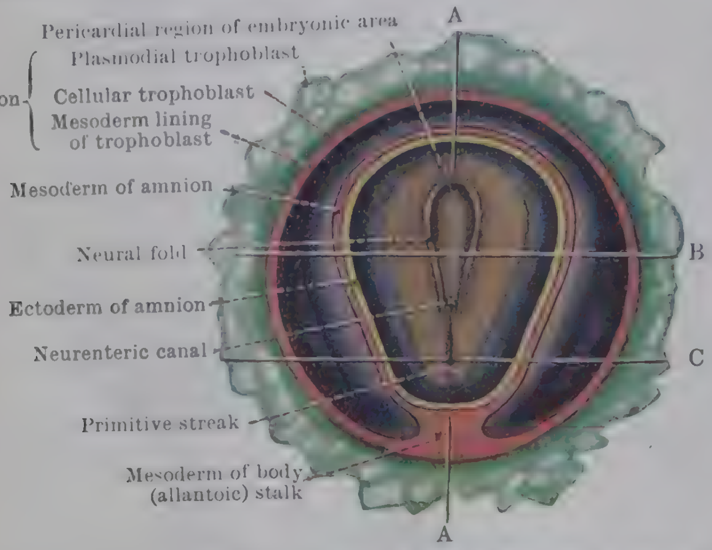


FIG. 58.—SCHEMA OF DORSAL SURFACE OF EMBRYONIC AREA OF ZYGOTE AFTER THE REMOVAL OF PART OF THE CHORION AND PART OF THE AMNION.

After a time the cylindrical notochordal rod is surrounded by secondary mesoderm which becomes converted into the vertebral column. As the vertebral column is formed the notochord is enlarged in the regions of the intervertebral discs and for a time assumes a nodulated appearance.

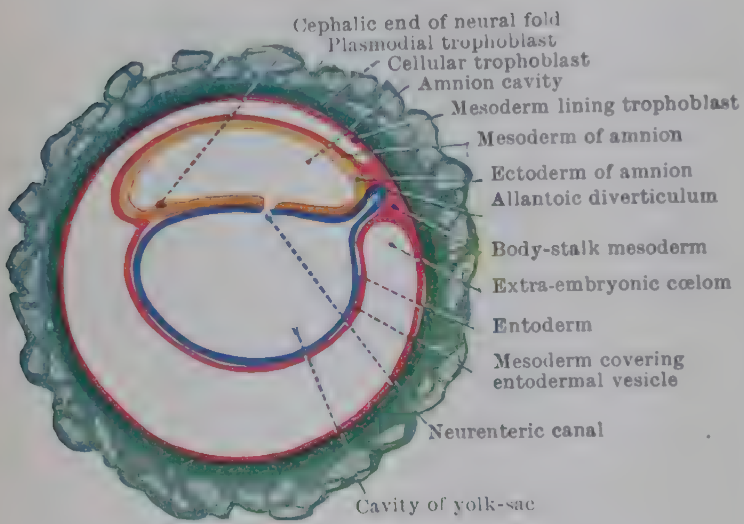


FIG. 59.—SAGITTAL SECTION OF ZYGOTE ALONG LINE A-A IN FIG. 58.

Ultimately the notochord disappears as a distinct structure, but remnants of it are believed to persist as the pulpy centres of the intervertebral discs. The extension of the notochord into the region of the head is of interest from a morphological, and possibly also from a practical, point of view. It extends through the base of the cranium from the anterior border of the foramen magnum into the posterior part of the body of the sphenoid bone. Its presence in the posterior part of the skull-base suggests that that region was, primitively, of vertebral nature. As the notochord passes through the occipital portion of the skull it pierces the basilar portion of the occipital region first from within outwards and then in the reverse direction (p. 212). It lies, therefore, for a short distance, on the ventral surface of the rudiment of the occipital bone, in the dorsal wall of the pharynx; proliferation of remnants of its pharyngeal portion may give rise to tumours known as *chordomata*.

Differentiation of the Embryonic Mesoderm.—It has already been noted that the *primary mesoderm*—derived either from the inner cell-mass or directly from the trophoblast—is formed outside the embryonic area, and is therefore *extra-embryonic mesoderm* (p. 41).

After the formation of the embryonic area, the ectodermal thickening which forms the primitive streak becomes the main source of the mesoderm; and as this mesoderm appears after the primary mesoderm, and is formed in the embryonic

area, it may be termed **secondary mesoderm** or **embryonic mesoderm**. It is the formation and fate of this embryonic mesoderm which arises from the primitive streak that is now to be considered.

The primitive streak (Figs. 58, 63) is formed by the proliferation of the ectodermal cells of the caudal part of the embryonic area. The deeper cells of the streak which displace any primary mesoderm that may lie in the median plane and thus come into contact with the entoderm, are the rudiments of the embryonic mesoderm, which buds off from the primitive streak into the interval between the ectoderm and the entoderm (Figs. 56, 57, 63). The superficial cells form part of the surface ectoderm of the embryo.

The embryonic mesoderm soon forms a continuous sheet of cells which spreads laterally and headwards in the embryonic area on each side of the median plane. Each of these lateral sheets is thickest where it abuts against the notochord and the wall of the neural groove, and thinnest at its peripheral margin, where it is continuous with the extra-embryonic mesoderm (Fig. 64 A).

At the cephalic end of the embryonic area the medial margins of the mesodermal sheets fuse together across the median plane, forming a transverse bar called the **pericardial mesoderm** (Fig. 69), because the pericardium is afterwards developed in it. The area in which this mesoderm lies is named the *pericardial region* of the embryonic area (Fig. 58).

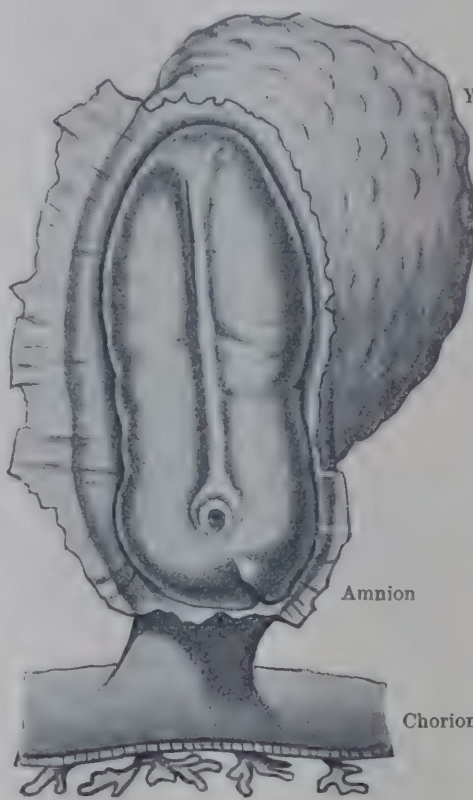


FIG. 60.—DORSAL VIEW OF HUMAN EMBRYO (v. SPEE) OF 20 DAYS. (Keibel & Elze, 1908.) Length of embryonic area 1·54 mm. The chorion is attached to the caudal end of the embryo by the body-stalk. A portion of the amnion is still attached to the margin of the embryonic area, the dorsal surface of which is exposed. In the median plane of the area is the neural groove, and at the caudal end of the groove is the neurenteric canal. The caudal part of the area is bent ventrally, and upon it is the remains of the primitive groove. The yolk-sac with blood-islands is seen at the upper and right part of the illustration. For median section of this embryo, see Fig. 61.

Between the bar of pericardial mesoderm and the cephalic end of the neural groove, and bounded laterally by the mesodermal sheets, there is a small part of the embryonic area in which the ectoderm and entoderm are in contact. This is the **bucco-pharyngeal area**. It afterwards becomes the **bucco-pharyngeal membrane** (Figs. 71, 75), which has been noted (p. 48) as the transitory membrane that separates the primitive mouth or oral pit from the cephalic end of the primitive entodermal alimentary canal. When the bucco-pharyngeal membrane disappears the oral pit and the primitive alimentary canal become continuous with each other.

Between the bucco-pharyngeal area and the cephalic end of the primitive streak the medial margins of the mesodermal plates are separated from each other by the notochord and the neural groove (Fig. 64 B), and still more caudally they are united with the sides of the streak (Fig. 63).

Intra-Embryonic Cœlom.—After the intra-embryonic mesodermal sheets are definitely established, a series of cleft-like cavities appear in their peripheral margins. These cavities, on each side, soon run together to form the rudiments of the **intra-embryonic cœlom** (Fig. 64 B).

The septum of cells at the lateral border of the embryonic area on each side, which, for a time, separates the intra-embryonic from the extra-embryonic cœlom, soon disappears, and the cœlom becomes then one continuous cavity (Fig. 65 B).

The intra-embryonic cœlom extends medially also, but the medial extension ceases at some distance from the median plane, except at the cephalic end of the embryonic area, where the two halves of the cœlom become continuous with each other through the interior of the pericardial mesodermal bar (Figs. 70, 71). The further development of the intra-embryonic cœlom into the several parts of the body-cavity of the embryo is described on p. 92.

As the intra-embryonic cœlom is forming and extending, a longitudinal constriction appears in each half of the mesoderm a short distance from its medial border. This constriction separates each plate into three parts: (1) a medial bar called the **paraxial mesoderm**, which lies at the side of the neural groove and the notochord; (2) the constricted portion, called the **intermediate cell-mass**; and (3) the part lateral to the constriction, called the **lateral plate** (Fig. 65 B).

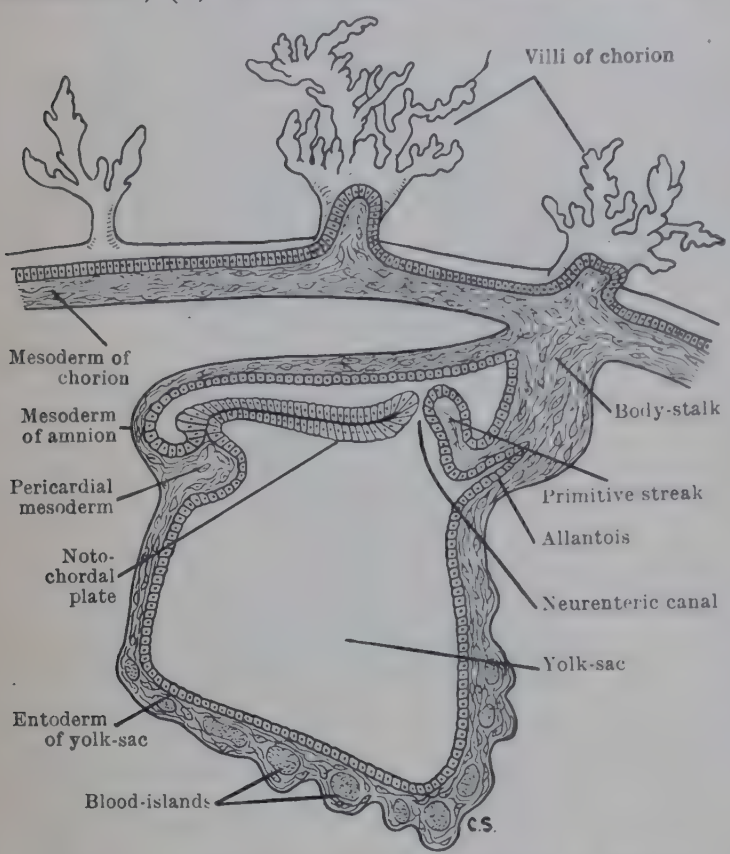


FIG. 61.—RECONSTRUCTED MEDIAN SECTION OF HUMAN EMBRYO OF 20 DAYS. (After v. Spee, 1889.) For dorsal view of this embryo, see Fig. 60.

The intra-embryonic cœlom is confined, in the human embryo, to the lateral plate, which it divides into a superficial layer next the ectoderm, called the **somatic mesoderm**, and a deeper layer next the entoderm, called the **splanchnic mesoderm**. Ectoderm and somatic mesoderm together constitute the *somatopleure*: entoderm and splanchnic mesoderm are together known as the *splanchnopleure*.

The medial borders of the somatic and splanchnic mesoderm are continuous with each other round the medial border of the cœlom. The lateral border of the somatic mesoderm is continuous, at the margin of the embryonic area, with the mesoderm which covers the outer surface of the amnion; the lateral border of the splanchnic layer is continuous with the mesoderm on the wall of the extra-embryonic portion of the entodermal vesicle or yolk-sac.

Paraxial Mesoderm.—Each paraxial mesodermal bar soon assumes the form of a triangular prism. The cephalic portion of each paraxial bar, as far as the middle of the hind-brain (see p. 60), remains unsegmented, but the remainder is cut into a number of segments, called the **mesodermal somites**, by a series of transverse clefts (Figs. 73, 75). The first cleft appears in the region of the hind-brain, and the others are formed successively, each caudal to its predecessor. Only three or four somites lie in the region of the head. The segmentation of the paraxial bars begins before they have reached their full length, and somites continue to be separated off as the paraxial bars are extended by proliferation from the nodal point at the cephalic end of the primitive streak. The total number of somites in the human embryo is thirty-eight or thirty-nine, not counting a few that develop in the tail and soon disappear.

When the somites are first defined they are solid masses of cells, but in a short time a cavity—the **myocœle**, because muscles are derived from the somites—appears in each mass.

In many animals the myocœle is continuous with the more lateral parts of the cœlom through a cavity in the corresponding portion of the intermediate cell-mass—the *nephrocœle*, because the excretory (nephric) organs are derived from the intermediate cell-mass.

The ventro-medial portion of the hollow mesodermal somite is known as the **sclerotome** (Goodsir, 1856), since it produces *scleratogenous cells* which are responsible for the formation of 'hard' skeletal structures. The cells of the scleratogenous section of the somite undergo rapid proliferation and assume the character of the variety of mesoderm to which the special name of **mesenchyme** has been given. Some of these cells invade the myocœle; others migrate towards the notochord; finally, the scleratogenous cells separate from the remainder of the somite, and, as they increase in number, they migrate along the sides of the notochord and neural tube (which has been formed in the meantime from the neural groove) and mingle with those of the opposite side and with those derived from adjoining cephalic and caudal somites (Fig. 67). In this way a continuous sheath of mesoderm is formed around the neural tube and the notochord; it is called the **membranous vertebral column**, and, in later stages, the following structures are differentiated from it — the vertebral column and its ligaments, and the dura mater of the brain and spinal cord (see p. 61).

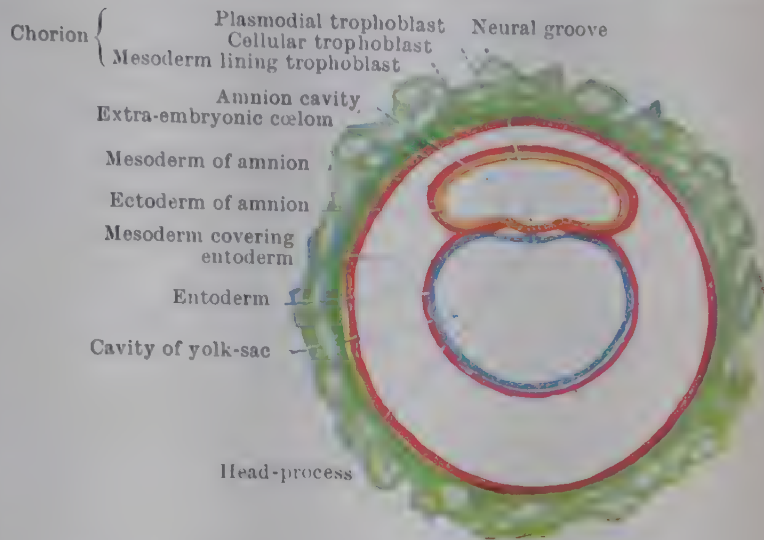


FIG. 62.—TRANSVERSE SECTION OF ZYGOTE ALONG LINE B IN FIG. 58.

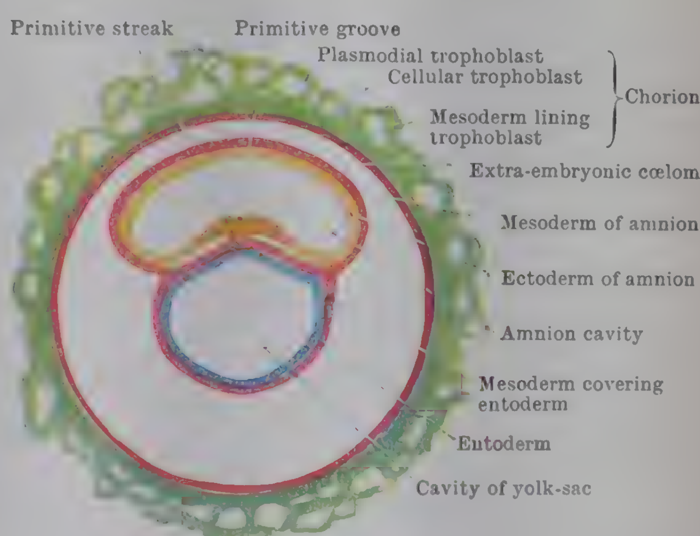


FIG. 63.—TRANSVERSE SECTION OF ZYGOTE ALONG LINE C IN FIG. 58.

The part of a mesodermal somite left after the separation of the sclerotome is called a **myotome**; each myotome gives rise to a flat plate with incurved dorsal and ventral margins, known as a **muscle-plate** because from these plates voluntary muscle-fibres are derived (Fig. 67). The outer portion of each of the myotomes is developed into the cells of subcutaneous connective tissue; consequently it is spoken of as a *cutis-plate*.

Intermediate Cell-Mass.—The continuous tract of cells, lateral to the paraxial mesoderm on each side, to which this name is given, remains unsegmented; but as it gives rise to a series of excretory structures it corresponds to the segmented portions of mesoderm known in lower forms as **nephrotomes**. The intermediate cell-mass gives rise to the greater part of the urogenital system (p. 74), with the exceptions of the genital glands, most of the urinary bladder, the urethra, and the prostate.

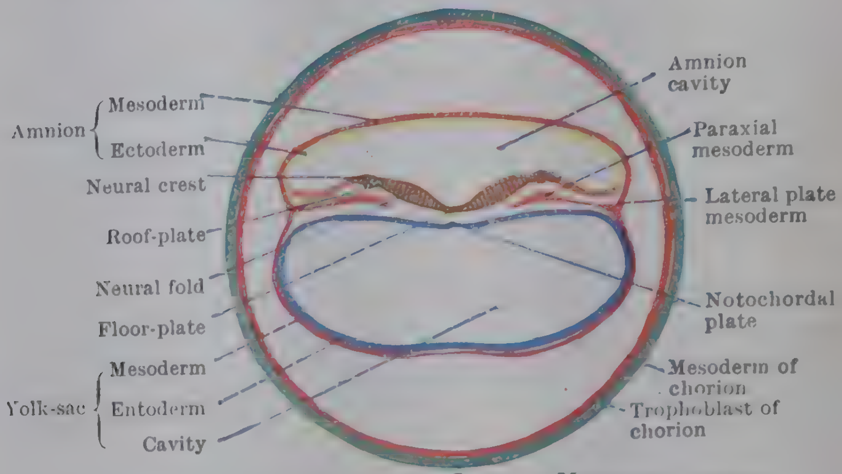
Lateral Plates.—The cells of the lateral plates give origin to:—(1) the lining mesothelial cells of the great serous cavities of the body—the pleuræ, the pericardium, and the peritoneum; (2) the majority of the connective tissues (with the exception of those of the vertebral column and the head); (3) the greater part or the whole of the mesoderm of the limbs; and, probably, (4) the plain muscle-fibres of the walls of the alimentary canal and the blood-vessels. Most of these tissues are derived from mesenchymatous cells budded off from the lateral plates.

Cephalic Mesoderm.—It has already been noted that the mesoderm of the

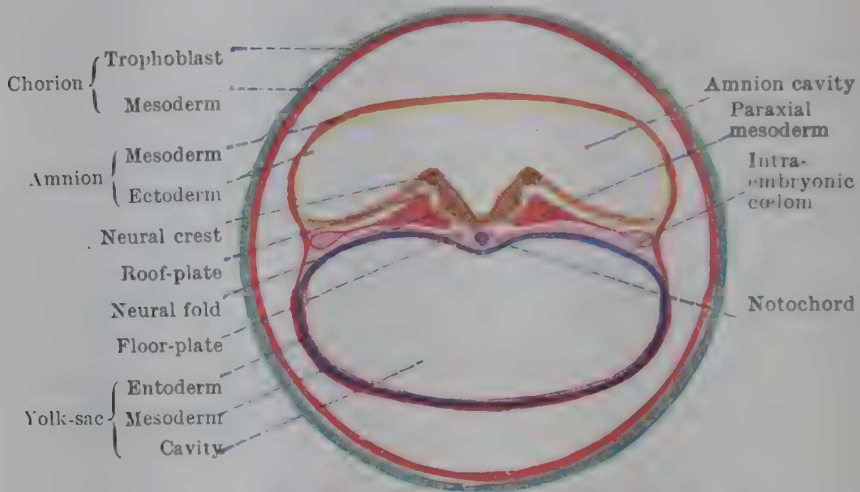
head becomes segmented only in the region of the caudal part of the hind-brain, where four cephalic mesodermal somites are formed on each side. From the scleratogenous portions of these somites the occipital part of the skull and the corresponding part of the dura mater of the brain are developed; and their muscle-plates give rise to the intrinsic muscles of the tongue.

The unsegmented part of the cephalic mesoderm gives rise to the remaining muscles and connective tissues of the head-region.

Mesenchyme.—Before the formation of the embryo many cells, of irregular



A. Neural Folds, Paraxial and Lateral Mesoderm before Appearance of Intra-Embryonic Cœlom.



B Neural Groove, Differentiation of Mesoderm and Early Stage of Intra-Embryonic Cœlom.

Fig. 64.—Diagrammatic Transverse Sections of Chorionic Vesicles showing Development of Neural Groove, Notochord, Intra-Embryonic Mesoderm and Cœlom.

form and wandering habits, appear between the more definite layer of mesoderm and the adjacent ectoderm or entoderm. They are called **mesenchyme-cells.** The scleratogenous cells that wander out from the somites are of this nature; the remainder of the mesenchyme is derived largely from the lateral plates of mesoderm, though it may have other sources, possibly even from ectoderm and entoderm.

The complete rôle of the mesenchyme in development has not yet been elucidated, but in addition to connective tissues in general, the tissues of the vascular and lymphatic systems, the reticulo-endothelial system in general and plain muscle-fibres in the walls of the alimentary canal and elsewhere, it appears to be concerned with the development of striated muscles in the limbs, which have not been proved to be directly derived from myotomes.

Germ-Layers and their Derivatives.—The formation and development of the embryonic area have now been traced to a point at which the general relation

of the three main cellular sheets or layers to each other can be understood (Figs. 62-67). The *ectoderm*, the *entoderm*, and the *mesoderm* are in the early stages of

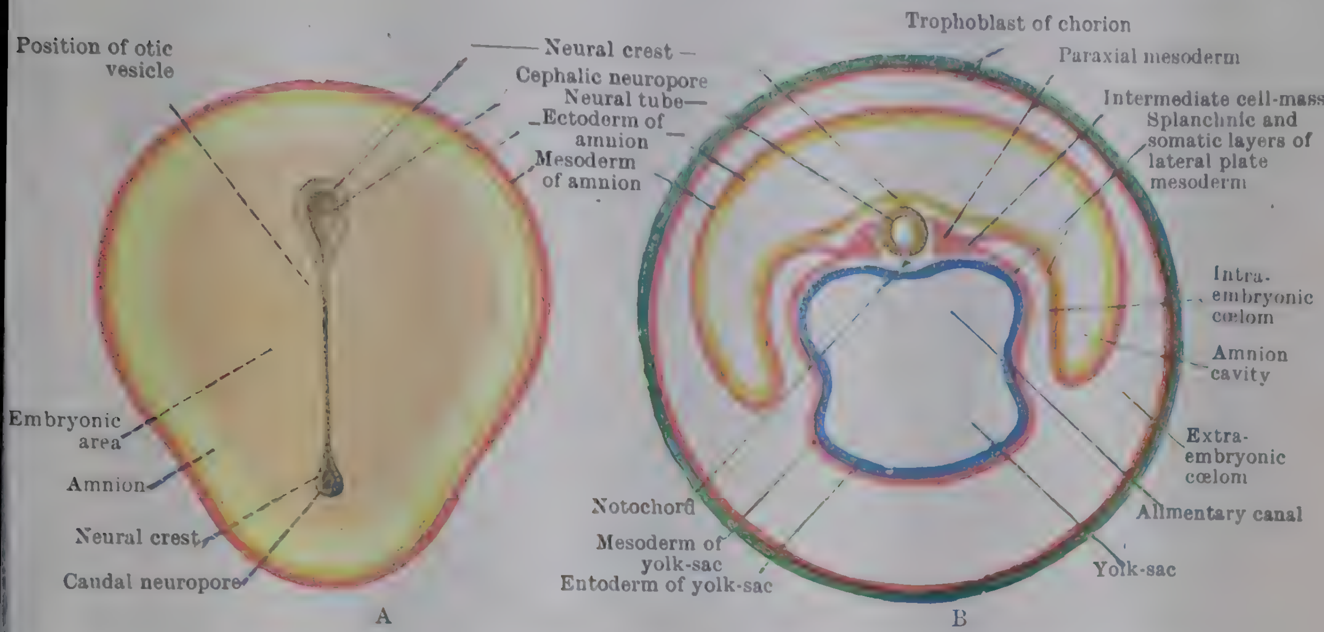


FIG. 65.—A. DIAGRAM OF EMBRYONIC AREA showing closure of neural groove with cephalic and caudal neuropores. Compare with surface view of embryo in Fig. 73 and with Figs. 115, 116.

B. CORRESPONDING TRANSVERSE SECTION; the neural tube has formed but has not separated from the surface ectoderm. The section also shows union of intra- and extra-embryonic parts of cœlom, paraxial bars, intermediate masses and lateral plates of mesoderm, with separation of lateral plates into somatic and splanchnic layers by the intra-embryonic part of the cœlom.

development distinct sheets of cells, each with its own part to play in the building-up of the embryo and its organs; they are therefore known as the primary **germ-**

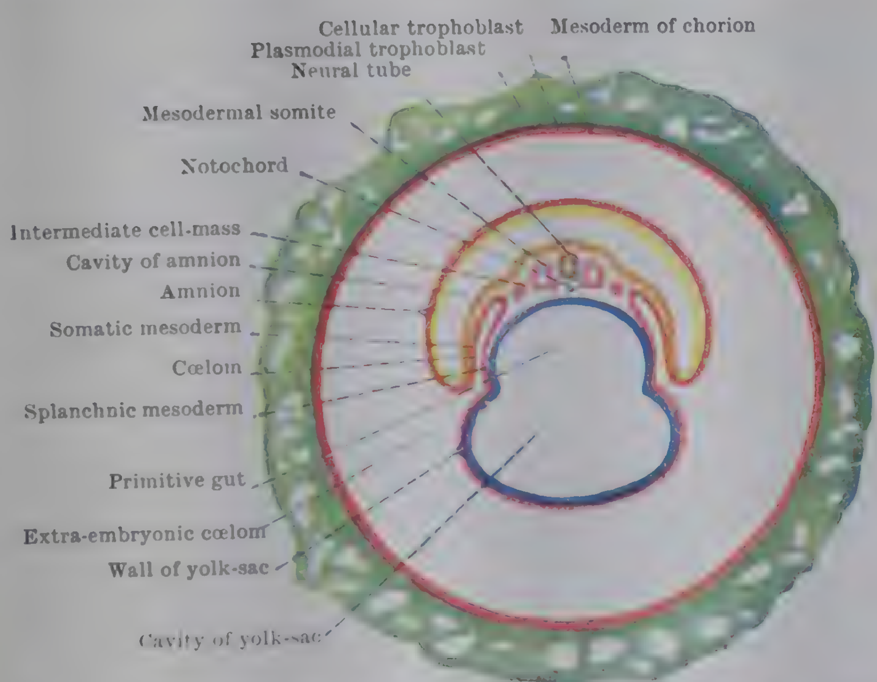


FIG. 66.—TRANSVERSE SECTION OF THE ZYGOTE SHOWN IN FIG. 73, showing the differentiation of the mesoderm.

layers. It must be emphasized, however, that the germ-layers are not independent elements in the structural organization of the embryo, or even completely specific: on the contrary, their interaction and co-operation are essential for normal development; and, since the destiny of their cells is partly due to their positions, they may even, under abnormal or experimental conditions, deputize for one another.

Before the description of the formation of the embryo and of the initial stages in the development of the principal organs, it is useful to summarize the

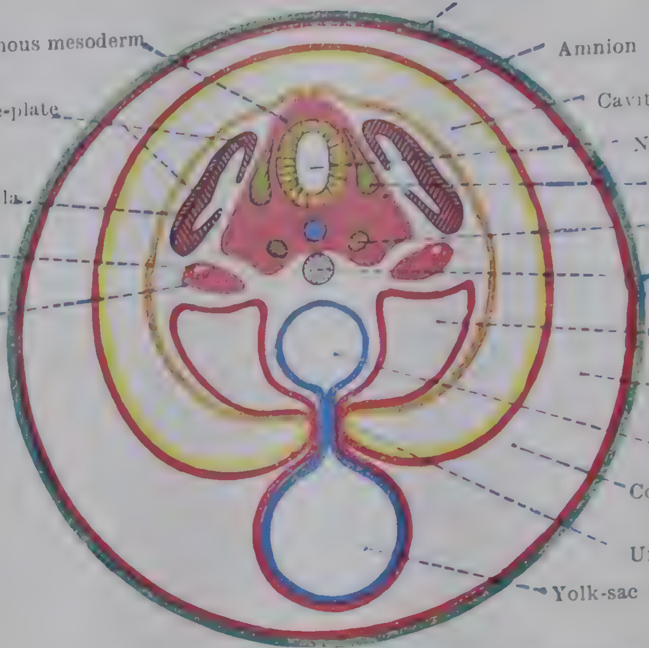


FIG. 67.—SCHEMA OF TRANSVERSE SECTION OF ZYGOTE, showing differentiation of mesoderm, formation of umbilicus, and ventral extension of amnion. The notochord is in the scleratogenous mesoderm between the neural tube and the aorta.

parts played by the three germ-layers. In general, it may be said that there is a functional distinction between them: thus, the *ectoderm*, the original external covering of the body, has a protective function, and, since it is in contact with the external environment, it is also the source of the essential elements of the sense-organs and of the whole of the nervous system; the *entoderm*, the original lining of the internal tube that becomes the alimentary and respiratory tracts, has digestive and absorbing functions; and the *mesoderm*, between the other two, gives origin to connective and muscular tissues, is the basis of the circulatory system, and provides for excretion and reproduction by means of the urogenital organs.

FIG. 68.—TRANSVERSE SECTION OF THE SAME YOUNG HUMAN EMBRYO AS IN FIGS. 56 AND 57. The neural plate in a shallow neural groove is seen on the surface of the embryonic area; beneath it is the notochordal plate in the roof of the yolk-sac. Note the commencing cœlomic spaces in the sheets of lateral mesoderm which are continuous with the thickened paraxial mesoderm and the mesoderm of the amnion and yolk-sac. (Embryo M'Intyre. Bryce, 1924.)

The following table, arranged in parallel columns for convenience of reference, gives some details of the derivatives of the germ-layers.

DERIVATIVES OF GERM-LAYERS

ECTODERM	MESODERM	ENTODERM
Epidermis of skin Hair-follicles and hairs; nails Epithelium of glands of skin Sebaceous; sweat; mammary Epithelium of sense-organs Eye: Retina (including ciliary and iridial parts) Lens; cornea and conjunctiva Lacrimal gland and ducts Ear: Membranous labyrinth External auditory meatus Nose: Olfactory epithelium and vomero-nasal organ Nasal cavity and paranasal sinuses (including glands) Nervous System (central and peripheral) Nerve-cells; nerve-fibres; neuroglia (except microglia); ependyma Pia-arachnoid membrane Pineal body; post. lobe of hypophysis cerebri Medulla of suprarenal glands and other chromaffin tissues Epithelium of lips, cheeks, gums and hard palate (including glands); salivary glands) Anterior lobe of hypophysis cerebri Enamel of teeth Epithelium of lower half of anal canal; terminal part of male urethra; vestibule of vagina and vestibular glands Plain muscle of iris and sweat-glands	Connective tissues, including bone and cartilage Synovial membranes; bursæ and tendon-sheaths Serous membranes: pleura; pericardium; peritoneum; tunica vaginalis testis Muscle—plain, striated, and cardiac (except plain muscle of iris and sweat-glands) Endothelium of heart, blood-vessels, and lymph-vessels Blood and bone-marrow Lymphoid tissue Lymph-glands; tonsils; lymphatic nodules Spleen Coats and contents of Eye (except ectodermal parts specified) Internal and Middle Ear, except epithelium of membranous labyrinth (ectodermal) and of tympanum, etc. (entodermal) Dura mater and microglia Teeth (except enamel) Cortex of suprarenal glands Urogenital organs (except epithelium of most of bladder, of prostate, urethra, and part of vagina)	Epithelium of Alimentary Tract (except ectodermal parts of mouth and anal canal) Tongue and taste-buds Epithelium of glands of alimentary canal (except salivary) Liver; gall-bladder; bile-passages Pancreas Epithelium of pharyngeal organs Thyroid Parathyroids Thymus Epithelium of Respiratory Tract (except nasal cavity) Nasal part of pharynx Pharyngo-tympanic-tube; tympanum; tympanic antrum; mastoid air-cells Larynx Trachea; bronchi; pulmonary alveoli Epithelium of urinary bladder (except trigone); urethra (except terminal part in male); prostate; bulbo-urethral glands; lower part of vagina

FORMATION OF THE EMBRYO

The transformation of the relatively flat embryonic area into the form of the embryo is due, in the first instance, to the rapid extension of the area compared with the slow growth of the immediately adjacent parts; and the later modelling of the various parts of the embryo is due to different rates of growth in different regions.

By the rapid proliferation of cells from the nodal growing-point at the cephalic end of the primitive streak, the surface length of the area is increased, whilst its cephalic and caudal ends remain relatively fixed; consequently the area becomes convex longitudinally. At the same time, the cephalic end of the neural groove is pushed away from the nodal point, so that it appears to rise out of the embryonic area and projects beyond its cephalic border. As a result of this movement the bucco-pharyngeal and the pericardial areas become reversed in position, and a **head-fold** is formed. This fold is bounded dorsally by what is now the head-portion of the embryo, and ventrally by the reversed pericardial region (Fig. 70).

The rapid growth at the nodal point not only produces a head-fold, but at the same time it forces the rest of the primitive streak over the caudal end of the embryonic area, thus forming a **tail-fold**.

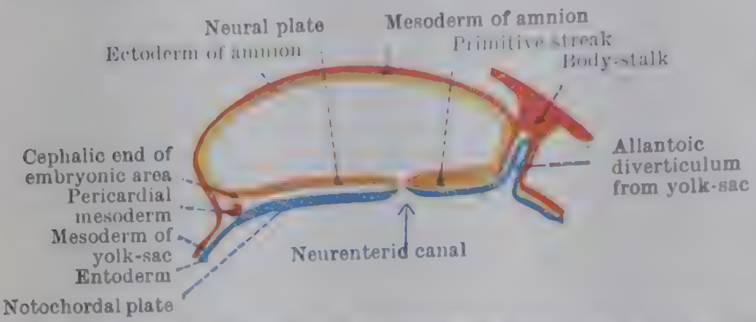


FIG. 69.—SCHEMA OF SAGITTAL SECTION OF EMBRYONIC AREA AND AMNION BEFORE THE FOLDING OF THE AREA.

As the head-fold and the tail-fold are being produced by the longitudinal increase of the embryonic area, transverse growth of the area results in the formation of right and left **lateral folds** (Figs. 65, 66), and as the various folds are formed the embryo rises, like a mushroom, into the cavity of the amnion.

The portion of the entodermal sac which is enclosed within the embryo by the folding of the embryonic area is the **primitive entodermal alimentary canal.** The part which remains outside the embryo is the definitive **yolk-sac**; and the connecting passage between the two is the **vitello-intestinal duct** (Fig. 75).

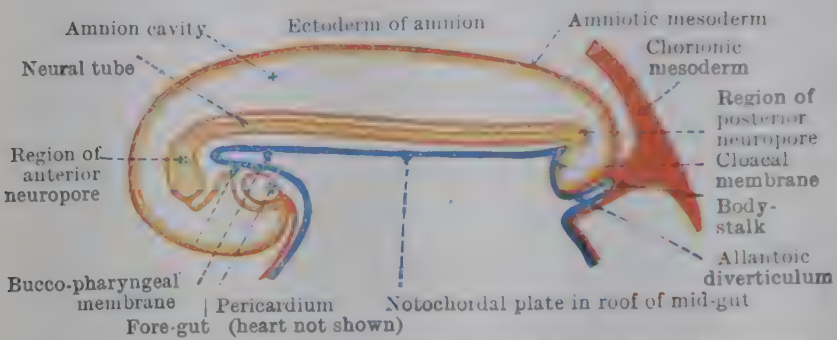


FIG. 70.—SCHEMA OF SAGITTAL SECTION OF EMBRYONIC AREA SHORTLY AFTER THE FOLDING HAS BEGUN. The pericardial mesoderm is carried into the ventral wall of the fore-gut, and the cœlom has extended through it. The cephalic end of the neural tube and the caudal part of the primitive streak are bent ventrally, and the latter now forms the cloacal membrane.

That portion of the primitive alimentary canal which lies in the head-fold is termed the **fore-gut**, the part in the tail-fold is the **hind-gut**, and the middle portion, which at first is in open communication with the yolk-sac, is the **mid-gut**.

As the extension of the embryonic area and its folding proceed, the margin of the area, which remains relatively stationary, becomes the margin of an orifice through which the primitive alimentary canal of the embryo communicates with the yolk-sac, and the intra-embryonic part of the cœlom with the extra-embryonic part. That orifice is the **primitive umbilical orifice**. Around its margin the body-wall of the embryo, formed by the somatopleure, is continuous with the wall of the amnion.

The young embryo is connected also with the inner surface of the chorion by a band of tissue which is continuous with the caudal part of the wall of the amnion. The mesoderm in this region is thickened, and it contains in its interior the **allantoic diverticulum**, which is primarily derived from the entodermal sac (Fig. 70) but is afterwards connected with the hind-gut (Fig. 71): it contains also the blood-vessels that pass between the embryo and the chorion. This connecting band between embryo and chorion is generally called the **body-stalk**; but, since the entodermal diverticulum which it contains represents the mammalian **allantois**, it is also termed the allantoic stalk.

At first the umbilical orifice is relatively large, but as the embryo rapidly extends in all directions from its margins the orifice soon becomes relatively small. Ultimately the margins of the orifice fuse together, closing the opening and forming a cicatrix on the ventral wall of the abdomen known as the **umbilicus** or **navel**.

THE EMBRYO

While the embryonic area is being folded into the form of the embryo, the neural groove on the surface of the area is being converted into the neural tube. After the neural tube is completely closed and separated from the surface, during the fourth week, the embryo is an elongated organism, with a larger cephalic end and a smaller caudal end, attached by the body-stalk to the chorion. Its dorsal surface is continuous and unbroken, but its ventral surface is separated into cephalic and caudal portions by the umbilical orifice. It contains three cavities:—(1) The cavity of the neural tube; (2) the primitive alimentary canal, which is a portion of the entodermal vesicle constricted off during the folding of the embryonic area (Figs. 66, 67); (3) the embryonic cœlom.

The embryonic cœlom consists of a pericardial portion, which lies in a projection ventral to the fore-gut between the growing head and the umbilicus, and

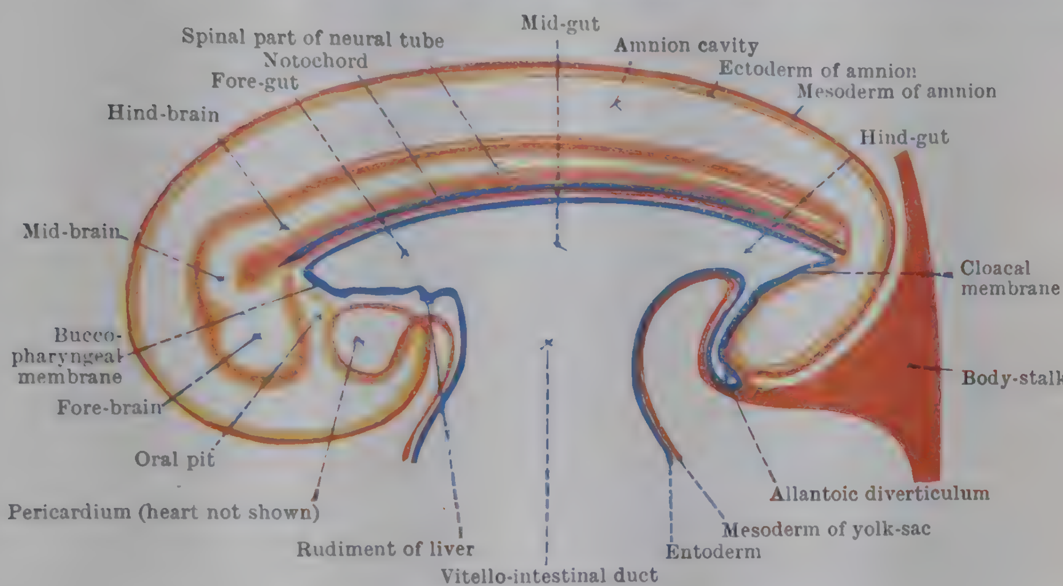


FIG. 71.—SCHEMA OF SAGITTAL SECTION OF EMBRYO AFTER THE FOLDING HAS DEFINED BOTH FORE-GUT AND HIND-GUT.

right and left lateral portions, which lie at the sides of the fore-gut, the mid-gut, and the hind-gut.

The right and left portions communicate with each other, ventral to the fore-gut, through the pericardial portion; at the sides of the mid-gut and ventral to the hind-gut, they communicate also with the extra-embryonic cœlom at the lateral and caudal margins of the umbilical orifice.

By this time the embryo has become easily distinguishable from the remainder of the zygote, and it is so far developed that indications of its general plan of organisation are discernible.

It has, as yet, no limbs, but the general contour of the head and body are defined. It possesses a primitive skeletal axis—the notochord—afterwards replaced by the permanent vertebral column. On the dorsal aspect of the notochord lies the neural tube, which is the rudiment of the brain and the spinal cord.

At the sides of the neural tube and the notochord are the mesodermal somites and the ganglia of the spinal nerves (Figs. 66, 67).

Ventral to the notochord is the primitive alimentary canal closed at its cephalic end by the **bucco-pharyngeal membrane**, and at its caudal end by the **cloacal membrane**; this was originally the caudal portion of the primitive streak, and it now separates the amniotic cavity from the caudal end of the hind-gut (Figs. 71, 75), which becomes the **entodermal cloaca** when the primary excretory (mesonephric) ducts open into it (p. 74).

At the sides of the primitive alimentary canal are the right and left parts of the cœlom, and between the dorsal angle of each half of the cœlom and

the mesodermal somites of the same side lies the intermediate cell-mass, which is the rudiment of the greater part of the urogenital system (Figs. 66, 67).

Ventral to the fore-gut is the pericardial mesoderm, thickening behind to form the *septum transversum* (pp. 71, 93) and traversed by the pericardial portion of the cœlom, which is connected dorsally, on each side, with the corresponding lateral portion of the cœlom; and ventral to the hind-gut is the cloacal membrane. Between the pericardial region at the one end and the cloacal membrane at the other is the umbilical orifice, through which the mid-gut communicates with the yolk-sac, the intra-embryonic part of the cœlom with the extra-embryonic cœlom, and the allantoic diverticulum with the cloaca (Figs. 66, 71).

The Limbs

For some time after its general form is well-defined the embryo is entirely devoid of limbs (Figs. 115-117). During the fifth week a slight ridge appears on each side, opposite the intermediate cell-mass in the interior. On this ridge the rudiments of the limbs—the **limb-buds**—are formed as secondary elevations (Fig. 72); the upper limb precedes the lower limb in time of appearance and in the development of its segments (Figs. 118-120). (See also p. 325.)

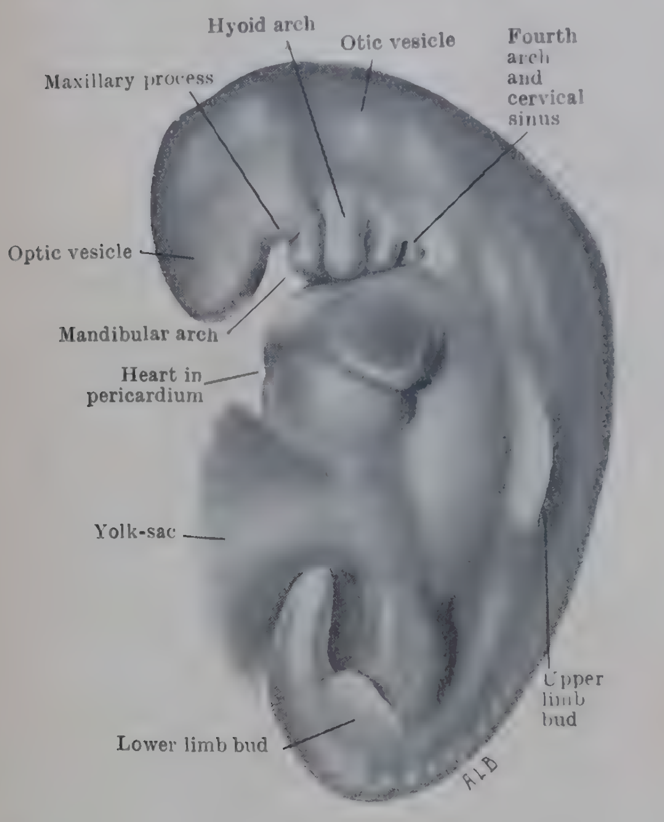


Fig. 72.—Human Embryo, 5·3 mm. long, to show the Development of the Limb-Buds. (After G. L. Streeter, *Carnegie Contrib. Embryol.*, Embryo No. 8066, 1945.) The rudiment of the Upper Limb, more advanced than that of the Lower Limb, appears as a longitudinal ridge on the side of the embryo.

Shortly after each limb-bud has appeared, it assumes a semilunar outline; it projects at right angles from the surface of the body, and it possesses dorsal and ventral surfaces, and cephalic or preaxial, and caudal or post-axial borders. The bud is the rudiment of the distal segment—hand or foot—of the future limb.

As the limb-rudiment increases in length the more proximal segments of the limb are differentiated. At the same time the limbs are folded ventrally, so that their original ventral surfaces become medial and their original dorsal surfaces lateral, and the convexities of the elbow and knee are directed laterally. At a later period, on account of a rotation which takes place in opposite directions in the two limbs, the convexity of the elbow is turned towards the caudal end of the body and that of the knee towards the head (Fig. 121).

The distal segment of each limb is, at first, a flat plate with a rounded margin, but it soon differentiates into a proximal or basal part and a more flattened marginal portion (Fig. 119). It is along the line where these two parts are continuous that the rudiments of the **digits** appear. They become evident as small elevations on the dorsal surface of the limb-bud about the sixth week; the ridges extend peripherally, and by the seventh week the fingers project beyond the margins of the hand-segment (Fig. 120), but the toes do not attain a corresponding stage of development until the early part of the eighth week (Fig. 121).

The **nails** are later developments, with finger-nails always in advance of toe-nails. They are apparent by the end of the third month but do not reach the ends

of the digits until the last month of fœtal life, a point which may be noted as a sign of maturity.

Each limb-bud is essentially an extension from a definite number of segments of the body. It consists, at first, of a core of mesenchyme covered with ectoderm. As it grows, the anterior primary rami of the spinal nerves of the corresponding segments are prolonged into it, together with a number of blood-vessels. The nerves remain as the nerves of the fully-developed limb, but the blood-vessels are reduced in number and are modified to form the permanent main trunks.

The mesenchymatous core of the primitive limb-rudiment is derived mainly from somatic mesoderm of the lateral plate. As the development proceeds it is differentiated into the cartilaginous and other connective tissue elements which are the rudiments of the skeletal framework and the fasciæ of the fully-formed limb.

The rudiments of the muscles of the limbs appear in the mesenchyme as **pre-muscle masses** which have no direct connection with the myotomes of the segments to which the limb-buds are related. There is evidence, however, that cells do migrate from the myotomes to mingle with the mesenchyme of the limbs; and in this way the myotomes may take part in the development of the limb-muscles which are innervated by the nerves of the segments to which they belong.

OUTLINE OF DEVELOPMENT OF NERVOUS SYSTEM

Early Stages of Development of Nervous System.—No definite trace of the nervous system is present until the primitive streak has appeared and the embryonic area has passed from a circular to a pear-shaped form. An area of thickened ectoderm, called the **neural plate**, then appears in the longitudinal axis of the cephalic half of the embryonic area. It begins to differentiate near the cephalic end of the area, and its caudal extremity embraces the nodal end of the primitive streak. Its margins fade into the surrounding ectoderm; but, while the plate lengthens with the elongation of the embryonic area, its margins are elevated by the thickening mesoderm beneath them, and so they become distinct.

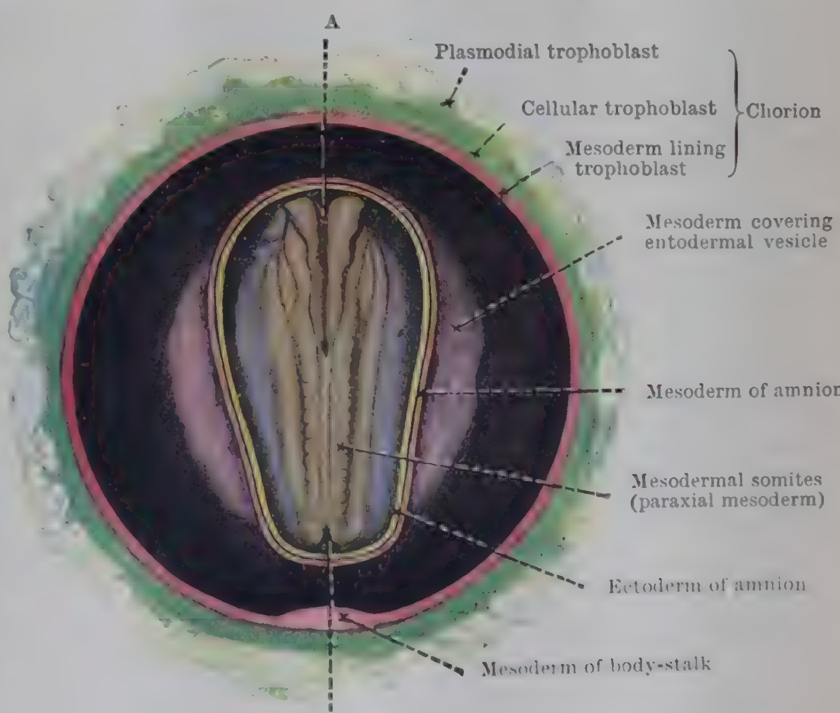


Fig. 73.—Schema of Dorsal Aspect of Embryo, showing partial closure of neural groove. For section along line A-A see Fig. 80. Portions of the chorion and amnion have been removed. The neural folds have fused, except in the cephalic and caudal regions; both the cephalic and the caudal ends of the embryo have been bent ventrally and thirteen mesodermal somites have been formed.

As the margins of the neural plate are raised the plate is necessarily folded longitudinally, and the sulcus so formed is called the **neural groove** (Figs. 60, 64, 114). Each half of the neural plate, as it is raised to form a lateral wall for the groove, is then named a **neural fold**. At a very early period the neural folds unite to form a cephalic boundary of the neural groove, and, a little later, they unite caudal to the neurenteric canal and across the primitive streak. After the neural groove is thus defined, the neural folds approach each other until they meet and fuse in the median plane, and the neural groove is converted into the **neural tube**. The ventral wall of the tube,

formed by the central part of the original neural plate, is called the *floor-plate*; the dorsal wall, formed by the union of the neural folds, is called the *roof-plate*, and it is soon separated from the surface-ectoderm.

The fusion of the margins of the neural folds to form the roof-plate begins in the cervical region, and from there it extends headwards and tailwards. The last parts of the roof-plate to be formed are, therefore, its cephalic and its caudal extremities; consequently, for a time, the **neural canal**, which is the cavity of the tube, opens on the surface at the two ends; the openings are called the **cephalic** and the **caudal neuropores** (Fig. 65 A). Eventually, however, about the third week of embryonic life, both apertures are closed and, for a time, the neural canal becomes a completely closed cavity.

Failure of union of the neural folds to form a closed neural canal may occur at any point but is commonest at the two ends, and it is the basis of gross malformations such as *anencephaly* and complete *spina bifida*. The union of the neural folds is an example of the process of 'embryonic healing' by which growing edges come together and unite to form a continuous structure—as in the case of the face and palate (pp. 63, 65), or to enclose a cavity—as in the case of the neural canal, or the lens of the eye (p. 60), or the otic vesicle (p. 67). Keith (1921) has emphasized the importance of this process, which he speaks of as the "healing of evolutionary wounds".

As the neural folds rise and approach each other their dorsal margins give rise on each side to a column of cells which comes to lie in the angle between the neural tube and the surface-ectoderm. This column is called the **neural crest** (Fig. 64).

The neural crest is the rudiment of the cranial and spinal nerve-ganglia, the sympathetic ganglia, the chromaffin cells of the chromaffin organs (medulla of suprarenal glands, etc.), and the primitive sheaths of the peripheral nerves; details will be found in the Section on the Peripheral Nervous System and also, in the case of the chromaffin organs, in the Section on the Ductless Glands (p. 809).

The neural tube becomes transformed into the brain and spinal cord, and the brain-portion gives origin also on each side to the essential part of the eye—the retina—and the optic nerve.

Differentiation of Neural Tube.—Before the neural groove is converted into a closed tube, an expansion of its cephalic part indicates the distinction between brain and spinal cord.

While the cerebral portion is still unclosed, three secondary dilatations of its walls indicate its separation into three sections—the primitive **fore-brain**, the **mid-brain**, and the **hind-brain** (Figs. 73-75, 85).

Shortly after the three segments of the brain are defined, and before it becomes a closed tube, a vesicular evagination forms at the cephalic end of each side-wall of the primitive fore-brain. These evaginations are the **primary optic vesicles**, and they are the rudiments of the **optic nerves**, the **retinæ**, and the **posterior epithelium of the ciliary body** and of the **iris**. As the optic vesicle approaches the surface of the head, the lens of the eye develops from the overlying ectoderm (p. 18), which thickens and forms a depression which is finally cut off from the surface by the union of its edges. The **lens-vesicle**, thus produced, is received into a depression in the optic vesicle which deepens until the vesicle is transformed into the **optic cup**. (For the development of the Eye, see the Section on the Organs of the Senses.)

When the cephalic portions of the neural folds meet and fuse dorsally the secondary dilatations become the primitive brain-vesicles, each vesicle possessing its own cavity and walls; but the cavities of the three vesicles are continuous with one another, and the cavity of the hind-brain is continuous with the central canal of the spinal part of the neural tube.

After the three brain-vesicles are formed, a diverticulum grows out from the cephalic end of the primitive fore-brain. This is the rudiment of the **secondary fore-brain**. It soon divides into right and left halves, which are the rudiments of the **cerebral hemispheres** of the adult brain.

After their formation the cerebral hemispheres expand rapidly in all directions. They soon overlap the primitive fore-brain and the mid-brain, and eventu-

lly the hind-brain also, and each gives off from the cephalic end of its ventral wall a tertiary vesicle—the **olfactory diverticulum**—which becomes converted, later, into the olfactory bulb and olfactory tract.

Flexures of Brain and Head (Figs. 72, 74, 85). In conformity with the general curvature of the embryo, but due mainly to the rapid, unequal growth of the three brain-vesicles, the head-region of the embryo bends ventrally as the brain develops. At first the curvature is continuous, but very soon it is accentuated opposite the mid-brain to form the **cephalic flexure**; the mid-brain, which remains relatively small, becomes the most prominent part of the head, and, as the flexure increases until its angle becomes quite acute, the fore-brain and the hind-brain approach each other until their ventral walls lie almost parallel.

At the same time a **cervical flexure** develops at the junction of the hind-brain with the spinal portion of the neural tube; it affects the whole head and keeps the facial region in close relation with the pericardium.

At a later stage the exuberant growth of the hind-brain causes that vesicle to bend in an opposite direction to the other flexures, so that its ventral wall forms a prominent convexity. This bend affects the brain only, and it is called the **pontine flexure** as it occurs in the region where the pons is formed.

The cervical flexure eventually disappears as the heart and pericardium descend into the thorax and the neck is formed; but the cephalic and pontine flexures have a permanent influence on the form of the brain.

(For details of the development of Brain and Spinal Cord, see the Section on the Central Nervous System.)

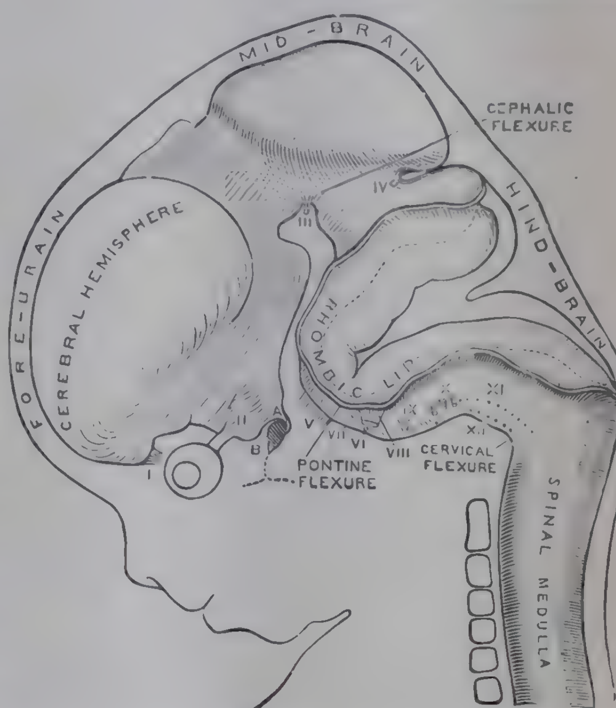


FIG. 74.—HEAD OF HUMAN EMBRYO OF 8 WEEKS TO SHOW THE PRIMARY PARTS OF THE BRAIN AND THE CEPHALIC, CERVICAL, AND PONTINE FLEXURES (His).

A, B, Cerebral and buccal rudiments of hypophysis cerebri. The cranial nerves are indicated by numerals.

Cavities and Meninges of Neural Tube.—The cavity of the spinal portion of the neural tube becomes the central canal of the spinal cord. The cavities of the primitive brain-vesicles are transformed into the ventricles, the interventricular foramina, and the aqueduct of the mid-brain. All these cavities are filled with *cerebrospinal fluid*, secreted by the *choroid plexuses* of blood-vessels which invaginate the thin wall of the ventricles at certain places.

The cavities of the developing cerebral hemispheres become the **right** and **left lateral ventricles** of the brain. The cavity of the central portion of the fore-brain becomes the **third ventricle**, and the Y-shaped aperture of communication between the third ventricle and the lateral ventricles is the **interventricular foramen**.

The cavity of the hind-brain vesicle becomes the **fourth ventricle**, and the cavity of the primitive mid-brain is converted into the **aqueduct of the mid-brain**, which connects the third ventricle with the fourth.

After the neuropores (p. 60) are closed, the cavity of the neural tube is, for a time, a completely enclosed space. Subsequently three membranous sheaths or *meninges* are developed around the tube; they are the **pia mater**, the **arachnoid mater**, and the **dura mater**. The dura mater, which is the outermost, is derived from the scleratogenous parts of the mesodermal somites; but the pia mater, which is the innermost, and the intervening arachnoid mater are possibly formed in part by ectodermal cells derived from the neural crest (Harvey *et al.* 1933).

As the meninges are differentiated narrow **subdural** and more extensive **subarachnoid spaces** are formed between them. After a time, the **median aperture of the fourth**

ventricle and a pair of **lateral apertures** appear in the dorsal wall of the fourth ventricle and in the pia mater which covers it, and thus the fourth ventricle becomes connected with the subarachnoid space. By these apertures, cerebro-spinal fluid passes into the subarachnoid spaces and a circulation is set up (p. 1003).

Early Development of Alimentary Canal and Formation of Oral and Anal Pits

The greater part of the permanent alimentary canal is derived from the entodermal vesicle and is therefore lined with entodermal cells. This part is enclosed in the embryo as it is folded off from the remainder of the zygote (Figs. 71, 80), but the two ends of the alimentary canal are formed by depressions of the surface of the embryo and are therefore lined with ectoderm.

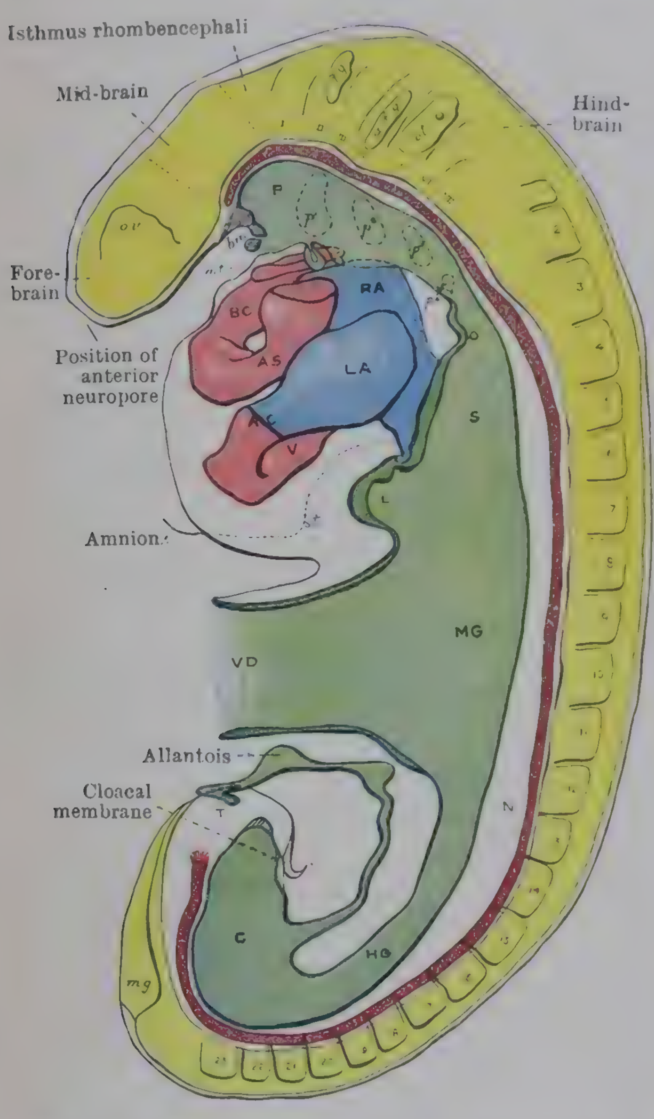


Fig. 75.—Reconstruction of Human Embryo, 2·5 mm. long, with Twenty-three Pairs of Somites. (Cf. Fig. 117, p. 98. (Thompson, 1907.)

o.v., optic vesicle; *i.-vii.*, neuromeres of hind-brain; *t.g.*, trigeminal ganglion; *a.f.g.*, auditory-facial ganglion; *o.t.*, otic vesicle; 1-23, somites; *b.m.*, remains of bucco-pharyngeal membrane; *m.t.*, median thyroid rudiment; P., pharynx; $p.^1$ $p.^4$, pharyngeal pouches; O., œsophagus; S., stomach; L., liver; *s.t.*, septum transversum; V.D., vitello-intestinal duct; M.G., mid-gut; N., notochord; H.G., hind-gut; C., cloaca; T., tail; *m.g.*, neural groove (post. neuropore); R.A., L.A., right and left atria; A.C., atrio-ventricular canal; V., ventricle; B.C., bulbus cordis; A.S., truncus arteriosus.

The cephalic end of the alimentary canal is formed from a portion of a space called the **stomodæum** or **oral pit**, which lies, at first, between the ventrally-bent extremity of the head and the bulging pericardial region (Figs. 71, 75). When the oral pit first appears it is separated from the entodermal alimentary canal by the **bucco-pharyngeal membrane**, but when that septum disappears, during the fourth week, the oral pit communicates with the fore-gut. Later, it is separated into nasal and oral portions by the formation of the palate, and the oral portion forms that part of the mouth in which the gums and the teeth are developed.

The terminal portion of the permanent canal is formed by the elevation of a surface fold around a pit-like hollow called the **proctodæum** or **anal pit** (Fig. 88), which is separated from the blind end of the entodermal alimentary canal until about the eighth week by the **anal membrane**, which is a portion of the more extensive cloacal membrane mentioned on p. 57.

Derivatives of the Oral Pit.—When the oral pit is definitely established, it is bounded cranially by the bent, terminal part of the head, caudally by the conjoined ends of the **mandibular arches** (p. 66), and laterally by the **maxillary processes**, which grow ventrally from the dorsal parts of the mandibular arches. The space is open ventrally, and it is closed dorsally by the bucco-pharyngeal membrane until that membrane disappears (Fig. 75).

In the roof of the oral pit in front of the attachment of the bucco-pharyngeal

membrane there is a depression which is deepened by the growth of mesoderm around it so that it appears as a diverticulum of the roof. It is lined with ectoderm and is known as **Rathke's pouch**. The blind end of the pouch comes into relation with the hypophysial diverticulum from the floor of the third ventricle of the brain and dilates. The dilated part becomes the anterior lobe of the **hypophysis cerebri**

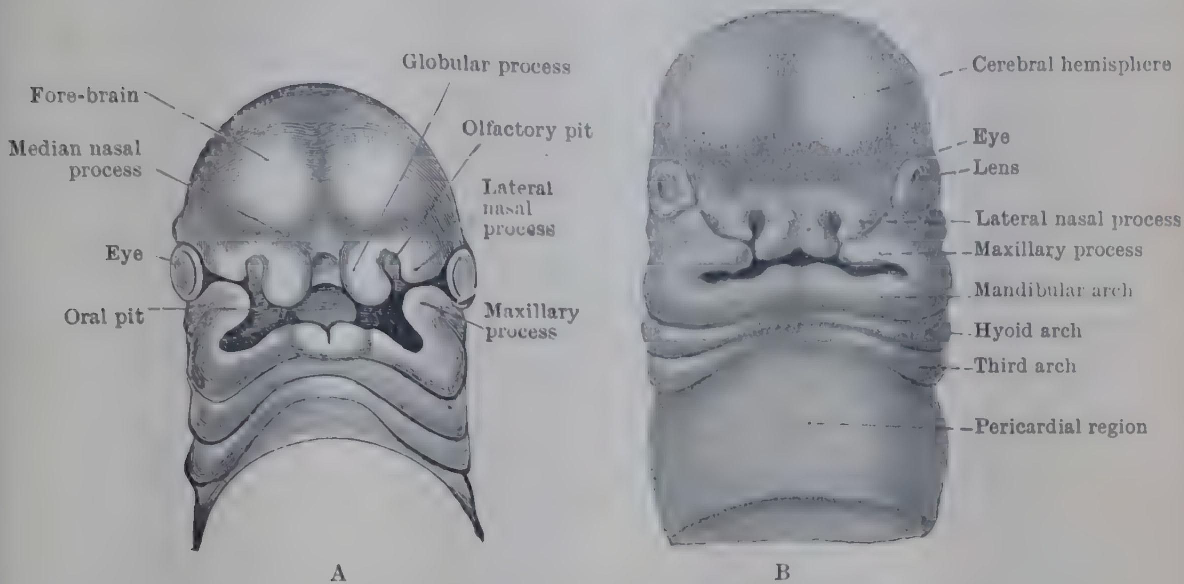


FIG. 76.—TWO STAGES IN DEVELOPMENT OF FACE. Cf. Fig. 1028, p. 1202.

A. BOUNDARIES OF STOMODÆUM BEFORE COMPLETION OF PRIMITIVE UPPER LIP.

B. COMPLETION OF UPPER LIP. Note the union of maxillary process with lateral and medial nasal processes to form cheek and upper lip.

or *pituitary body*; the rest disappears (Figs. 86-88). (For the development of the hypophysis, see the Section on the Ductless Glands.)

Development of Face and Separation of Nose and Mouth.—The frontal end of the head lies in the cephalic boundary of the oral pit and is called the **fronto-nasal process**. The upper part of the fronto-nasal process remains undivided and represents the region of the future forehead; but a pair of shallow depressions—the **olfactory pits**—divide the lower part into a *median nasal process* and a pair of *lateral nasal processes*; and a median groove divides the median process into right and left *globular processes* (Figs. 76 A, 1028, p. 1202). As the margins of these processes increase in height the olfactory pits deepen.

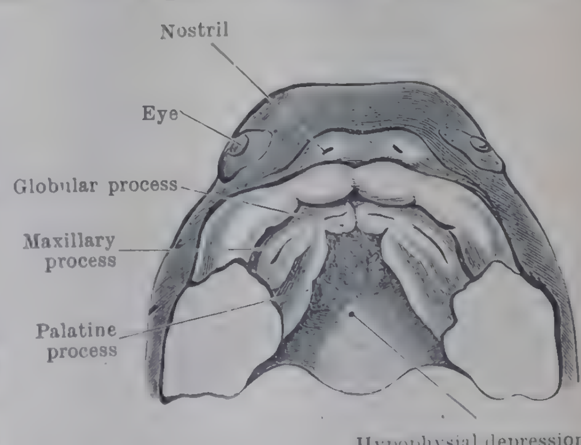


FIG. 77.—PORTION OF THE HEAD OF A HUMAN EMBRYO ABOUT 8 WEEKS OLD (His). The lips are separated from the gums, and the line of the dental lamina is visible in the gums. The palatine processes are growing inwards from the maxillary processes.

The lateral boundary of the oral pit is at first formed by the maxillary process springing from the dorsal part of the mandibular arch. As the maxillary process grows forwards it approaches the lateral nasal process, and the projecting eye is enclosed in the angle between them; and the groove between the two processes—the **naso-lacrimal sulcus**—leads downwards and forwards from the eye to the olfactory pit (Figs. 76 B, 1028).

As growth proceeds and each maxillary process grows ventrally, it fuses with the lateral nasal process along the line of the naso-lacrimal sulcus, and then, carrying the lateral nasal process with it, it fuses also with the globular process of the same side and overgrows it. The olfactory pits are thus completely separated, for a time, from the oral pit and they lie in the newly constituted ledge which now forms its boundary. This ledge consists of the two globular processes, fused into a

single mass, and the two maxillary processes—the lateral nasal processes being shut off from the margin of the ledge by the maxillary processes (Fig. 76 B).

Thus, the upper parts of the *cheeks* are formed by the maxillary processes and the *upper lip* by their fusion with the lower part of the median nasal process. At a later stage, the *maxillæ*—the bones of the upper jaw—are formed in the mesodermal core of these united processes; the *premaxillæ,* which ossify separately but in the human jaw unite with the maxillæ and are not seen on the surface (p. 234), are developed in the median nasal process. The lower parts of the cheeks and the *lower lip* are derived from the mandibular arch; the *aperture of the mouth,* which is at first wide, is gradually reduced by the progressive fusion of the maxillary processes with the mandibular arch.

FIG. 78.—CORONAL SECTION THROUGH THE NOSE AND MOUTH OF A 20 MM. HUMAN EMBRYO ABOUT 7½ WEEKS OLD (×28).

The *external nose* is developed from the nasal processes: the lateral nasal process forms the lateral part of the external nose, including the ala, and the prominence of the nose rises gradually from the root of the median nasal process where it blends with the forehead. The external openings of the olfactory pits become the *nostrils.*

Along the line of fusion of the maxillary and lateral nasal processes there remains a buried tract of ectodermal cells; it leads from the developing eye to the olfactory pit, and is the rudiment of the **naso-lacrimal duct** by which the tears are drained to the nasal cavity.

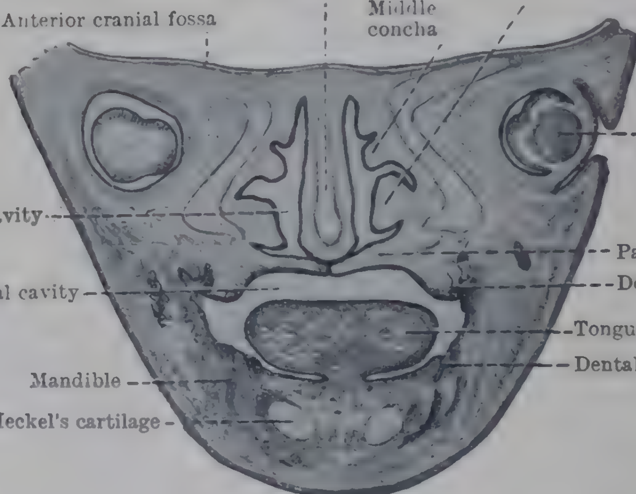


FIG. 79.—CORONAL SECTION THROUGH FACE OF HUMAN EMBRYO ABOUT 9 WEEKS OLD.

The olfactory pits at first are blind and are separated from the cavity of the oral pit by thin **bucco-nasal membranes**: but these soon disappear, and the olfactory pits then communicate directly with the cavity of the oral pit through openings which are called the **primitive posterior apertures of the nose.** The olfactory pits now form the **primitive nasal cavities**; they extend upwards and backwards excavating the roof of the main cavity of the oral pit on each side so that a median **nasal septum** appears between them.

After the formation of the primitive apertures of the nose a ledge grows from

the medial surface of each maxillary process towards the median plane. These ledges—the **palatine processes**—are separated for a while by the developing tongue, which rises from the floor of the primitive pharynx (Fig. 78), but they meet and fuse during the third month of intra-uterine life, the fusion beginning ventrally and being completed dorsally in the region of the uvula. In this way the palate is formed, and bone develops in the ventral portion of it and becomes the *hard palate*; the dorsal portion becomes the *soft palate*. The original oral cavity is thus separated into a cranial and a caudal portion. The cranial portion is the **nasal cavity**; it is divided into lateral halves as the palatine processes fuse also with the free edge of the nasal septum (Fig. 79). The caudal portion of the original cavity blends with the ventral part of the primitive pharynx. It forms the cavity of the vestibule of the mouth and from its walls the gums and teeth are developed.

The separation of the lips and cheeks from the gums and the development of the teeth and of the salivary glands are described in the Section on the Digestive System.

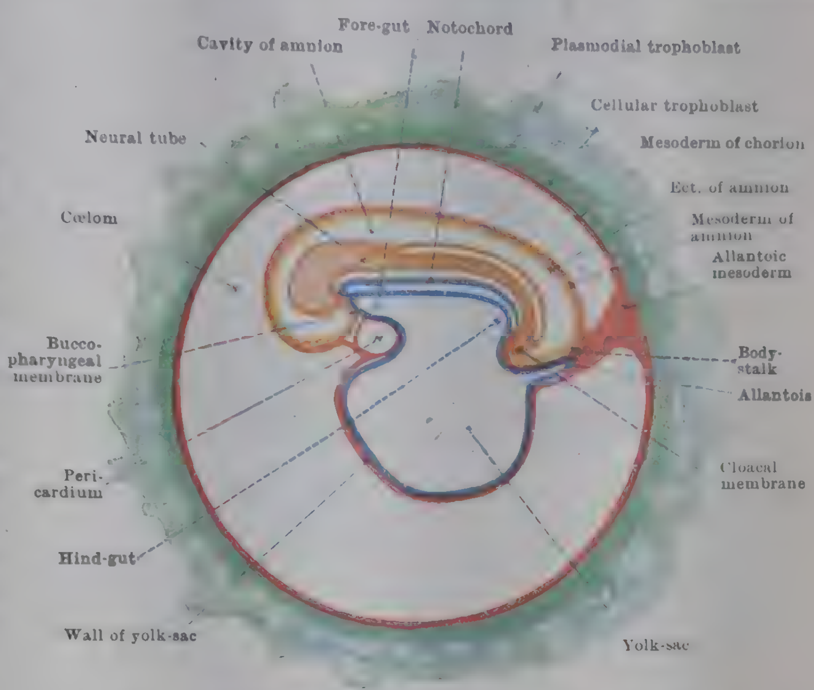


FIG. 80.—MEDIAN SECTION OF ZYGOTE SHOWN IN FIG. 73.

As in the case of the neural folds (p. 59), the union of the various elements from which the face and palate are formed takes place by a process of 'embryonic healing'; and failure of union causes a variety of malformations. The commonest are *hare-lip* and *cleft palate*, which often occur together. Hare-lip is due to failure of union of the maxillary and median nasal processes; it may occur on one or both sides; and, when it is double, the premaxillary part of the upper jaw is isolated and often develops into a projecting mass (Fig. 1201, p. 1467).

DIFFERENTIATION OF FORE-GUT

Derivatives of the Side-Wall.—While still separated from the oral pit by the bucco-pharyngeal membrane the cephalic part of the fore-gut, situated dorsal to the pericardium (Fig. 75), dilates to form the primitive pharynx, and thirteen depressions are formed in its walls. There are five in each side-wall called the **pharyngeal pouches**. There are two in its ventral wall: the first is the rudiment of the thyroid gland; and the other, situated more caudally, is the origin of the respiratory system and provides the epithelial lining of larynx, trachea, bronchi, and lungs. The thirteenth depression is called **Seessel's pouch**. It is formed in the dorsal wall, immediately caudal to the dorsal end of the bucco-pharyngeal membrane, and it extends into the floor of the primitive cranium (Fig. 86).

Simultaneously with the formation of the pharyngeal pouches internally a series of grooves appear externally. They correspond in position with the first four pharyngeal pouches, and they are called the **external pharyngeal grooves** (Figs. 72, 117). There is no external groove corresponding to the fifth pouch, which has a common opening into the pharynx with the fourth (Figs. 81, 83).

The pharyngeal pouches and the external grooves divide each side-wall of the primitive pharynx into a series of bars called the **pharyngeal arches**. The bars are five in number, but the fifth is distinctly visible only in the inner aspect of the pharynx.

Because of the obvious resemblance to the homologous parts in gill-breathing vertebrates, the formations described are often called **branchial** pouches, clefts, and arches.

The first pharyngeal bar is the rudiment of the maxillary and mandibular regions; it is called the **mandibular arch**. The second is the **hyoid arch**. The others are numbered as the third, fourth, and fifth arches. Each pharyngeal arch consists at first of simple mesoderm—covered externally by ectoderm, internally by entoderm—but a series of similar structures soon develop in them. Each arch then contains a cartilaginous skeleton, a muscle-rudiment, two nerves (main and subsidiary), and an artery. The cartilage of the first arch (Meckel's cartilage) is the forerunner of the *mandible* (p. 204); those of the second and third give rise to the *hyoid bone* (p. 207); those of the fourth and fifth arches belong to the *larynx* (p. 723). The arteries are the *aortic arches* which connect the ventral and dorsal aortæ (Fig. 106); the history of these vessels is mentioned on p. 91 and described with the Vascular System. The muscles and nerves of the arches are dealt with on p. 555 and with the Peripheral Nervous System.

When the arches first appear, they extend from the level of the dorsal wall

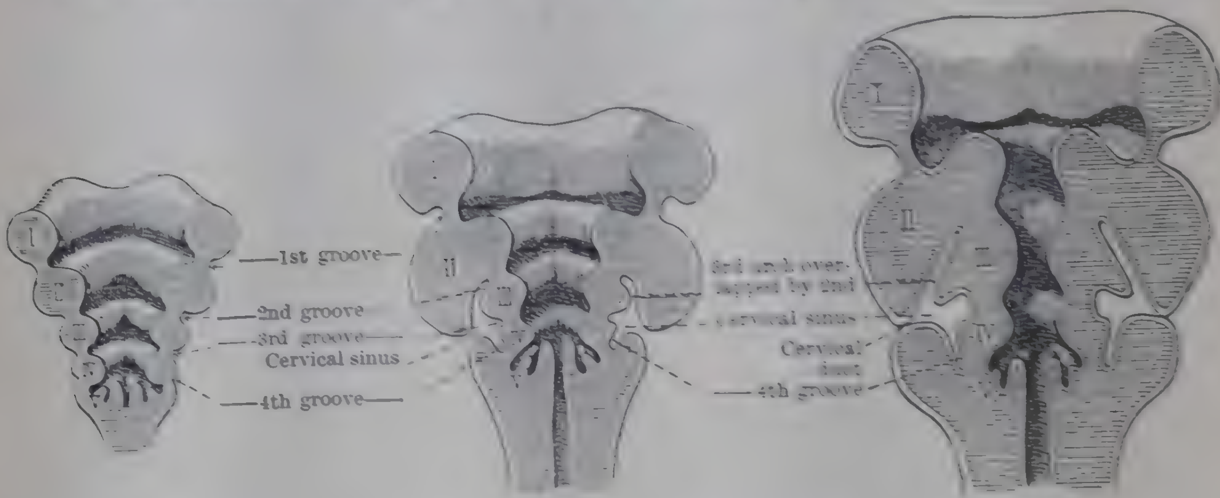


FIG. 81.—SCHEMA SHOWING FORMATION AND CLOSURE OF CERVICAL SINUS.

of the fore-gut to the pericardium; but as growth proceeds, and the neck is developed between the head and the pericardium, the ventral ends of the arches come to lie in the ventral wall of the primitive pharynx, though the mandibular arch is the only one that meets its fellow of the opposite side externally. The growth of the mandibular and the hyoid arches soon greatly exceeds that of the other arches, which gradually recede from the surface until, on each side, they lie at the bottom of a depression—the **cervical sinus**—overlapped by the caudal border of the hyoid arch (Figs. 81, 118). The increasing growth of the hyoid arch reduces the opening of the cervical sinus to a narrow channel called the *cervical duct*, but this is soon obliterated, and then the sinus becomes the *cervical vesicle*. The cervical vesicle lies at the side of the third pharyngeal groove, and it is associated with the second and fourth grooves by narrow canals called the 'branchial' ducts, which are the remains of the external pharyngeal grooves or 'branchial clefts'. Ultimately these submerged spaces (lined with ectoderm) are obliterated; but they may on occasion give rise to a *branchial cyst* or—if the communication with the exterior remains and a separating membrane (see below) breaks down—a *branchial fistula* (p. 811). There is some evidence that the ectoderm of the cervical vesicle comes into contact with the entoderm of the third pharyngeal pouch and takes part in the formation of the thymus (p. 811).

Frazer (1926) gives a different interpretation of the changes in this region. His observations show that the area of the cervical sinus is reduced to a triangular field by a ridge which limits it behind, and a ventral (epipericardial) ridge which separates the ventral ends of the arches from the pericardial swelling. These ridges contain pre-muscle cells passing forwards from the occipital myotomes to the developing tongue. The fourth arch is covered in by the growth of the posterior ridge, and the flattened third arch remains on the surface, so that the closure of the cervical sinus is only partial.

The portion of the wall of the primitive pharynx which lies between any two adjacent arches and separates the external groove from the internal pouch is called the **separating membrane**. In the earliest stages it consists of ectoderm and entoderm separated by mesenchyme; then the mesenchyme disappears, so that, for a time, the membranes consist of ectoderm and entoderm only. At a later period the ectoderm and entoderm are again separated by ingrowing mesoderm.

In gill-breathing animals the membranes break down so that *gill-clefts* are formed; but, except as a malformation, the separating membranes are never perforated in mammalian development, so that no complete 'cleft' ever exists.

The first external pharyngeal groove is the only one that is not submerged in the cervical sinus (Fig. 1028, p. 1202); it is the site of the formation of the **external auditory meatus**, and a series of tubercles which appear at its margins develop into the **auricle** of the external ear. In Man, as in other mammals, the organ of hearing consists of:—the **internal ear** or labyrinth; the **middle ear** or tympanum, which is connected to the pharynx by the **pharyngo-tympanic tube**; and the **external ear**, which includes the external auditory meatus and the auricle. The **tympanic cavity** and the **pharyngo-tympanic tube** are developed from a lateral extension of the upper part of the cavity of the primitive pharynx, between the first and third arches, which contains in its floor the second arch and parts of the first and second pouches; it is called the **tubo-tympanic recess** (Frazer, 1914). [A part of the cavity of the second pharyngeal pouch may be represented in the adult by the *intratonsillar cleft*, which passes into the upper part of the tonsil in the side-wall of the pharynx (Fig. 83).] The **tympanic membrane**, which separates the tympanic cavity from the external auditory meatus, is formed in the position of a 'separating membrane' between the tubo-tympanic recess and the first external groove. But it is a secondary formation, since the deeper part of the meatus is first formed by a solid plug of ectodermal cells which later breaks down in its centre to form the meatus.

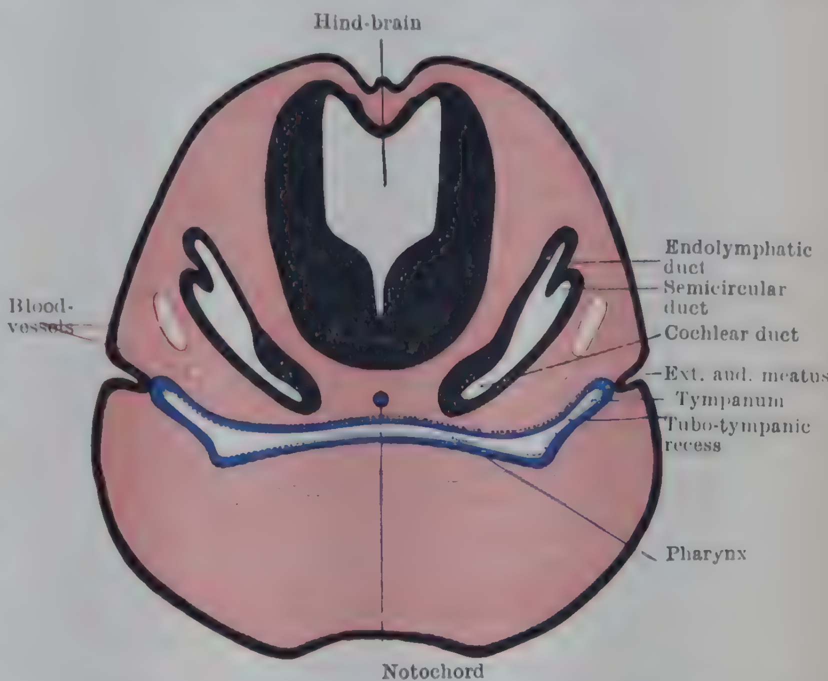


FIG. 82.—DIAGRAM OF TRANSVERSE SECTION THROUGH THE HEAD OF AN EMBRYO. Showing the rudiments of the three parts of the ear and their relation to the tubo-tympanic recess and the first pharyngeal groove.

The development of the conducting parts of the organ of hearing is thus intimately associated with the development of the primitive pharynx. Meanwhile, the essential part of the organ—which is concerned with the function of balancing the body as well as with the sense of hearing—has developed from the ectoderm of the side of the head in close relation to the hind brain and the 'auditory' (eighth cranial) nerve (Figs. 75, 85). The **otic vesicle**, formed by thickening and invagination of the ectoderm, becomes converted into the **membranous labyrinth** which includes the *utricle*, the *saccule*, and the three *semicircular ducts*, all concerned with equilibration, and the *duct of the cochlea* which contains the essential organ of hearing. But for the details of the development of the Ear the student must refer to the Section on the Organs of the Senses.

The third pharyngeal pouch opens, like the first and second, directly into the cavity of the fore-gut, but the communication is soon drawn out into a duct-like

passage; the fourth and fifth pouches lie in the side-wall of a common recess which opens by a single aperture or 'duct' into the cavity of the primitive pharynx (Fig. 83).

The cavities of the third, fourth, and fifth pouches ultimately disappear.

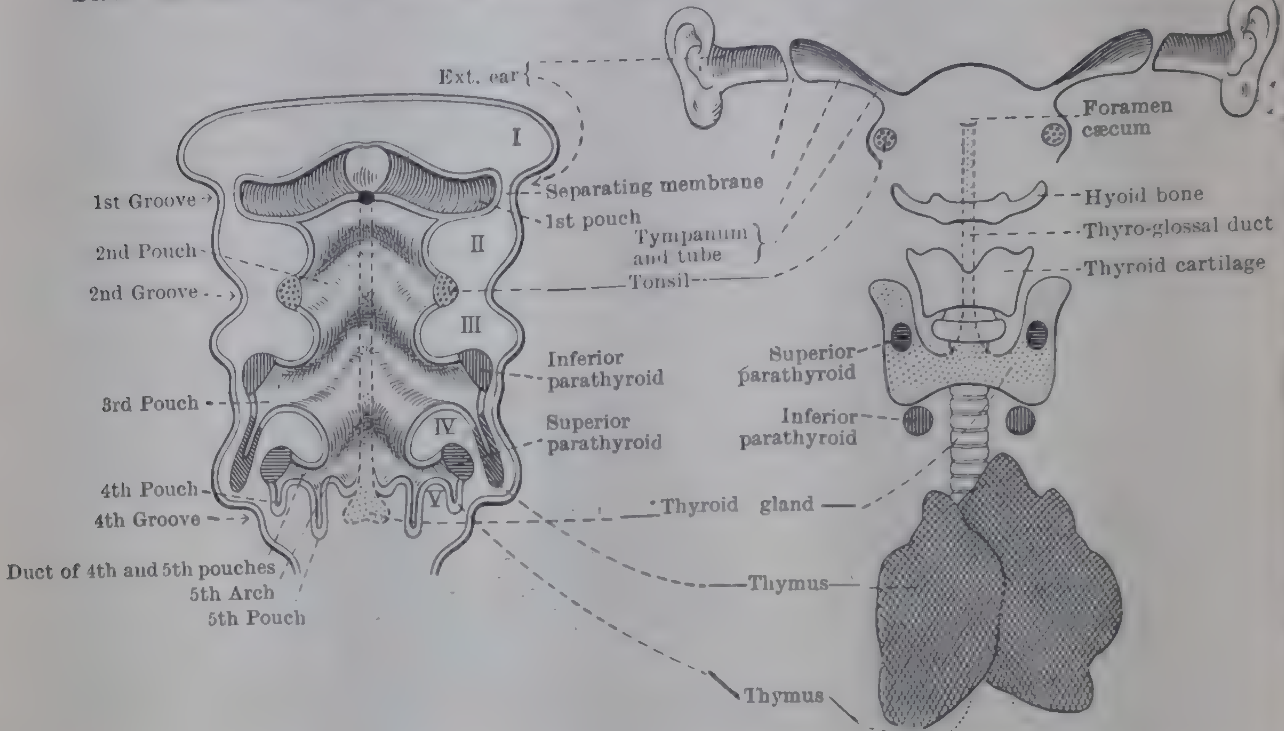


Fig. 83.—Schema showing the Pharyngeal Pouches, the External Pharyngeal Grooves, the Pharyngeal Arches and the Thyro-Glossal Duct and some of their Derivatives. I, II, III, IV, and V, the five arches. The cervical sinus is not represented.

Before they disappear a diverticulum, at first hollow but afterwards solid, grow from the ventro-lateral wall of each, and a solid **epithelial body** buds from the dorso-lateral wall of each of the third and fourth pouches (Fig. 83).

Organs derived from Pharyngeal Pouches.—The diverticula and the epithelial bodies of the third, fourth, and fifth pouches give rise to a series of important organs which belong to the 'ductless glands' of the body (Fig. 83). The

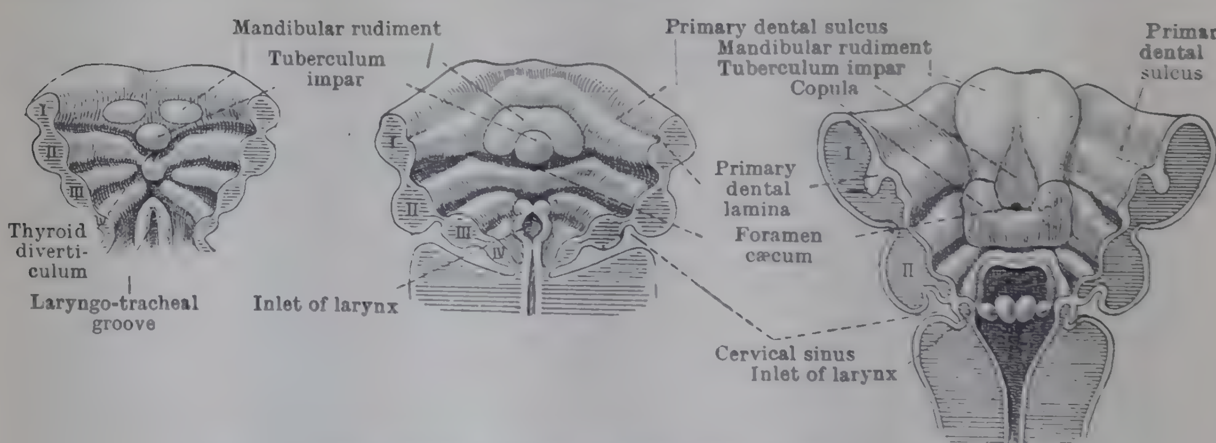


Fig. 84.—Schema showing Stages in the Development of the Tongue.

diverticula from the third and fourth pouches are concerned in the development of the **thymus**; and the epithelial bodies of the same pouches become the **parathyroid glands**. Changes in the situation of these organs occur as the heart in its pericardium moves caudally and the neck is formed; thus, the thymus extends into the thorax, and the parathyroids alter their relative position, the one derived from the third pouch being drawn down so that it comes to lie inferior to the other.

The diverticulum from the fifth pharyngeal pouch is transformed into the

ultimo-branchial body, which receives its name because it is the last of the series of organs derived from the branchial region of the pharynx. It is associated with the corresponding lobe of the thyroid gland and may contribute to its formation (Weller, 1933). The development of all these organs (including the thyroid gland) is dealt with in detail in the Section on the Ductless Glands.

Derivatives of Ventral Wall.—The main rudiment of the **thyroid gland** appears first as a diverticulum from the ventral wall of the primitive fore-gut. It begins in the median plane between the ventral ends of the mandibular and hyoid arches. It first grows ventrally into the substance of the neck, and then caudally, passing ventral to the cartilage bars which appear in the second, third,

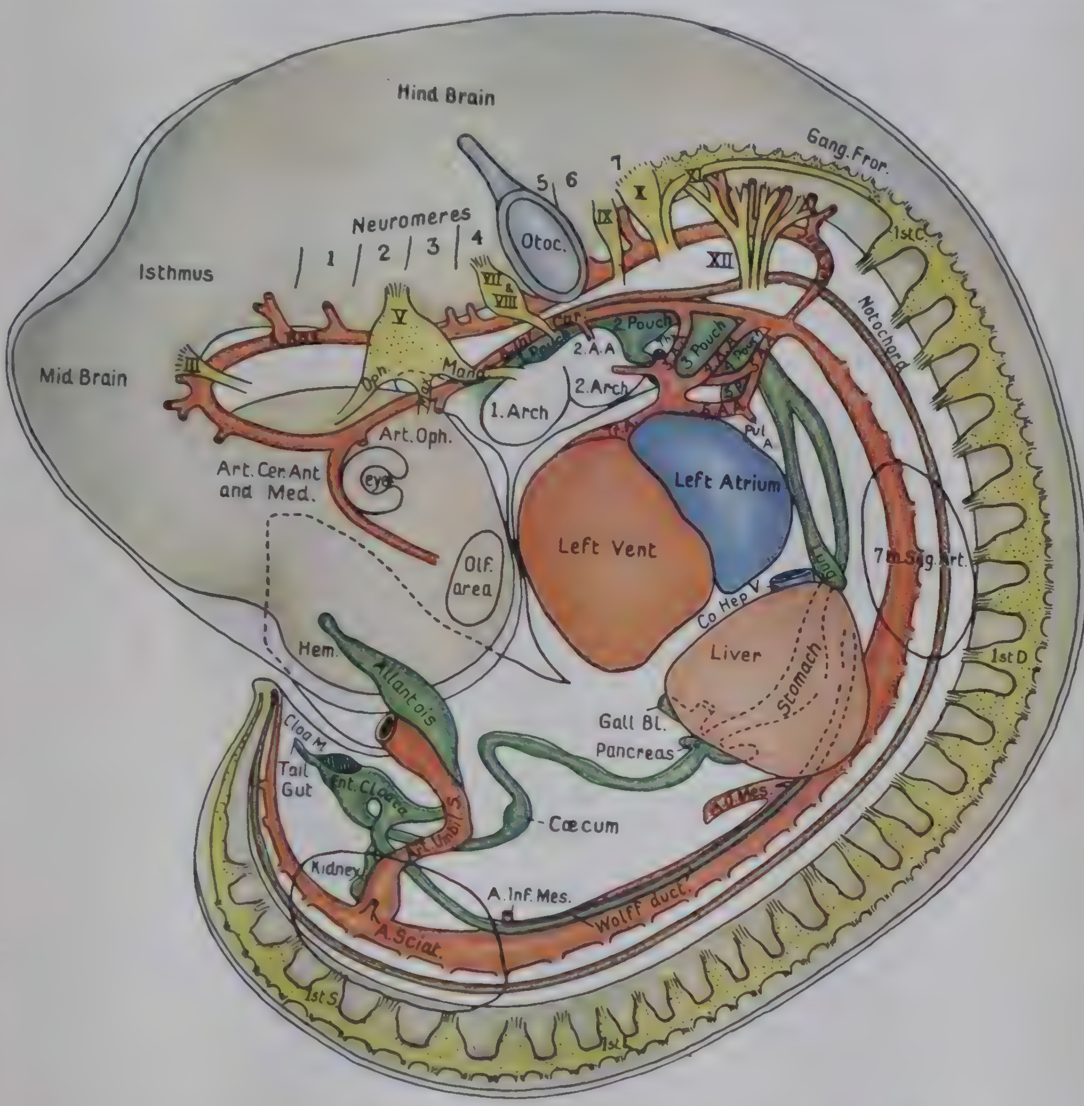


FIG. 85.—RECONSTRUCTION OF HUMAN EMBRYO, 7 mm. long. (Peter Thompson, *Studies in Anatomy*, University of Birmingham, 1915.) Cf. Fig. 75 and subsequent figs. showing differentiation of the alimentary canal. *1st D*, 1st thoracic ganglion; *Co. Hep. V.*, Common hepatic vein; *Gang. Fror.*, Froriep's ganglion (XII); *Hem.*, cerebral hemisphere; *Otoc.*, otic vesicle; *Wolff. duct*, mesonephric duct.

and fourth arches and are developed into the hyoid bone and the cartilages of the larynx. When the caudal end of the diverticulum reaches the level of the origin of the trachea it becomes bilobed, and is thus differentiated into the isthmus and the adjacent parts of the two lobes of the permanent gland (Fig. 83). The stalk of the diverticulum is the **thyro-glossal duct**; the position of its original upper end is indicated by the **foramen cæcum** of the tongue. The caudal end of the stalk sometimes persists and is transformed into the *pyramidal lobe of the thyroid* gland, and persistence of other parts of the duct may give rise, at any point between the gland and the tongue, to swellings known as *thyro-glossal cysts*.

Respiratory System.—A more caudally situated diverticulum from the ventral wall of the fore-gut is the rudiment of **the respiratory system** (Figs. 84, 86). It first appears behind the developing tongue as a longitudinal groove bounded at

its cranial end and on each side by a ∩-shaped ridge (Fig. 84). The caudal end of this **laryngo-tracheal groove** soon dilates into a pouch. Then the pouch and groove are separated from the more dorsal part of the fore-gut, which becomes the *œsophagus*, by a constriction which passes from the caudal towards the cranial end. The constricting process ceases before the separation reaches the cranial end of the respiratory rudiment, which therefore remains in communication with the pharynx and forms the permanent *inlet of the larynx*. As the groove is separated from the primitive fore-gut it is converted into a tube which is gradually differentiated into the *larynx* and the *trachea*. The pouch at the caudal end of the tube soon divides into right and left lobes, each of which is the rudiment of the epithelium lining the bronchi and lung of the corresponding side.

The Tongue.—The mucous membrane of the tongue is formed by *four separate rudiments* which appear in the ventral wall of the primitive pharynx. Two of these are elevations formed on the ventral ends of the mandibular arches. The third is a median elevation, called the **tuberculum impar**, which is situated immediately caudal to the conjoined ventral ends of the mandibular arches. The

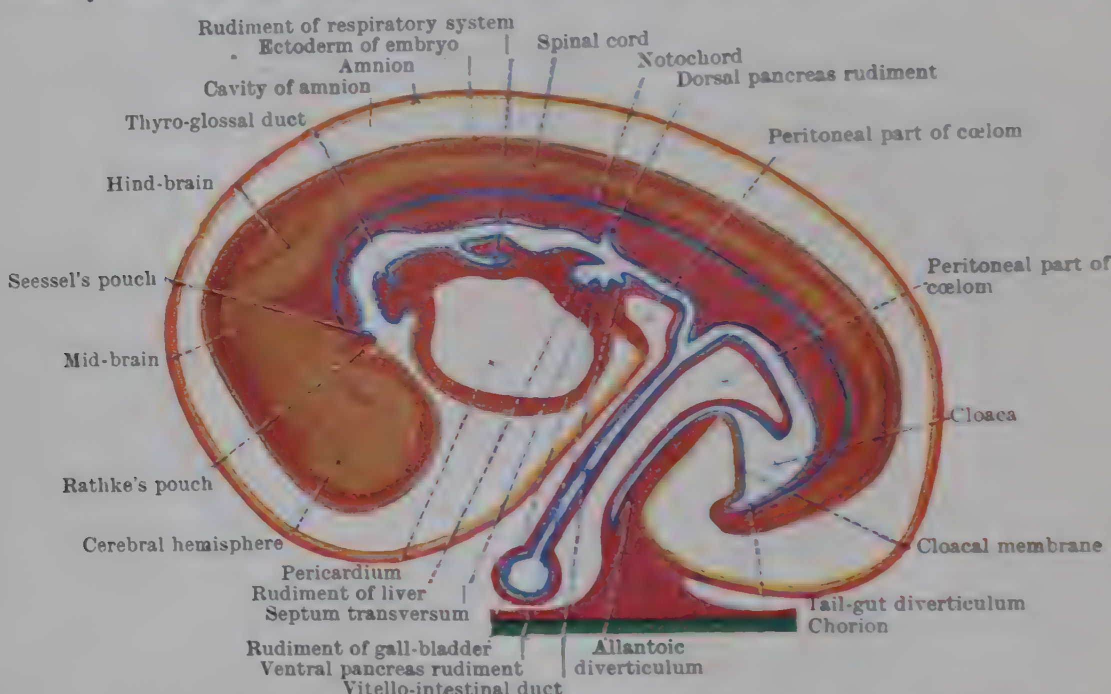


FIG. 86.—SCHEMA OF SAGITTAL SECTION OF 5 MM. EMBRYO (about 5 weeks old), showing dorsal and ventral diverticula of alimentary canal. The heart is not shown. (After Mall, modified.)

fourth rudiment, the **copula** of His, so called because it is formed by the conjoined ventral ends of the second and third pairs of arches, is separated from the tuberculum impar by the orifice of the thyroid rudiment (Fig. 84).

The elevations on the mandibular arches submerge the tuberculum impar and unite to form the greater part of the anterior two-thirds of the tongue—the part on which all the papillæ are developed. The posterior third of the tongue, which lies in the ventral or anterior wall of the permanent pharynx, is formed by a V-shaped swelling which rises from the copula and blends with the anterior two-thirds along the line of the *sulcus terminalis*. The foramen cæcum is a depression left in the median plane at the junction of the two parts of the tongue, and it therefore indicates the site of origin of the thyroid gland.

Derivative of Dorsal Wall.—The only dorsal diverticulum from the cranial part of the fore-gut is **Seessel's pouch**, which is formed immediately behind the dorsal attachment of the bucco-pharyngeal membrane (Fig. 86). The ultimate fate of the pouch in human development is uncertain, but it may be represented by a depression, known as the *pharyngeal bursa*, in the naso-pharyngeal tonsil, which is situated in the nasal part of the pharynx (p. 589 and Fig. 502).

Abdominal Portion of Fore-Gut.—The portion of the fore-gut that has now been considered gives rise to the lower part of the mouth (with the exception of

the lips, teeth, and gums) the pharynx, the thyroid gland, the thymus, the parathyroid glands, the respiratory organs, and the œsophagus. The œsophagus extends through the part of the embryo that will become the thoracic region of the body, and the remainder of the fore-gut is situated in the upper part of the abdominal region. The abdominal portion of the fore-gut is differentiated into the **stomach** and the first and second parts of the **duodenum**, and from it the liver and pancreas take origin as outgrowths.

In that region it is attached to the posterior wall by that part of the general dorsal mesentery of the gut (splanchnopleure) known as the *dorsal mesogastrium* because its main attachment is to the stomach. It lies dorsal to the *septum transversum*—the mesodermal partition continuous with the caudal wall of the pericardium (Fig. 86)—from which a *ventral mesogastrium* will be separated as the liver grows into it (p. 95).

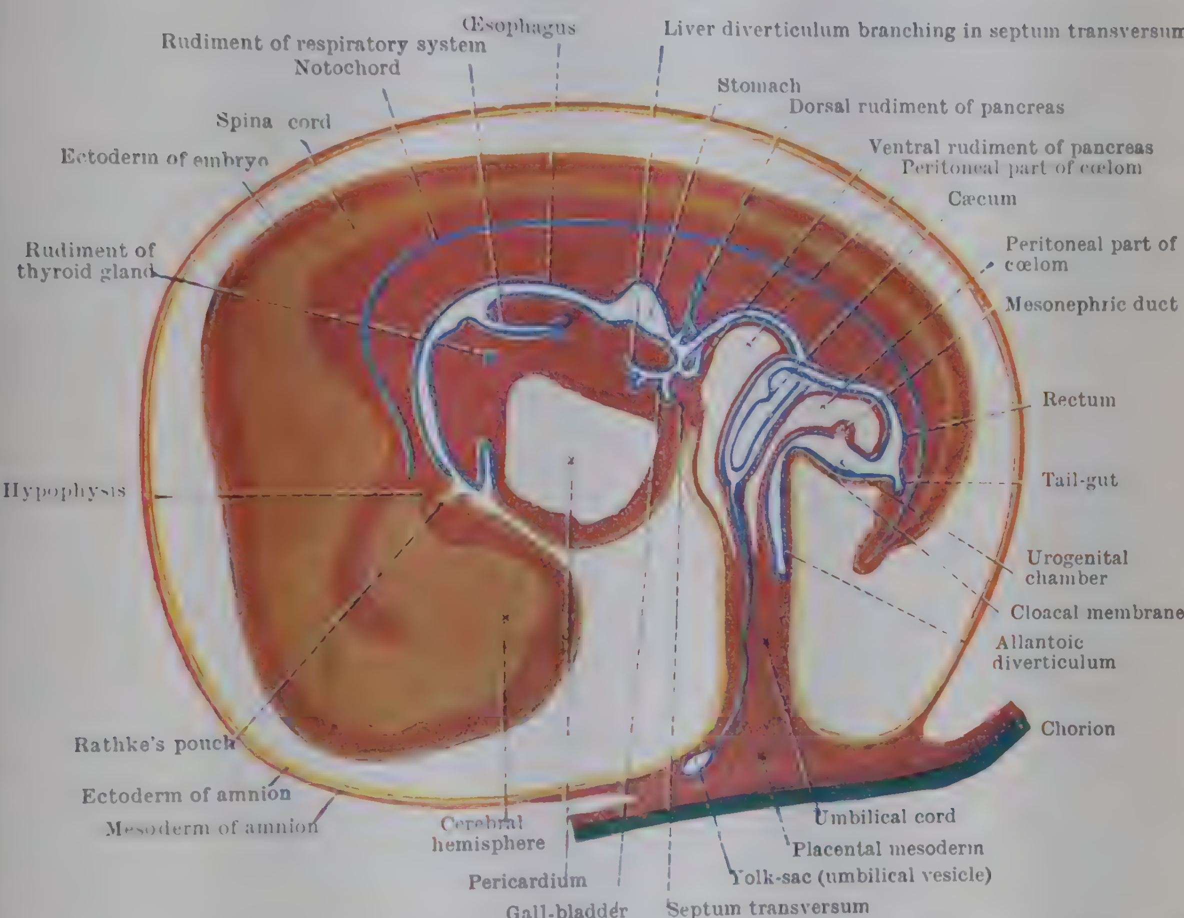


Fig. 87.—Schema of Sagittal Section of 10 mm. Embryo (about 6 weeks old), showing further stages in the development of the diverticula from the primitive gut and rotation of the mid-gut loop in which the rudiment of the cæcum has appeared. Note the passage of the gut into the umbilical cœlom. The heart is not shown. (After Mall, modified.)

Liver and Pancreas.—When the embryo is about four weeks old and has attained a length of 2·5 mm. a diverticulum appears in the angle between the widely open vitello-intestinal duct and the ventral wall of the fore-gut (Fig. 75) and grows into the septum transversum (Fig. 79); and when the length of the embryo has increased to about 4 mm. another diverticulum is formed in the dorsal wall of the duodenal part of the fore-gut a little nearer the stomach. The ventral pouch is the rudiment of the *liver*, the *gall-bladder*, the *bile-ducts*, and a portion of the *pancreas*. The remainder of the pancreas is formed from the dorsal diverticulum (Figs. 86, 87).

The further development of these organs and of the parts derived from the mid-gut and hind-gut, mentioned in the following outline, is considered in the Section on the Digestive System.

Differentiation of Mid-Gut and Hind-Gut

Derivatives of Mid-Gut.—The mid-gut is that part of the primitive alimentary tract which is in free communication with the yolk-sac by the vitello-intestinal duct. It is transformed into the greater part of the **small intestine** (from the entrance of the bile-duct into the duodenum to the end of the ileum) and part of the large intestine (cæcum and appendix, ascending colon and most of the transverse colon).

Derivatives of Hind-Gut.—The parts formed from the hind-gut are: (1) The remainder of the large intestine, except a small portion of the anal canal; (2) the urachus and part of the urinary bladder; (3) the urethra in the female, and part of the urethra in the male.

As development proceeds, the mid-gut forms a U-shaped tube with cephalic and caudal limbs, and a ventral knuckle which points towards the umbilical orifice, through which it remains connected with the yolk-sac by the narrowed and elongated **vitello-intestinal duct** (Fig. 86).

In embryos about 8 or 9 mm. long (between five and six weeks old) there appears about the middle of the caudal limb of the loop an enlargement which is the rudiment of the **cæcum** and **vermiform appendix**, thus demarcating the large intestine from the small.

But before this rudiment appears rotation of the loop has begun, and the growth of other structures in the abdomen, especially of the liver, is relatively so great that there is not sufficient room for the developing intestines. When the embryo is between 5 and 8 mm. long, the loop begins to pass out through the umbilical orifice into an **umbilical sac** which has been formed in the umbilical cord by the enclosure of part of the extra-embryonic cœlom (cf. Figs. 86, 87, 88).

As the loop enters this sac its limbs lie already side by side—the cephalic limb on the right, the caudal on the left—and there it remains for a considerable time while a further stage of its rotation and further development take place.

The chief change that now occurs is the rapid elongation of the part of the loop (mainly the cephalic limb) that becomes small intestine, which is thrown into the numerous coils of the **jejunum** and **ileum**. The vitello-intestinal duct has meanwhile separated from the loop and disappeared, leaving the coiling gut free in the umbilical sac. With the duct there goes also the part of the vitelline artery which ran along it to the yolk-sac—the embryonic part of that artery remaining in the mesentery of the loop as the *superior mesenteric artery*, which thus supplies both small and large intestine.

As the intestines return into the abdomen the last stage of the rotation of the loop occurs. The rotation as a whole is usually described as taking place round the superior mesenteric artery as an axis; and it is now completed by the passage of the caudal limb of the loop to the right in front of the trunk of tha artery and in front of the coils of small intestine derived from the cephalic limbt so that the cæcum—the last part to leave the umbilical sac—comes to lie immed,iately below the right lobe of the liver.

Subsequently, certain parts of the large intestine are fixed in their permanent positions by peritoneal adhesions. The **ascending colon** and the **transverse colon** are derived from the distal part of the caudal limb of the loop, whilst the proximal part of the hind-gut is transformed within the abdomen into the **descending colon** and the **pelvic colon**. The developing intestines remain in the umbilical sac until the embryo is about 40 mm. long and about ten weeks old, when they return rather suddenly to the abdomen, in which room is obtained by reduction in the rate of growth and therefore in the relative size of the liver (Frazer & Robbins, 1915); after the return of the intestines to the abdomen the cœlomic space in the umbilical cord is obliterated.

Occasionally the site of attachment of the vitello-intestinal duct is indicated by the persistence of a portion of it as a *diverticulum of the ileum* (Meckel's diverticulum) not far from the cæcum. This diverticulum may rarely be attached to the back of the umbilicus by a fibrous thread; such a thread, from the distal small intestine to the umbilicus and continuous with the end of the superior mesenteric artery, is normally present in many new-born animals (*e.g.*, cats).

The umbilical sac and its communication with the peritoneal cavity may fail to close; and the child may then be born with the malformation of the abdominal wall known as *congenital umbilical hernia*. The developmental extrusion of the intestines from the abdomen of the embryo is so striking a phenomenon that it is often called the 'normal umbilical hernia'.

Development of Caudal Part of Hind-Gut.—When the hind-gut is first enclosed, its blind end and its ventral wall are bounded by the caudal portion

FIG. 88.—SCHEMA OF 25 MM. EMBRYO (about 8 weeks old), showing complete separation of cloaca into dorsal and ventral parts and the temporary ventral hernia of a portion of the gut through the umbilical orifice. The heart is not shown. (After Mall, modified.)

of the primitive streak—the **cloacal membrane**—which is bent ventrally during the folding-off of the embryo (Fig. 86).

The terminal part of this portion of the gut becomes expanded to form a chamber called the **entodermal cloaca**, because the entrance of the **mesonephric ducts** from the primitive kidneys which open into it, one on each side, recalls the permanent *cloaca* of the lower vertebrates.

The ventral part of the cephalic end of the cloaca is continuous with the allantoic diverticulum, and the dorsal part with that portion of the hind-gut which forms the descending colon and the pelvic colon.

As the temporary tail is formed and turned ventrally by the growth energy of the nodal point situated at the caudal end of the neural tube, a diverticulum of the caudal end of the dorsal part of the cloaca is prolonged into it, forming the **tail-gut.** This soon becomes shut off from the cloaca. It entirely disappears before the temporary tail is absorbed into the caudal end of the body (Figs. 86-88).

At a later period the cloaca itself is divided by a septum into a dorsal part which become the **rectum**, and a ventral part called the **urogenital chamber** (Figs. 88 and 672, p. 791). The septum begins in the angle between the allantoic diverticulum and the ventral wall of the hind-gut, and grows towards the surface till it reaches and fuses with the cloacal membrane; the membrane is thus separated into urogenital and anal portions, both of which disappear about the eighth week.

In both sexes the urogenital chamber is separable into three portions: (1) a cephalic portion called the **urachus**, which is continuous with the remnant of the allantois and becomes the *median umbilical ligament*; (2) a middle portion, which becomes the greater part of the *urinary bladder*; and (3) a caudal portion, known as the **urogenital sinus**, which becomes the *urethra* and the *vestibule of the vagina* in the female and part of the *urethra* in the male.

Urogenital System.—It has been noted (p. 51) that the greater part of the urogenital system is derived from the intermediate cell-mass of the mesoderm; that includes the series of excretory organs known as the **pronephros**, the **mesonephros**, and the **metanephros**—the last forming the permanent *kidney*—and the two primary ducts, the **mesonephric** and **para-mesonephric ducts**, which have a different fate in the two sexes. The history of these ducts and their relation to the urogenital part of the cloaca, with details of the development of the urogenital chamber itself, of the sex-glands from the genital ridge and of the external genital organs will be found in the full account of the development of the Urogenital System in the appropriate Section.

Derivative of Anal Pit.—The anal pit is a surface depression which owes its origin to the elevation of the surface around the margin of the anal portion of the cloacal membrane (Fig. 88). It forms the lowest portion of the **anal canal** of the adult.

FŒTAL MEMBRANES AND PLACENTA

Nutrition and Protection of Embryo.—While the zygote is passing along the uterine tube, and for a brief period after it enters the uterus—until the oolemma disintegrates and the blastula stage is reached—it depends for its nutrition upon the metaplasmic granules originally stored in the ovum.

As the human ovum is small, and as it contains but little metaplasm, there is urgent necessity for an external source of nutritive supply, and of oxygen for tissue respiration, and for provision for the removal of waste-products of its metabolism. It is probable that the naked morula obtains some food-material from the uterine secretions as well as the fluid essential for transformation into a blastula; but development cannot proceed beyond that stage until an intimate connexion between the zygote and the uterus is established by the critical operation of *implantation* or *embedding* in the endometrium.

That process, by which the trophoblastic covering of the sac within which the embryo develops and grows comes into direct contact with the maternal blood, is associated with the early development of a primitive heart and blood-vessels by means of which materials are carried to and from the embryo; but the details of the establishment of the embryonic circulation, which is related primarily to the yolk-sac and the placental area of the chorion, cannot be understood until the formation and arrangement of the *fœtal membranes* have been considered.

These important structures—the chorion, the amnion, the yolk-sac, and the allantois—have necessarily been named in describing the early stages of development, and it is convenient now to consider them together, noting their significance and functions, before the process of implantation and the development and structure of the placenta are described. The fœtal membranes are indeed intimately related to each other, and they are all, including the placenta, ultimately attached to the embryo by the umbilical cord, and are separated from it when the cord is severed.

Evolution of Fœtal Membranes.—The fœtal membranes are specialized portions of the somatopleure and splanchnopleure (p. 50) of the vertebrate embryo. In other words, parts of the original body-wall (amnion and chorion) and parts of the original gut (yolk-sac and allantois) are set aside to provide organs that adapt the embryo and fœtus to its temporary environment. These organs are extra-embryonic structures concerned with protection, nutrition, respiration, and excretion; and the manner in which they perform these functions, as well as the details of their arrangement, differs in different groups of animals. The four membranes are found only in the higher classes of vertebrates—the reptiles, the birds, and the mammals—whose embryos develop either within an egg-shell or within the body of the mother. Since they all possess the characteristic protective membrane called the amnion, the reptiles, birds, and mammals are grouped together as the *Amniota*.

The **amnion** provides a cavity full of fluid in which the embryo may develop under conditions which resemble the watery environment of the embryos of lower vertebrates—the amnion has been called a 'private pond'. Its mode of formation (Fig. 89, B, C, D) implies another external covering—the **chorion**—which is the remaining part of the extra-embryonic somatopleure.

The embryos of fishes and amphibia do not require an amnion, since for the most part they hatch from the egg and develop in water; and the only 'fœtal membrane' they possess is a yolk-sac which contains enough food-material for the initial stages of development. All the

Amniota also possess a **yolk-sac**, and in the embryos of all those that are oviparous—including the lowest group of mammals (the monotremes)—it is filled with food-material. Although the yolk-sac ceases to have any importance as a food-store in the viviparous mammals, including Man, it is retained in them because of its intimate relation to the development of the gut and also because the earliest blood-vessels are formed in its wall (Fig. 101).

The fourth membrane—the **allantois**—is as characteristic of the *Amniota* as the amnion itself; and it has a very remarkable history. It grows out as a diverticulum from the ventral wall of the hind-gut (Fig. 90), and in reptiles and birds it serves primarily as a urinary bladder for the embryo; its relation to the gut is exactly the same as that of the permanent urinary bladder of the amphibia, with which it is probably homologous. But the allantois in these animals, as it increases in size, comes into contact with the chorion and fuses with it to form a combined membrane which lines the inside of the egg-shell. This membrane, in virtue of the blood-vessels it contains, provides for the respiration of the embryo by gaseous exchange through the porous shell between the air and the blood. Thus, the allantois of oviparous animals comes secondarily, through fusion of its wall with the chorion, to act functionally as an embryonic

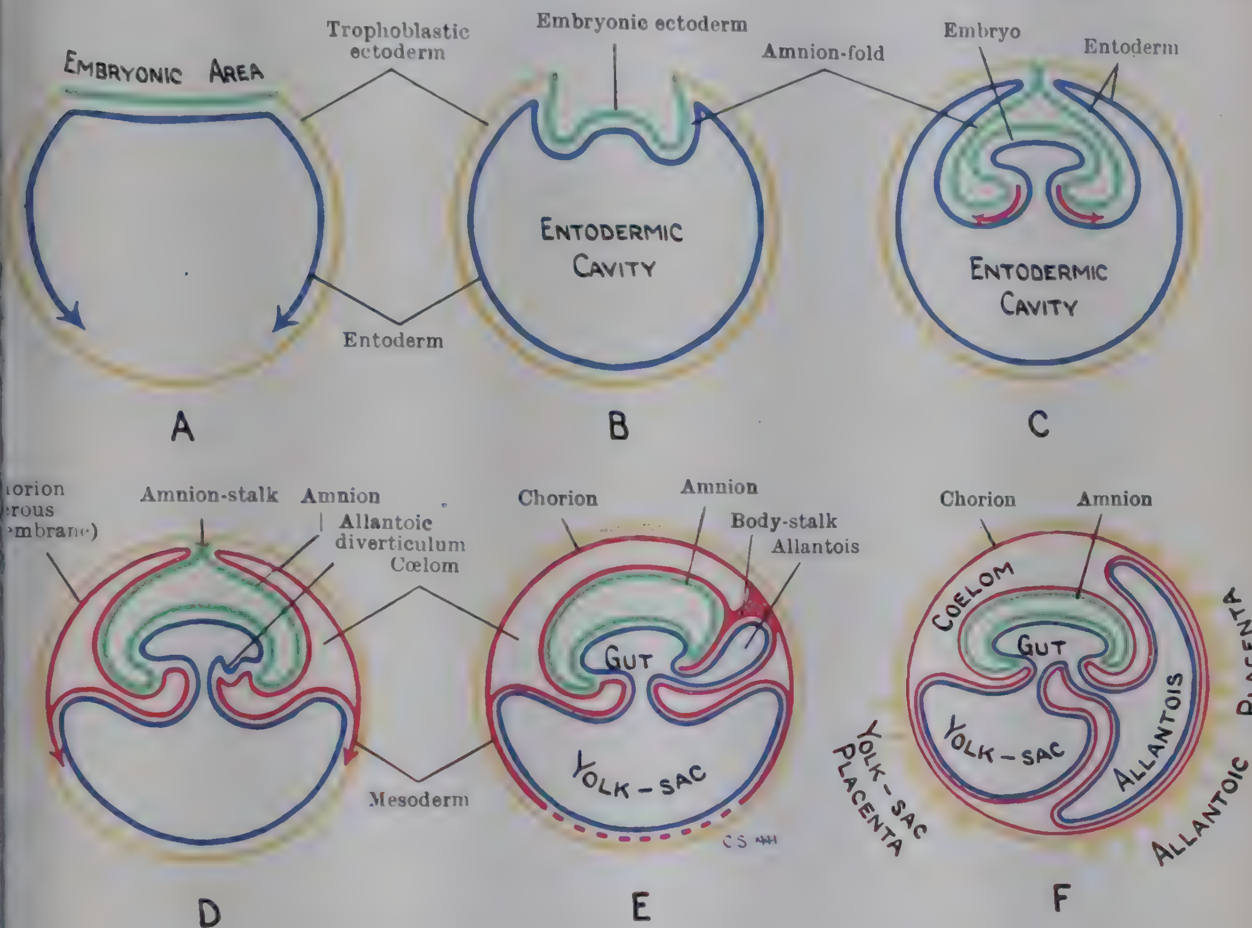


FIG. 89.—DIAGRAMS OF STAGES IN THE EVOLUTION OF THE FŒTAL MEMBRANES. (Adapted from Graham Kerr's *Text-Book of Embryology: Vertebrata*. Macmillan & Co.)

For detailed explanation, see text. Yellow = trophoblastic ectoderm; green = amniotic and embryonic ectoderm; blue = entoderm; red = mesoderm.

"lung". In most viviparous mammals the chorion is vascularized in the same manner by blood-vessels carried to it by the allantois and is thus enabled likewise to act as a respiratory membrane; but in this case the exchange of oxygen and carbon dioxide is not with the air but with the blood of the mother; and, in addition, food-materials also can be obtained by the embryo from the same source by the formation of a *placenta*.

The 'type' of placenta depends upon the extent to which the maternal tissues are destroyed by the action of the trophoblast (p. 81); when the uterine blood-vessels are opened into, so that the trophoblast comes into direct contact with the maternal blood, the placenta is said to be of the *haemochorial* type (Mossman, 1937).

The series of diagrams in Fig. 89 illustrate the evolution, development, and mutual relations of the fœtal membranes in the *Amniota*, with the proviso that the amount of yolk influences the disposition of the various layers. The form of the blastula in particular depends on the amount of yolk present in the egg (p. 23), but in general it becomes a two-layered vesicle by the growth of the entoderm round the inner surface of the ectodermal wall. Only a portion of the wall of the blastula—the 'embryonic area'—is destined to form the embryo; and as the entoderm grows centrifugally from that region, it encloses the mass of yolk if present. The embryonic area is originally exposed on the surface (Fig. 89 A).

As the embryo grows, it begins to sink into the interior of the vesicle, and folds of the two-

layered wall grow up around it. These are the 'amnion-folds' and at first they include the entoderm as well as the ectoderm (B). The amnion-folds meet above the embryonic area and the entoderm is carried with them so that the embryonic area is separated from the surface by a double layer, each composed of ectoderm and entoderm; the ectoderm and entoderm are necessarily reversed in position in the inner layer, an arrangement, called "inversion of the germinal layers", which is found even in the development of some mammals (C). Meanwhile, the embryo rises out of the embryonic area and is 'folded-off' so that the gut is formed and its connexion with the rest of the entodermal vesicle, which becomes the **yolk-sac**, is reduced to a narrow passage.

The next stage is the growth of the mesoderm outwards from the embryo (C), progressively separating the extra-embryonic ectoderm and entoderm and excluding the entoderm from the amnion-folds (D). As it grows, the mesoderm covers the inner layer of ectoderm to form the definitive **amnion**, and it lines the outer layer of ectoderm (the *trophoblast* of viviparous mammals) which thus becomes the **chorion**, often called the *serous membrane* in oviparous animals. The two layers of mesoderm enclose the extra-embryonic cœlom between them. The relation between amnion and chorion, which depends on their common origin from the ectoderm, is indicated by the *amnion-stalk* (D) which may persist for some time; traces of it are found even in the human embryo (see below), though the cavity of the amnion appears without the formation of amnion-folds (p. 35). In the same diagram (D), the growth of the mesoderm over the entoderm to form the definitive **yolk-sac** is shown, and this continues until the mesoderm completely separates the yolk-sac from the chorion (E, F). The origin of the **allantois** as an outgrowth from the gut, carrying mesoderm with it, into the extra-embryonic cœlom is also indicated.

As the allantois enlarges, the amnion-stalk disappears and the connexion between embryo and chorion is reduced to mesoderm only—the *body-stalk* of mammals (E). There is a certain antagonism or reciprocal relation between the allantois and the yolk-sac; the yolk-sac is progressively reduced as the yolk is used up and as the allantois grows, so that in oviparous forms and in many viviparous mammals too, the yolk-sac is entirely or almost entirely excluded from contact with the chorion. Finally, in reptiles and birds, the membrane formed by the union of the wall of the allantois with the chorion acts as a respiratory membrane under the shell, and in most mammals it is the basis of the 'allantoic placenta'; but in some marsupial mammals the allantois remains small and a temporary 'yolk-sac placenta' is formed where the wall of the yolk-sac is in contact with the chorion (F).

In human development, both yolk-sac and allantois remain very small; but the placenta is of the allantoic variety because it is formed from the chorion in the region of the attachment of the body-stalk, into which the allantois grows.

Amnion.—The human **amnion** is formed from that portion of the wall of the ectodermal or amnio-embryonic vesicle which does not take part in the formation of the embryo (p. 35). It consists of ectoderm cells covered externally by a layer of extra-embryonic mesoderm, and it is continuous with the margin of the embryonic area (Figs. 90, 91). Whether the amnion is formed by splitting in the inner cell-mass or by separation of a layer of cells from the trophoblast (p. 35), the ectodermal cells of the amnion are at first continuous with the trophoblast (Fig. 51); a remnant of this connexion, in the form of a strand of cells passing from the amnion to the chorion in the body-stalk, persists in some early human embryos, and is a reminder of the evolutionary origin of the amnion by folds which meet to form an amnion-stalk (Fig. 89 D).

The cavity of the ectodermal vesicle, enclosed between the amnion and the embryonic area, is the **amnion cavity**; it is filled with fluid which raises the amnion in the form of a cupola over the embryonic region (Fig. 90). The amnion progressively enlarges as the amount of fluid increases until it fuses with the chorion and obliterates the extra-embryonic cœlom; by that time its attachment to the embryo is around the umbilical orifice and it forms a sheath for the umbilical cord (Fig. 98).

Yolk-Sac.—When the embryonic area is folded into the form of the embryo, the entodermal vesicle (secondary yolk-sac) is differentiated into three parts:—(1) a part enclosed in the embryo, where it forms the **primitive entodermal alimentary canal**; (2) a part which lies external to the embryo in the extra-embryonic cœlom—this is the yolk-sac proper or **definitive yolk-sac**; (3) the third portion is the **vitello-intestinal duct**, which connects the yolk-sac with the primitive alimentary canal (Figs. 75, 86, 87, 97).

The cavity of the yolk-sac is therefore in free communication with that of the alimentary canal, and their walls are continuous with each other and identical in structure, each consisting of an internal layer of entodermal cells and an external layer of mesoderm.

Free communication between the yolk-sac and the primitive alimentary canal appears to exist in the human embryo until it is four weeks old and about 2·5 mm. long (Fig. 75). During the fifth week the vitello-intestinal duct is elongated into a relatively long, narrow tube, lodged in the umbilical cord, and the yolk-sac, which has become a relatively small vesicle, is placed between the outer surface of the amnion and the inner surface of the chorion, in the region of the placenta. The reduced yolk-sac, on account of its relation to the umbilical cord, is sometimes called the *umbilical vesicle* (Figs. 86, 87). By the end of the fifth week, when the embryo has attained a length of about 5 mm., the vitello-intestinal duct begins to undergo atrophy, and it separates from the intestine when the embryo is about 11 mm. long; but remnants of it may be found in the umbilical cord up to the third month.

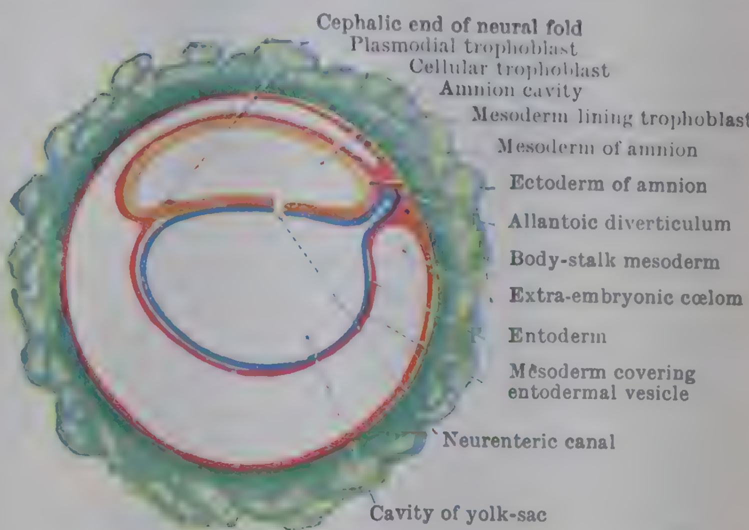


FIG. 90.—SAGITTAL SECTION OF ZYGOTE ALONG LINE A-A IN FIG. 58.

The yolk-sac itself persists until birth, when it may be found as a minute object lying between the amnion and the placenta near the end of the umbilical cord.

The human yolk-sac, since it contains no yolk, is in a sense a 'vestige' from the evolutionary point of view; yet, in the early stages of human development it is relatively quite large (Fig. 117), and it retains its special importance in the development of the blood and blood-vessels (p. 87). The vessels which develop in the wall of the yolk-sac are soon connected with others in the body of the embryo to form a *vitelline circulation.* This circulation is mainly responsible for the transfer of nutriment from the yolk to the embryos of birds and reptiles; and in mammals the vessels are formed in the same way since they are the basis of the vascular arrangements of the gut. At a very early period, before the paraxial mesoderm has commenced to divide into mesodermal somites, a number of **primitive vitelline arteries** are distributed to the yolk-sac from the primitive aortæ, and the blood is returned from the yolk-sac to the embryo by a pair of **vitelline veins** (Fig. 102).

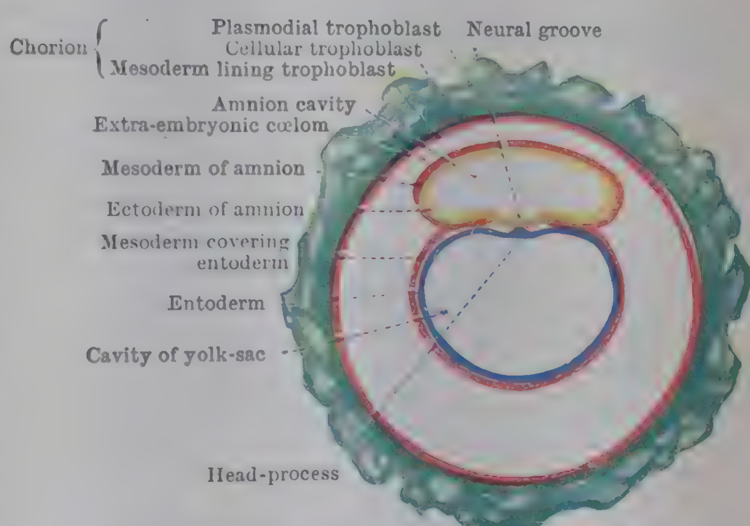


FIG. 91.—TRANSVERSE SECTION OF ZYGOTE ALONG LINE B IN FIG. 58.

After a time the arteries are reduced to a single pair, and the pair become converted into a single trunk, which passes through the umbilical orifice along the vitello-intestinal duct to the yolk-sac (Fig. 104). After the umbilical cord is formed, the extra-embryonic parts of the vitelline veins disappear and can no longer be traced in the cord. The same fate overtakes the vitelline artery—all except the portion of its intra-embryonic part which persists as the *superior mesenteric artery.*

Allantois.—The human **allantois**, like the yolk-sac, is a greatly reduced structure. In its relation to the chorion and the formation of the placenta, it too

may be considered an evolutionary vestige; but it cannot disappear entirely, for it is the basis of the development of the urinary bladder (pp. 73, 790). The allantoic diverticulum grows into the body-stalk but stops short of the chorion (Fig. 90); it arises from the primary entodermal vesicle and so appears at first to come from the yolk-sac; but its site of origin is included in the tail-fold of the embryo and so is transferred to the ventral wall of the cloacal part of the hind-gut (Figs. 69-

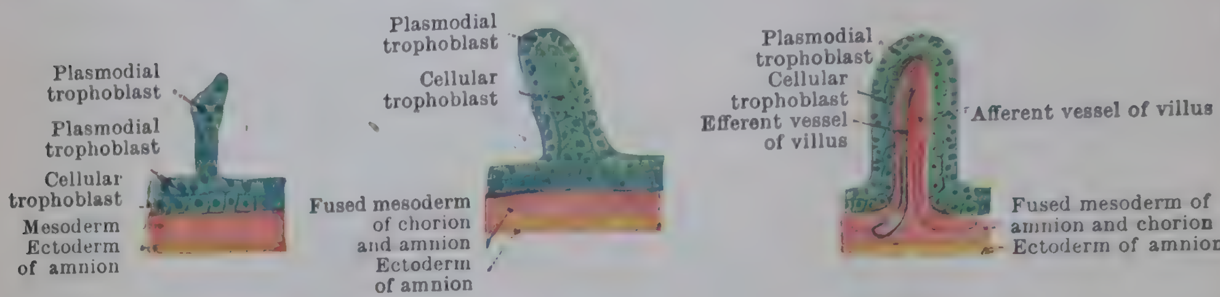


FIG. 92.—THREE STAGES IN THE FORMATION OF A CHORIONIC VILLUS.

71). The allantois is included in the umbilical cord, where it shrivels and disappears. It does not contribute directly to the formation of the urinary bladder, but it determines the site of the separation of the urogenital chamber from the cloaca (p. 73); and it is at first continuous with the *urachus*, which becomes the median umbilical ligament.

Chorion.—When the human blastocyst is first implanted in the endometrium, its wall consists solely of trophoblast (Figs. 39, 40); but the primary mesoderm soon appears and, after the formation of the secondary yolk-sac (p. 42), the **extra-embryonic cœlom** splits the primary mesoderm into two layers—one lining the inner surface of the trophoblast and the other covering the outer surfaces of the two inner vesicles (Figs. 90, 91).

The trophoblast and its lining of mesoderm together constitute the **chorion**, and the essential function of that membrane, in addition to providing an outer protective sac within which the embryo may develop in its amnion, is the formation of the **placenta**. The development and vascularization of the **chorionic villi**, and the separation of the chorion into placental and non-placental regions, are described with the account of the formation of the placenta itself (p. 81).

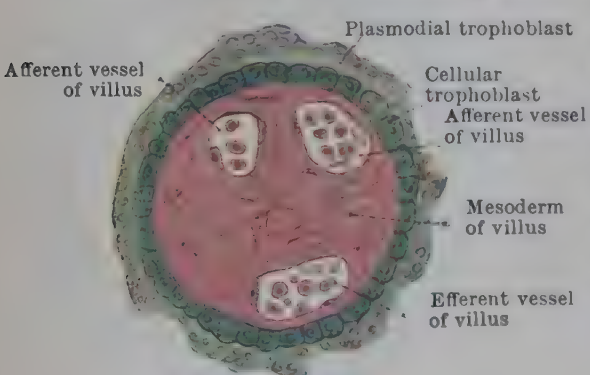


FIG. 93.—TRANSVERSE SECTION OF A SECONDARY CHORIONIC VILLUS. A loop of the afferent vessel has been cut at two points.

Body-Stalk and Umbilical Cord.—It has been explained (p. 42) that the mesoderm of the median part of the caudal portion of the amnion retains its connexion with the chorion and becomes thickened to form the **body-stalk**. In the thickened strand lies the allantoic diverticulum of the entodermal vesicle (Fig. 83), whilst through it, on each side of the allantois, pass the umbilical arteries and veins, by means of which blood is conveyed between the embryo and the chorion. It is important to note that the blood-vessels which thus pass through the body-stalk enter or leave the body of the embryo through the umbilical orifice, which is, at first, a relatively large aperture (Figs. 71, 104).

As the embryonic area is folded into the form of the embryo the amnion increases in extent, filling more and more of the extra-embryonic cœlom, and the embryo rises into its cavity. In other words, the walls of the amnion bulge ventrally round the ends and the lateral borders of the embryo (Figs. 70, 71, 96). As the distension of the amnion still continues, the ventral bulging round the margin of the umbilical orifice becomes more pronounced, the yolk-sac is forced farther and farther away from the embryo, the vitello-intestinal duct is elongated and it is surrounded by

a tube of mesoderm. The cavity that is present in this tube for a time—the proximal part of it becomes the umbilical sac—is an elongated part of the extra-embryonic cœlom, and its walls are covered by the amnion (Figs. 86-88). The caudal wall of the tube necessarily consists of the elongated body-stalk.

Umbilical Cord.—As the distension of the amnion still continues, the walls of the tube are forced against the vitello-intestinal duct, and the amniotic mesoderm fuses with the mesoderm surrounding that duct. When the fusion is completed, a solid cord—the **umbilical cord**—is formed (Figs. 97, 98, 100). It consists of an external covering of amniotic ectoderm, and a core of mesoderm in which lie the two umbilical arteries, a single umbilical vein formed by the fusion of the two primitive umbilical veins, and the remains of the vitello-intestinal duct and the vitelline vessels. One end of the umbilical cord is connected with the embryo; the other end is attached to the chorion. Near this attachment, in the mesoderm of the chorion, lies the yolk-sac, now a relatively small vesicle; and the allantois, continuous with the urachus of the urogenital chamber, projects into the cord from the embryo (Figs. 87, 97). For some time, too, the part of the cord where it springs from the belly of the embryo is distended by the *umbilical sac*, a portion of the cœlom in which the intestines develop (p. 72).

As the amnion grows still larger, all that part of its outer surface which does not take part in the formation of the umbilical cord is ultimately pressed into contact with the inner surface of the chorion, with which it fuses, and the cavity of the extra-embryonic part of the cœlom is thus obliterated (Fig. 98).

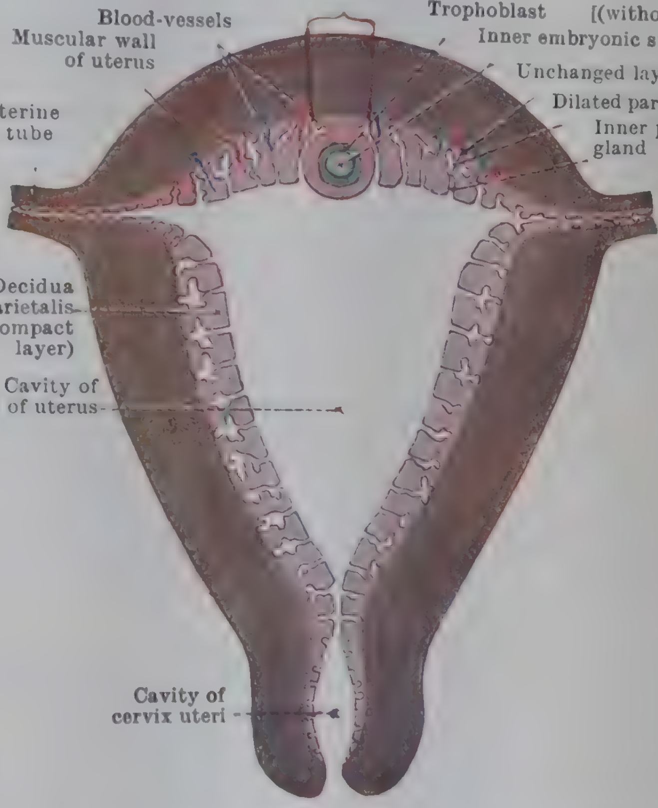


FIG. 94.—DIAGRAMMATIC CORONAL SECTION OF UTERUS, showing the various parts of the decidua and a zygote embedded in it.

The outer wall of the complete vesicle now consists of the fused chorion and amnion, and contains in its interior the amniotic cavity and the embryo, which is attached to the chorion by the umbilical cord.

When the umbilical cord is first formed it is comparatively short, but as the amniotic cavity increases the cord elongates, until it attains a length of from 18 to 20 inches (45 to 50 cm.); it then allows the embryo to float freely in the fluid in the amniotic cavity, whilst its nutrition is provided for by the flow and return of blood, through the umbilical cord, to and from the placenta, where interchanges take place between the maternal and the fœtal blood.

The Placenta.—The placenta is an organ developed for the purpose of providing the fœtus with food and oxygen, and removing the effete products produced by the metabolic processes which take place in the growing organism. It is formed partly from the chorion and partly from the mucous coat of the uterus, altered as explained below to form the uterine 'decidua'.

In the development of the placenta the blood-vessels of the fœtus and the blood of the mother are brought into intimate relation, so that free interchanges may readily take place between the two blood-streams; but the blood of the fœtus and

the blood of the mother are always separated from each other by two or more layers of fœtal cells.

The details of the early development of the human ovum are now almost completely known. It is highly probable that fertilization takes place in the lateral part of the uterine tube, that the zygote takes four to five days to pass along the tube, that it enters the uterus as a morula and begins to implant in six to seven days after ovulation (p. 34).

Endometrial Preparation.—The uterine mucous coat undergoes changes in preparation for the reception and retention of the zygote, and if implantation occurs the modified coat is known as the **uterine decidua.**[1]

The changes which take place, are, for the most part, hypertrophic in character. The vascularity of the mucous coat is increased, mainly by the dilatation of its capillaries. The tubular glands are elongated; they become tortuous, and dilatations form in their walls a short distance from their outer, closed extremities. At the same time the interglandular tissue increases in amount. As a result of the various changes the decidua is thicker, softer, more spongy, and more vascular than the endometrium during its resting phase.

Partly on account of the dilatation of the deep parts of the glands and partly on account of differences in texture of the internal and the external part of the decidua, the membrane is usually described as consisting of three layers:—(1) An internal layer, next the cavity, called the **stratum compactum.** (2) A middle layer—the **stratum spongiosum**—formed largely by the dilated parts of the glands. (3) An external **unchanged layer,** in which the comparatively unaltered outer ends of the glands lie.

These changes are an intensification of the periodic hypertrophy of the uterine mucous membrane which precedes menstruation. During menstruation the superficial part of the mucous coat disintegrates, and the whole of the stratum compactum with much of the stratum spongiosum is cast off. Repair ensues; and then the endometrium is built up again to the premenstrual state under the influence of the internal secretions, or hormones (p. 799)—*œstrin* and *progestin*—produced by the growing ovarian follicle and by the corpus luteum, the structure formed from the ruptured follicle after ovulation (p. 772). The evidence that ovulation occurs about 14 days before the expected onset of the next menstruation (Rock & Hertig, 1944, 1948) is reviewed by Davies (1948). This relation is of great importance in estimating the age of young embryos. If the ovum is not fertilized, the corpus luteum begins to degenerate, menstruation occurs, and thereafter the corpus luteum atrophies; but, if fertilization takes place, the corpus luteum grows and its increased secretion of progestin induces the final changes in the mucous coat, constituting the *decidual reaction,* which prepare it for the reception of the zygote. For further information the student should consult Marshall (1950), the chapters on reproductive physiology in standard text-books of Physiology or Obstetrics, or the account of the preparation of the uterus for the reception of the fertilized ovum in the special works on Human Embryology.

Implantation and Formation of Placenta.—When the zygote, in the morula stage, reaches the uterus, it acts as a parasite: it eats its way through the epithelium on the surface of the decidua, and implants itself in the stratum compactum (Figs. 39, 40). It may penetrate the decidua at any point of the wall of the uterine cavity; but it usually enters at some point of the dorsal or the ventral wall, and, pushing the glands aside, it is soon surrounded by the interglandular tissue of the stratum compactum of the decidua (Fig. 42). The aperture through which it passes is closed by proliferation of a portion of the trophoblast which acts as a sealing plug—the *operculum* (Teacher, 1924) (Fig. 41); and there is sometimes a *closing coagulum,* which may be partly blood-clot, superficial to the operculum and projecting from the aperture (Figs. 41, 47).

The portion of the decidua in which the zygote is embedded soon becomes thicker than the other parts of the membrane, and it is separated by the zygote into an internal part, called the **decidua capsularis,** and an external part—the **decidua basalis.** The remainder of the decidua—by far the larger portion—is the **decidua parietalis** (Fig. 95).

[1] A term based on the former belief that it has a larger share in the formation of the placenta and is to a great extent 'cast-off' when the placenta is detached.

As soon as the zygote becomes embedded in the decidua its trophoblast undergoes rapid proliferation and becomes multicellular wherever it is in direct contact with maternal tissue; and presently it differentiates into two layers—an inner cellular layer or **cytotrophoblast**, and an outer syncytial layer or **plasmoditrophoblast**. In the plasmodial layer cell-territories are not defined—an indication of intense growth-activity—and it consists therefore of multinucleated protoplasm.

As development proceeds, the trophoblast increases in thickness and continues to invade and destroy the decidua, probably by enzyme action. At this stage the decidual reaction becomes apparent. Its characteristic feature is the multiplication of the connective-tissue cells of the endometrium which become swollen and 'epithelioid' in appearance. These *decidual cells* (Figs. 43, 48) contain glycogen and lipoids, and they congregate in close proximity to the advancing trophoblast. Many of the decidual cells are engulfed by the trophoblast and doubtless they provide it with food-material; but it is generally believed that they act also as a defensive barrier against excessive penetration of the uterus by the trophoblast. If the balance between trophoblast and decidua

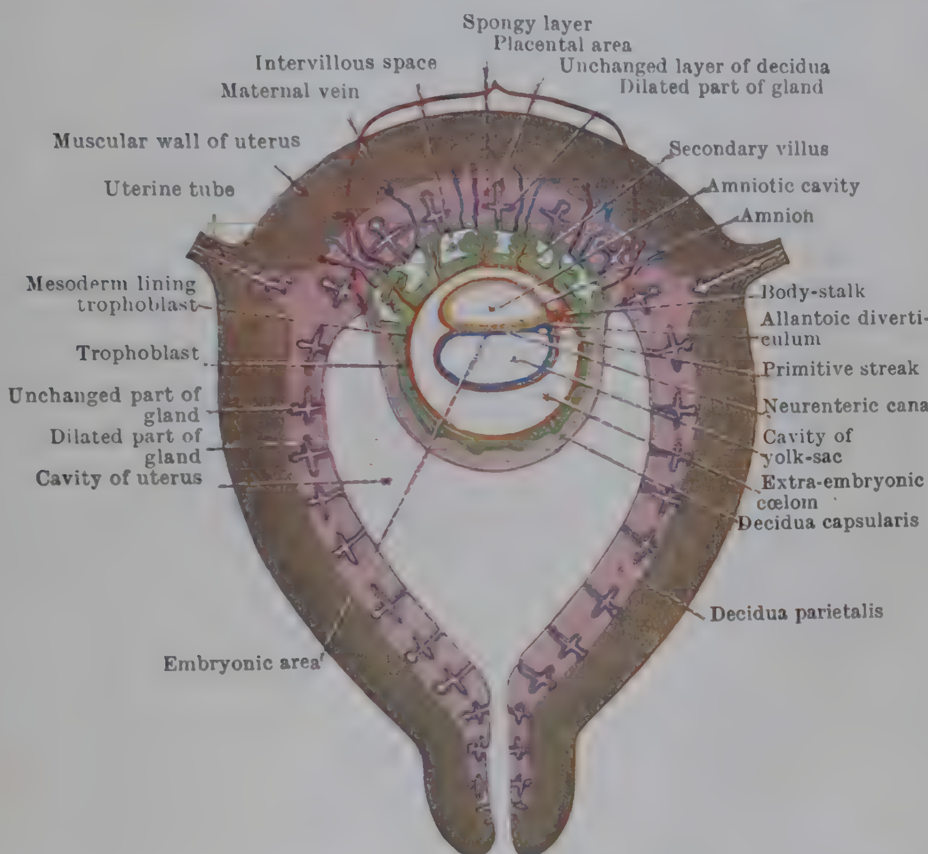


FIG. 95.—DIAGRAMMATIC CORONAL SECTION OF PREGNANT UTERUS AFTER THE FORMATION OF THE INTERVILLOUS SPACES.

is upset, then invasion may proceed without check—a rare occurrence that may result in a *chorionepithelioma*, one of the most malignant tumours known—or, on the other hand, the zygote may fail to implant properly and be cast off as an early *abortion*.

As the invasion of the decidua extends, the plasmoditrophoblast erodes the walls of maternal blood-vessels and itself becomes permeated with *lacunae* or spaces into which the maternal blood flows. The maternal blood thus begins to circulate slowly through the spaces in the trophoblast, the essential feature of the *haemochorial* type of placenta (p. 75).

The spaces in the plasmodium enlarge rapidly after the maternal blood begins to circulate within them, and the trophoblast becomes divided into three series of parts: (1) The **primary chorionic villi**, which lie between adjacent blood-spaces; (2) The parts which lie in contact with the mesoderm of the chorion and form, with the mesoderm, the **chorion-plate**; (3) The **basal layer**, composed of parts whch cover the maternal tissues and form the outer boundaries of the blood-spaces. The lacunar blood-spaces themselves are then called the **intervillous spaces** (Figs. 97, 99).

After a time each primary villus differentiates into a cellular core and plas-

modial periphery, and thereafter the villi are invaded by the mesoderm of the chorion and are thus converted into **secondary chorionic villi** (Figs. 95-97).

The first-formed villi are non-vascular, but by the time the secondary villi have developed the umbilical arteries have grown through the body-stalk into the mesoderm of the chorion, and branches from them enter the mesodermal cores of the villi, which thus become vascular. The secondary villi consist, therefore, of a mesodermal core, continuous with the mesoderm of the chorion and covered by a layer of cellular trophoblast (*Langhan's layer*) and a layer of plasmodium.

The proximal end of each villus is continuous with the chorion-plate of the intervillous spaces, formed by the chorion; the distal end is connected with the plasmodial basal layer of the trophoblast, which forms the outer boundary of the intervillous spaces and is fused with the maternal decidual tissue.

After a time the secondary villi send out numerous branches into the intervillous spaces, and thus increase greatly in complexity (Figs. 95-97). In this way two sets of secondary villi are differentiated :—(1) The **anchoring villi** which cross from the chorion to the basal layer of the trophoblast—they are attached to the basal layer of the trophoblast by cell-columns which are the outer parts of the primary villi not yet invaded by the embryonic mesoderm; (2) **Free or absorbing villi** which extend from the sides of the original secondary villi into the blood in the intervillous spaces (Figs. 97, 99).

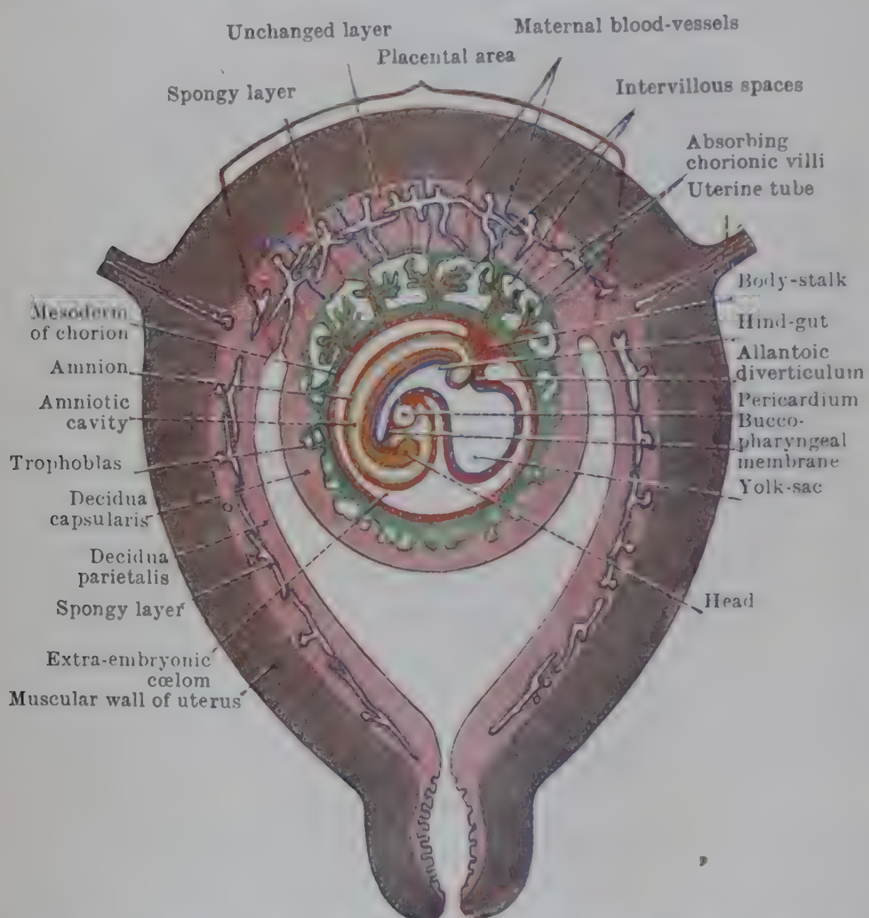


Fig. 96.—Diagrammatic Coronal Section of Pregnant Uterus at Period of Formation of Embryo. Note extension of amnion compared with stage shown in Fig. 95.

While the trophoblastic invasion of the compact layer of the decidua is proceeding, not only are the interglandular elements of the decidua destroyed, but the walls of the glands also; as a consequence, some of the glands in the decidua basalis open for a time into the intervillous spaces, and they become filled with blood which passes from the spaces into the cavities of the glands (Fig. 47). Frequently, however, before the glands are destroyed, their walls are converted into solid strands of cells, and thus the cavities of their more external undestroyed portions may become closed spaces.

The development of the chorionic villi does not proceed equally, however, in all parts of the membrane. As already noted, the trophoblast begins to thicken only where it is in direct contact with the uterine tissues. The embryonic pole of the blastula, which advances into the endometrium, is first affected and that region of the chorion, related to the body-stalk of the embryo—through which vascular connexions are established—maintains the lead thus acquired (Figs. 39-44). As implantation proceeds and the endometrium closes over the abembryonic surface of the zygote as it sinks deeper, the trophoblast reacts on that surface also and, for

a time, the whole surface of the chorion is covered with villi. But the supply of maternal blood is naturally less in the capsular portion of the decidua and is progressively diminished as the chorionic vesicle continues to expand, and the villi in that region undergo atrophy and disappear. When these degenerative changes have occurred, the portion of the chorion in association with the thinned decidua capsularis presents a relatively smooth surface and is known as the **chorion læve.** In the meantime the decidua basalis increases in thickness, and the villi associated with it increase in size and in the complexity of their branches. The portion of the chorion from which these large villi spring is termed the **chorion frondosum.**

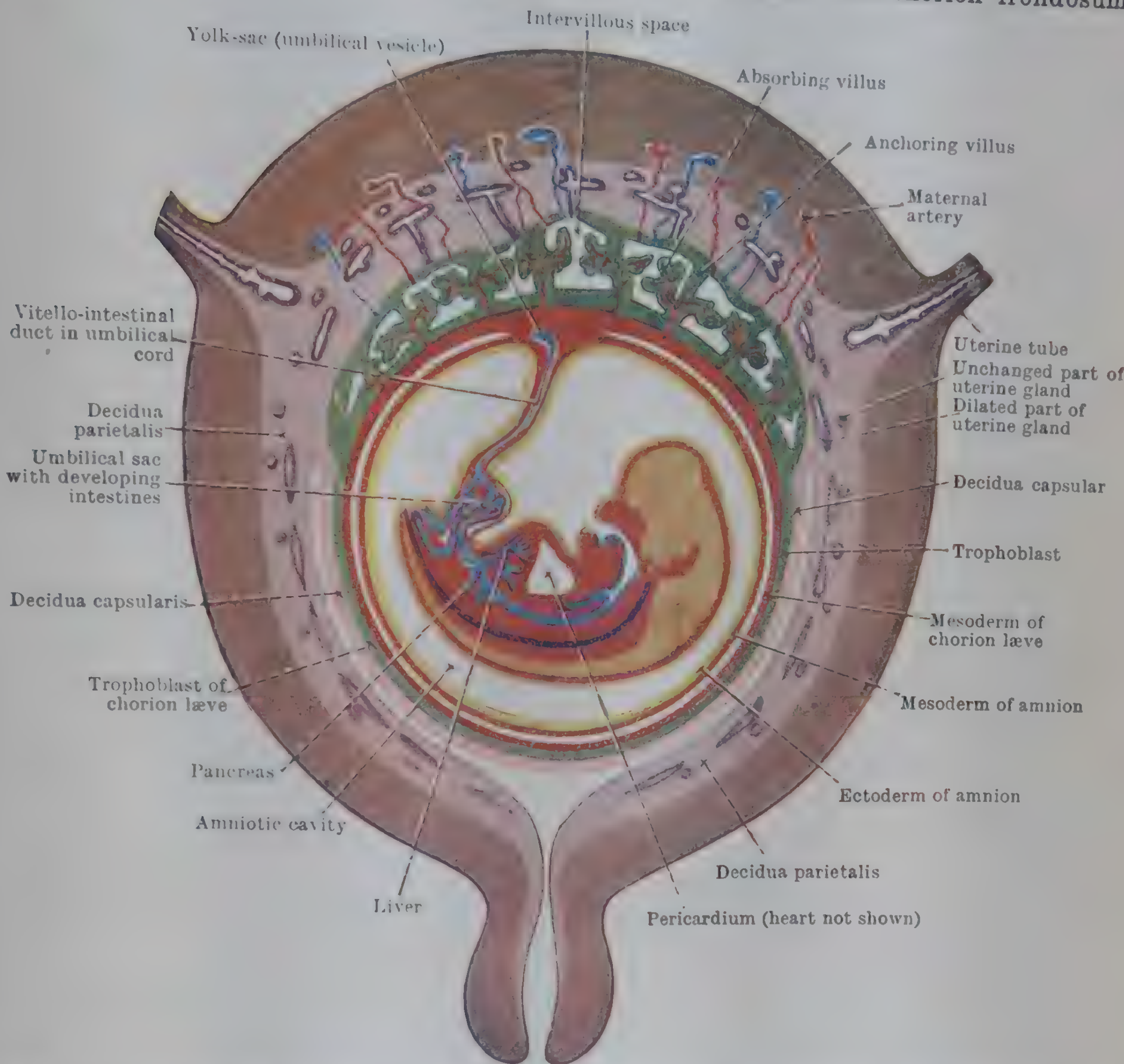


Fig. 97.—Diagrammatic Coronal Section of Pregnant Uterus after Formation of Umbilical Cord. Note that the expanding amnion has almost obliterated the part of the extra-embryonic cœlom which lies between it and the chorion. Cf. Fig. 121a, p. 101.

It is this portion of the chorion which takes part in the formation of the **fœtal portion** of the placenta, the **maternal (uterine) part** of that organ being formed by **the decidua basalis.**

The placenta, therefore, is formed mainly by the chorion frondosum and to a small extent only by maternal tissues; and the interchanges between the fœtal and the maternal blood take place in the substance of the fœtal part of the placenta through the trophoblast which covers the surfaces of the villi.

As the growth of the embryo and the distension of the amnion continue, the amnion is gradually forced against the chorion and fuses with it (Fig. 121 A, p. 101). When fusion is complete the extra-embryonic cœlom is obliterated and the zygote contains only one extra-embryonic cavity—the amniotic cavity—which contains the fœtus surrounded and supported by the amniotic fluid (Fig. 98).

At this period the cavity of the amnion is bounded by a wall composed of the

fused amnion, chorion, and decidua. As the distension of the amnion proceeds to a still greater extent, the part of the wall of the cavity formed by the fused amnion, chorion læve and decidua capsularis bulges more and more into the cavity of the uterus, until it is forced against the surrounding wall of the uterine cavity, where it fuses with the decidua parietalis, and thus the cavity of the uterus is obliterated. This fusion takes place towards the end of the second month, and as soon as it has occurred the discoid mass of placental tissue is continuous at its margin with the fused amnion, chorion, and decidua parietalis (Fig. 98).

After the second month the fœtus lies in the *amniotic cavity*, which is bounded by the fused chorion and uterine wall, except at the lower end of the uterus, over the internal os uteri, where the cavity of the body of the uterus communicates with the canal of the cervix; there the amniotic cavity is bounded by a membrane formed by the fused amnion, chorion læve, and the decidua capsularis only.

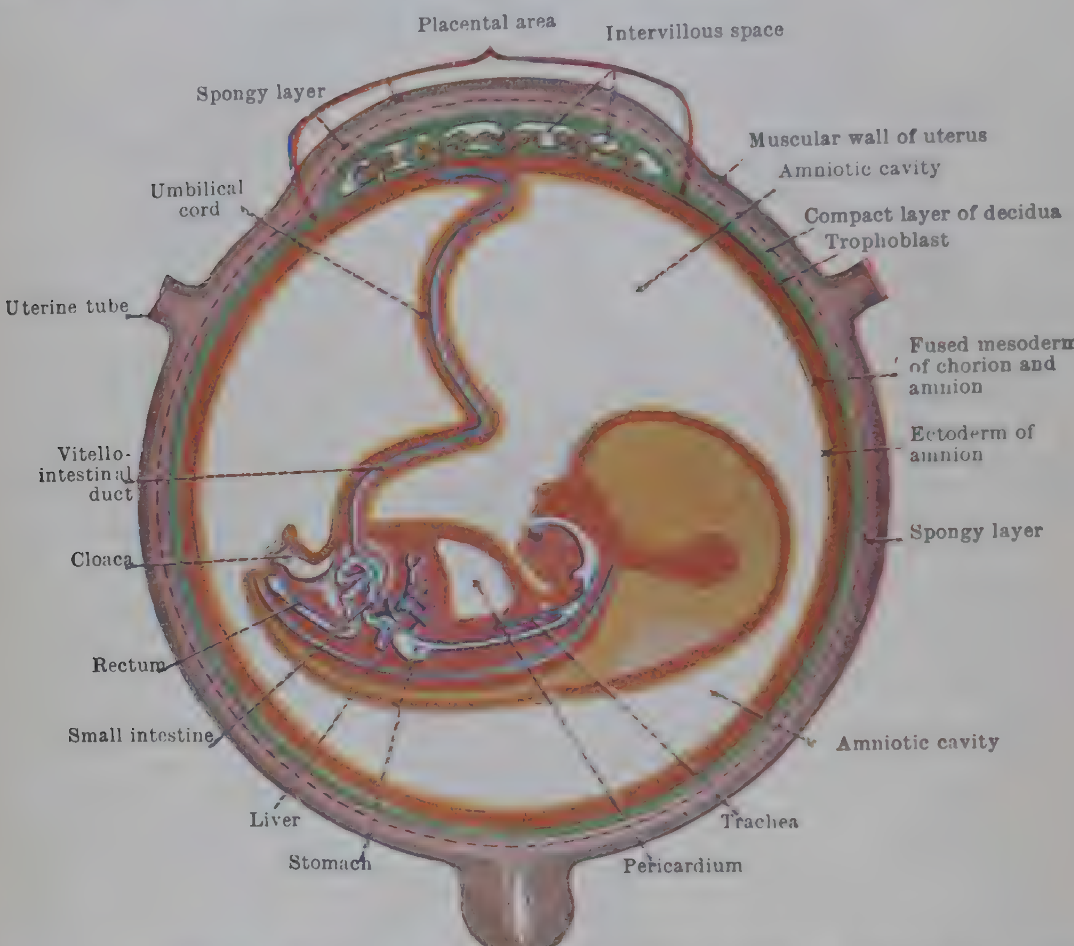


FIG. 98.—DIAGRAMMATIC SECTION OF PREGNANT UTERUS AFTER FUSION OF AMNION AND CHORION.

Completion of Placenta.—It has already been stated that each absorbing villus consists of a vascular, mesodermal core covered by a cellular and a plasmodial layer of trophoblast, the latter lying next the maternal blood in the intervillous spaces. As development proceeds and the intervillous spaces become larger, the villi become longer and more complicated, and at the same time the cellular layer of the trophoblast largely disappears, until in the majority of the villi the plasmodial layer alone covers the mesodermal core.

In still later stages, degeneration occurs not only in the villi, but also in the chorionic plate of the intervillous spaces and in the basal trophoblast which closes the spaces externally. One of the results of the degenerative processes is the deposit of fibrinoid material in the place originally occupied by the trophoblast: the fibrinous layers on the surfaces of adjacent villi adhere together, and the villi thus connected fuse into masses of intermingled fibrinous and vascular tissue.

When the fœtal (chorionic) part of the placenta is completed it consists of:—(1) the chorion plate closing the intervillous spaces internally; (2) the villi; (3) the intervillous spaces; and (4) the basal layer of the trophoblast, which closes the intervillous spaces externally and is perforated by the maternal vessels passing to and from the spaces.

The maternal (uterine) portion of the completed placenta consists from within out-

wards of :—(1) the basal layer of the decidua ; (2) the remains of the spongy layer of the decidua ; and (3) the unchanged layer (Fig. 99).

The basal layer of the decidua is the remains of the compact part of the decidua basalis of earlier stages. It is fused internally with the basal plate of the trophoblast, and is continuous externally with the spongy layer. The spongy layer contains a series of cleft-like spaces. These spaces are the cavities of the compressed remains of the earlier dilated portions of the glands of the stratum spongiosum from which the epithelial lining has to a great extent disappeared. The spongy layer is continuous externally with the unchanged layer, in which the unaltered outer parts of the glands and the intervening interglandular tissue lie.

The maternal blood-vessels pass from the muscular wall of the uterus directly into the placenta, where they traverse the maternal portion and the basal plate of the tropho-

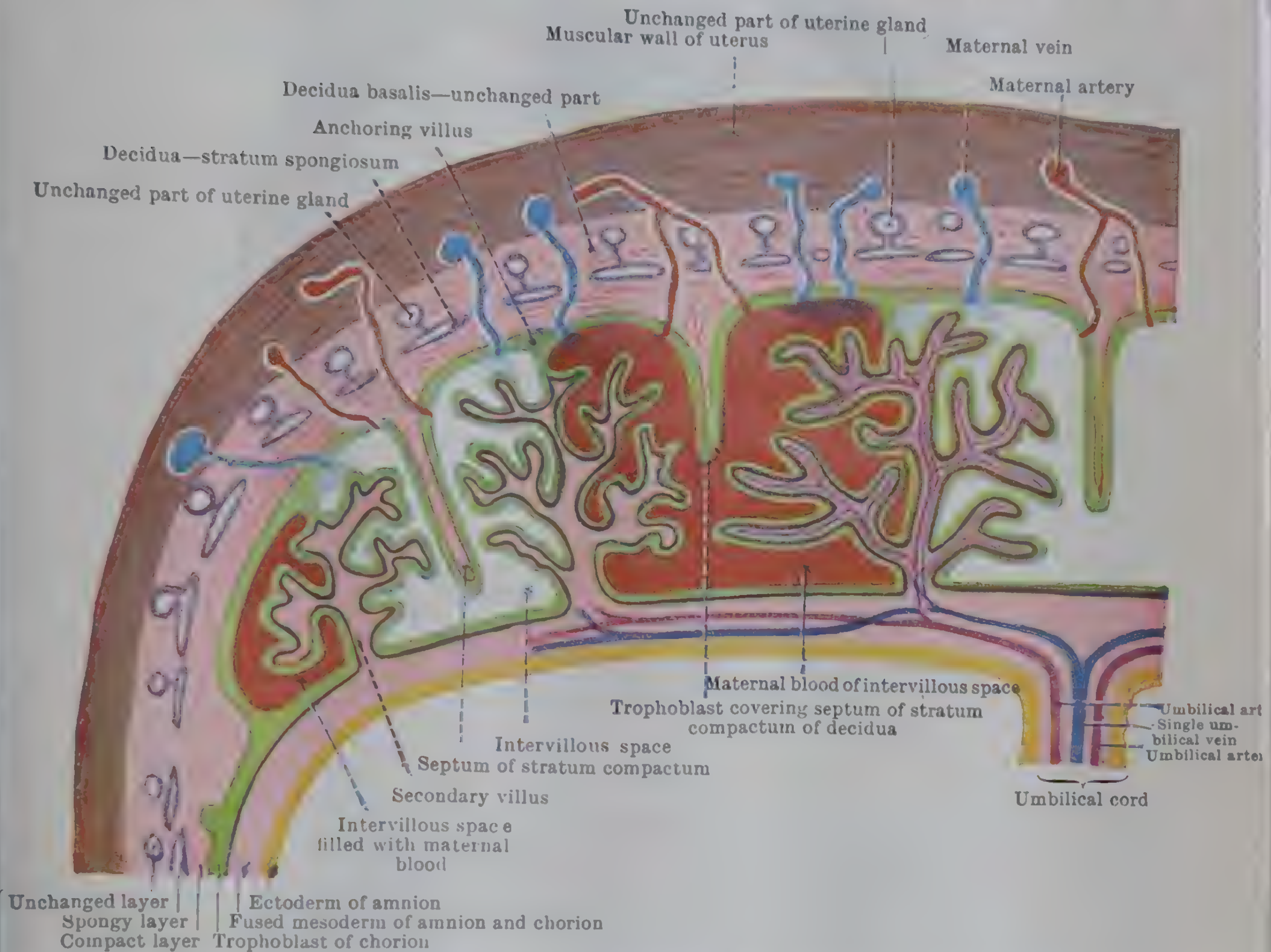


FIG. 99.—DIAGRAM OF STRUCTURE OF COMPLETED PLACENTA. The marginal sinus is not shown in the figure.

blast and open into the intervillous spaces. The arteries usually open on or near the septa and the veins begin in the areas between them. The veins of the pregnant uterus are greatly enlarged, and around the edge of the placenta there is a more or less complete venous space, called the *marginal sinus*, into which many of the maternal veins open ; it is believed by some observers that the greater part of the drainage of the intervillous spaces take place through the marginal sinus (Falkiner, 1939).

In addition, however, to the constituent parts already described, the fœtal part of the placenta contains some strands of maternal tissue, and in the maternal part there are portions of trophoblast.

The parts of the decidua found in the fœtal part of the placenta are a series of fibrous strands—the remains of parts of the stratum compactum which were not destroyed by the trophoblastic invasion. They form incomplete septa which serve to separate the placenta into lobes or *cotyledons*—from 15 to 20 in number. The cotyledons are spoken of as 'placental units' since each contains a main 'villous trunk' from which the free villi branch in the manner of a tree (Fig. 99). Recently it has been stated that most of the free villi take a recurved course back towards the chorion (Spanner, 1935) so that the whole system resembles a 'weeping willow' (Johnstone, 1945).

development proceeds, for the original plexuses are transformed into distinct stems and branches of varying size and importance. Therefore two groups of events in the development of the vascular system have to be considered—the evolution of the different kinds of blood-corpuscles and the development of the main embryonic blood-vessels.

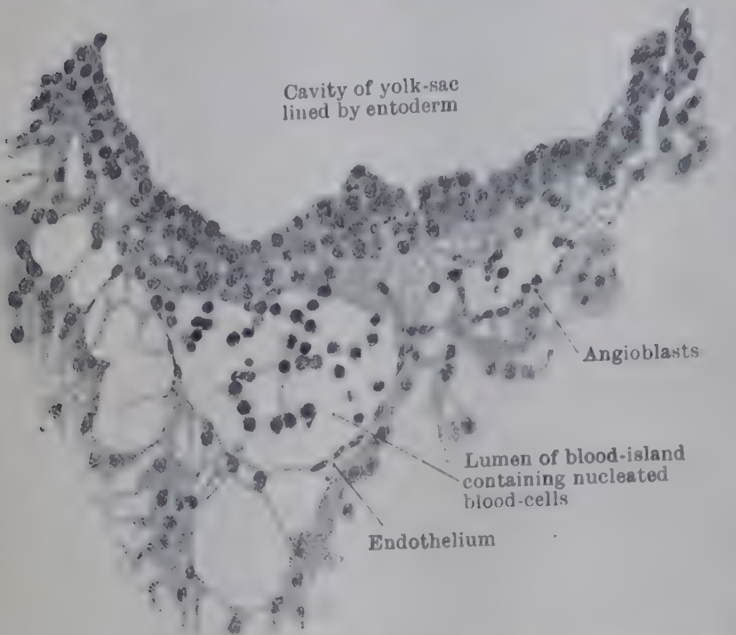


FIG. 101.—SECTION OF WALL OF YOLK-SAC OF YOUNG HUMAN EMBRYO (THIRD WEEK) SHOWING BLOOD-ISLANDS DEVELOPING IN THE MESENCHYME. × 250. (Thompson & Brash, 1923.)

Development of Blood-Corpuscles. — Numerous researches have been made with the object of discovering the mode of origin of the different kinds of blood-corpuscles, but there is as yet no general agreement either with regard to their exact genesis or to the terminology to be used in describing the stages through which they pass. This is indeed "one of the most controversial subjects in histology" (Maximow & Bloom, 1948).

The view that the angioblast is the parent-cell not only of the endothelium of blood-vessels but also of all the blood-corpuscles both red and white has been elaborated by Maximow (1924). It implies either that blood-formation in the growing embryo and fœtus takes place by the development of angioblastic cells from the mesenchyme in the same way as on the yolk-sac, or that the stem-cells that give rise to all the varieties of blood-corpuscles (*hæmocytoblasts*) are carried from the yolk-sac into the embryo to multiply there.

According to Sabin (1922), the angioblast produces the endothelium from which, by *intravascular* budding, only the red blood-corpuscles are derived. All the ordinary white corpuscles of the blood have an *extravascular* origin from a common progenitor —itself derived from the mesenchyme—called a *reticular cell*, by differentiation along special lines. A special kind of white corpuscle, few of which, however, are found in the blood-stream and most in the connective tissues, called a *clasmatocyte* or *histiocyte*, also is said to arise from the endothelium. The histiocytes, the reticular cells of reticular tissue and endothelium in certain situations all belong to the reticulo-endothelial system (pp. 12, 831).

The red blood-corpuscles pass through several stages to maturity; the original nucleated cells (*erythroblasts*) become laden with hæmoglobin, pass through a *normoblast* stage (in which the nuclei are contracted) and after the extrusion of their nuclei become *erythrocytes* or mature red blood-corpuscles.

This process goes on throughout life; it begins in the wall of the yolk-sac, is very active in the liver from the third month onwards, and occurs in the spleen in the later stages of intra-uterine life. When ossification begins, blood-formation is actively carried on in the developing bone-marrow; and after birth the continuous formation of red blood-corpuscles is entirely confined to that special hæmopoietic (blood-forming) tissue.

The three main kinds of white blood-corpuscles are *polymorphonuclear leucocytes, monocytes, and lymphocytes*. The bone-marrow is the great factory of the first two kinds (and their varieties) but the lymphocytes, which are relatively late in appearing, are formed in lymphoid (adenoid) tissue wherever it may be situated—in the spleen, in the mucous coat of the alimentary canal, and in the lymph-glands. All these cells reach the blood-stream by passing through the endothelial walls of blood-capillaries, but lymphocytes also reach it in great numbers *via* the lymph-vessels after the formation of lymph-glands.

In very young embryos both immature and mature blood-cells are present in the blood-stream, the mature cells being developed from the immature in the stream; but after bone-marrow and lymphoid tissue have been formed the proportion of immature cells decreases. After birth only mature erythrocytes pass into the blood-stream; but

under pathological conditions, in which there may be excessive formation of red corpuscles in the bone-marrow, immature reds (normoblasts) may again appear in the blood.

For discussions of the origin of the blood-corpuscles see Downey (1938) and Piney (1939).

Formation of Primitive Blood-Vessels.—It has been pointed out that in the yolk-sac area of the entodermal vesicle a plexiform system of tubes, filled with fluid and corpuscular elements, is formed from angioblastic cells (Fig. 101).

Similar but less easily demonstrated plexuses are formed in the mesenchyme of the body-stalk, and of the chorion, and also later in the embryonic area.

It is probable that the various plexuses become connected with one another very soon after they appear, so that a continuous capillary network is formed. By enlargement in some places and diminution in others the general vascular network becomes more open, and from this *retiform* arrangement by further enlargement of definite channels there are evolved what may be called the primitive stem-vessels of the embryo, through which the blood circulates from one area to another.

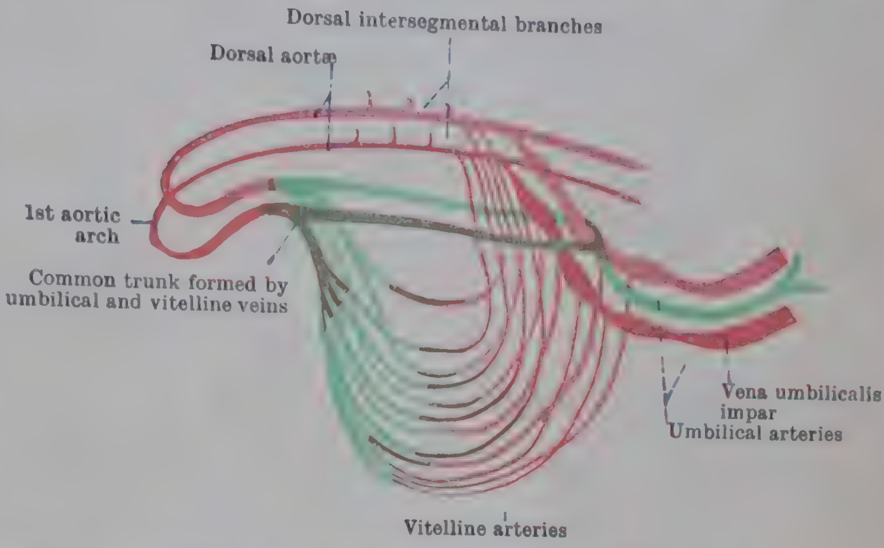


FIG. 102.—SCHEMA OF VASCULAR SYSTEM OF AN EMBRYO, 1·35 MM. LONG, WITH SIX SOMITES. (After Felix, 1910, modified.)

In the embryonic area a pair of main stem-vessels are first differentiated; they are the **primitive aortæ**. These vessels appear in the splanchnic mesoderm of the pericardial region of the embryonic area, whence they extend to the caudal end of the area.

At their cephalic ends the primitive aortæ are continuous with another pair of stem-vessels called the **vitelline veins**, which emerge from the vascular plexus in the wall of the yolk-sac.

As the aortæ pass tailwards in the embryonic area, ventral to the paraxial bars of mesoderm (see p. 50), they give off a ventral series of paired branches, called **vitelline arteries**, which terminate in the vascular plexus in the yolk-sac wall (p. 77); and from the caudal and dorsal part of that plexus, represented in Fig. 102 by a series of dilatations, a pair of vessels—the **umbilical arteries**—pass along the body-stalk to the vascular plexus in the chorion. Another stem-vessel, called the **vena umbilicalis impar**, begins in the vascular plexus in the chorion and passes along the body-stalk to the caudal margin of the embryonic

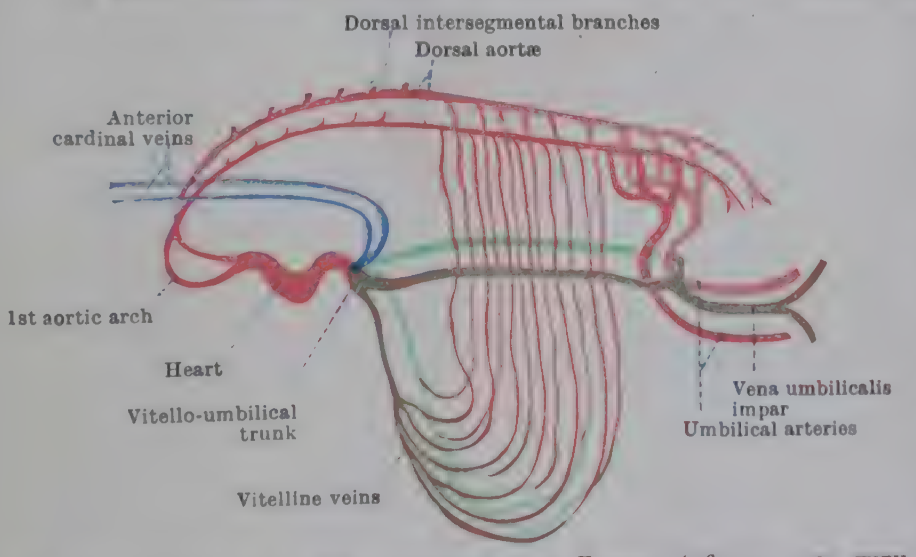


FIG. 103.—SCHEMA OF VASCULAR SYSTEM OF AN EMBRYO, 2·6 MM. LONG, WITH FOURTEEN SOMITES (arteries after Felix, 1910, modified).

area, where it divides into *right* and *left umbilical veins.* These two umbilical veins run along the corresponding margins of the embryonic area and fuse with the corresponding vitelline veins at the points where the latter join the primitive aortæ, forming with them **vitello-umbilical trunks.** Therefore, when rhythmic contraction begins in the pericardial portions of the primitive aortæ, the blood is driven through the primitive aortæ and passes through their vitelline and umbilical branches to the yolk-sac and the chorion, whence it is returned to the aortæ by the vitelline and umbilical veins.

In the meantime lateral branches have been given off from the primitive aortæ, and in later stages, as the mesodermal somites are defined, they become the intersegmental arteries (Fig. 105); but for a time no purely intra-embryonic veins are distinguishable.

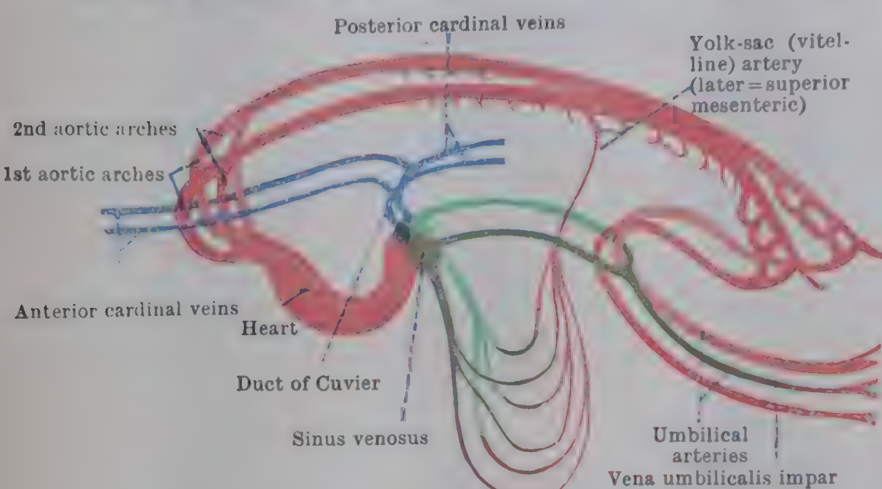


FIG. 104.—SCHEMA OF VASCULAR SYSTEM OF AN EMBRYO WITH TWENTY-THREE SOMITES (arteries after Felix, 1910, modified).

As the head-fold is formed and the pericardial region is turned over into the ventral wall of the fore-gut (see p. 55), the cephalic parts of the primitive aortæ are carried ventrally in the fold, and so are bent into the shape of hooks. That condition is well seen in an embryo of 1·35 mm. length which had six mesodermal somites (Fig. 102).

Three parts of each primitive aorta are now defined: the short, ventral limb of the hook is the *primitive ventral aorta*; the long or dorsal limb is the *primitive dorsal aorta.* The bend, which connects the two limbs, is the *first aortic arch*; it runs along the side of the bucco-pharyngeal membrane in the substance of the mandibular arch. What were previously the cephalic ends of the primitive aortæ have now become the caudal ends of the primitive ventral aortæ; they lie in the substance of the septum transversum—the bar of mesoderm which separates the pericardial cavity from the extra-embryonic cœlom at the cephalic margin of the umbilical orifice—and in that situation the common vitello-intestinal venous trunks are continuous with the primitive aortæ.

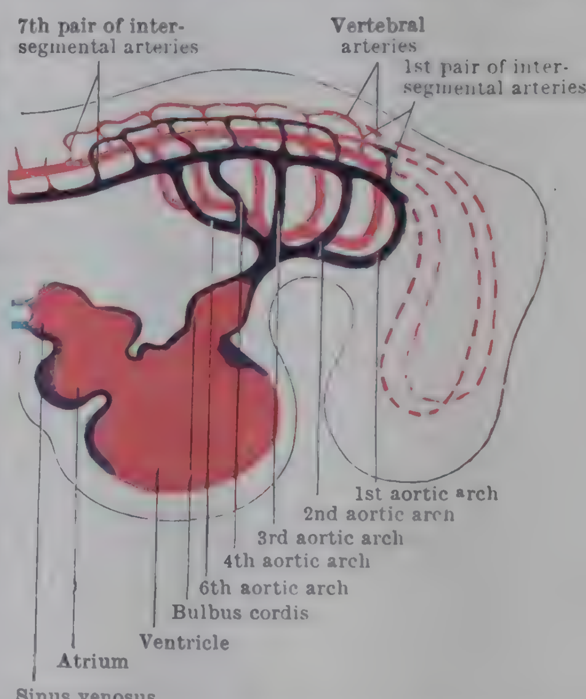


FIG. 105.—DIAGRAM SHOWING 5 MM. STAGE WITH FIVE AORTIC ARCHES. At this stage, as the 6th arch develops, the 1st and 2nd atrophy and disappear.

Three further important changes take place in the vascular system during the time in which the embryo grows a little more than another millimetre in length, and the tail-fold and lateral folds are formed and the number of its mesodermal somites increases to fourteen pairs.

(1) The caudal parts of the primitive ventral aortæ fuse together to form a single, median, tubular heart, which is divided by dilatations and constrictions into six parts, named, from the caudal, towards the cephalic end, the **sinus venosus** the **atrium**, the **atrio-ventricular canal**, the **ventricle**, the **bulbus cordis**, and the **truncus**

arteriosus. At the same time the heart increases in length more rapidly than the region in which it lies; it therefore becomes bent both in the longitudinal and the transverse direction, and its caudal and cephalic ends begin to come close together (Figs. 103, 104).

(2) The origins of the umbilical arteries are transferred from the vitelline plexus to the primitive dorsal aortæ from which they arise by three roots for each (Fig. 103).

(3) The **anterior cardinal veins** are defined (Fig. 103). They are the first pair of purely intra-embryonic veins. They begin in the head and end in the sinus venosus, which they enter, in the septum transversum, close to the common vitello-umbilical veins. They bring back to the heart the blood which has been distributed by the presegmental and intersegmental arteries to the head, neck, and headward part of the trunk of the embryo.

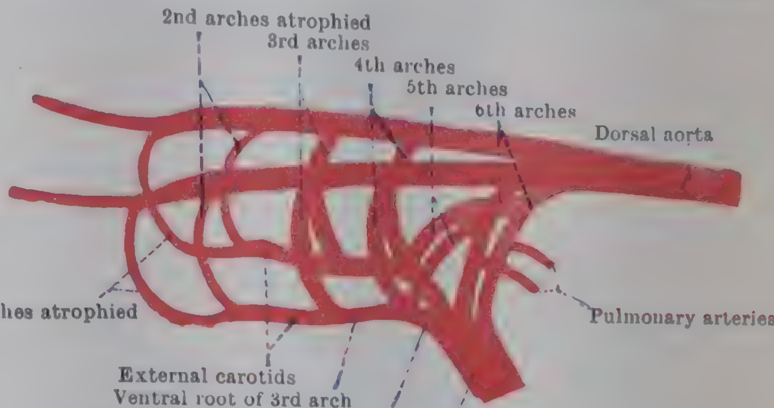


FIG. 106.—SCHEMA OF AORTIC ARCHES OF AN EMBRYO, 9 MM. LONG. (After Tandler, 1909, modified.) The first and second arches have atrophied and the transitory fifth has appeared.

Thereafter, numerous changes take place in the cardiac, the arterial, and the venous parts of the vascular system, and the rudiments of all the main blood-vessels of the adult are defined.

Heart.—The various chambers of the heart become more definitely demarcated (Fig. 105), the rudiments of the septa are formed by which the heart is divided into right and left sides, and valvular arrangements are developed.

Arteries.—The primitive dorsal aortæ fuse, from the region of the tenth (seventh cervical) somite tailwards, to form the permanent descending aorta (Fig. 104). The paired ventral or vitelline branches of the aortæ also fuse to form single trunks, and become reduced in number. In the abdominal region they are reduced to three main vessels—the cœliac artery, the superior mesenteric artery (which for a time passes to the yolk-sac as the vitelline artery) (Fig. 104), and the inferior mesenteric artery.

Branches are given off from the ventro-lateral aspects of the descending aorta to the rudiments of the nephric or urinary system, which are developed from the intermediate cell-mass, and to the rudiments of the genital glands.

Four additional pairs of aortic arches connecting the unfused portions of the primitive ventral and dorsal aortæ, appear in the following sequence, the second, the third, the fourth, and the sixth—the temporary fifth pair appearing later. These aortic arterial arches run in the *pharyngeal arches* of the embryo (p. 65), and they undergo a series of transformations as the arterial system of the thorax and neck develops. The first and second arches disappear, pulmonary arteries arise from the sixth arches (Fig. 106), and the truncus arteriosus divides so that a main pulmonary trunk communicates with the right side of the heart and the permanent aorta with the left side.

Veins.—Two additional pairs of intra-embryonic venous trunks are formed for the drainage of the hinder parts of the body.

The **posterior cardinal veins** (Fig. 104) appear in the thoracic and abdominal regions of the embryo dorso-lateral to the intermediate cell-mass.

They drain blood from the body-walls and from the nephric rudiments, and their cephalic ends join the anterior cardinal veins in the thoracic region at the point where the latter turn ventrally to enter the septum transversum (Fig. 104).

As soon as the union of the anterior and posterior cardinal veins is completed the parts of the anterior cardinals ventral to the points of union are called the **ducts of Cuvier**. The right duct later becomes the terminal part of the *superior vena cava*.

In the meantime the common vitello-umbilical venous trunks have been absorbed into the sinus venosus, and the vitelline and umbilical veins open independently into it; so that three pairs of veins now open into the sinus venosus of the heart.

The **subcardinal veins** appear in the abdominal region ventro-medial to the mesonephros—a large structure which contains nephric rudiments. They communicate both at their cephalic and caudal ends with the posterior cardinal veins.

In addition to the posterior cardinal and subcardinal veins still another pair of intra-embryonic veins is established at a later period in the abdominal and thoracic regions. They are called the **supracardinal veins** and they appear dorso-lateral to the descending aorta. All these veins are concerned in the complex manner of development of the *inferior vena cava.* (For the detailed development of the heart, the further history of the blood-vessels and the fœtal circulation see the Section on the Vascular System.)

CŒLOM AND DIAPHRAGM

Now that an outline of the formation of the body of the embryo and of the principal organs of the trunk—alimentary canal, respiratory system, excretory organs, heart and great vessels—has been given, the division of the cœlomic cavity into peritoneal, pleural and pericardial cavities and the manner in which these are separated from each other with the formation of the diaphragm may be considered.

The two parts of the cœlom—the extra-embryonic and the intra-embryonic—are derived independently as clefts in the mesoderm and are at first separate from each other (Figs. 64, B; 68); they become continuous, for a time, in the region of the umbilical orifice (Fig. 65, B), but are separated from each other again when the umbilical orifice closes. Later the extra-embryonic cœlom disappears, but the intra-embryonic remains as the cavities of the pericardium, pleura, and peritoneum.

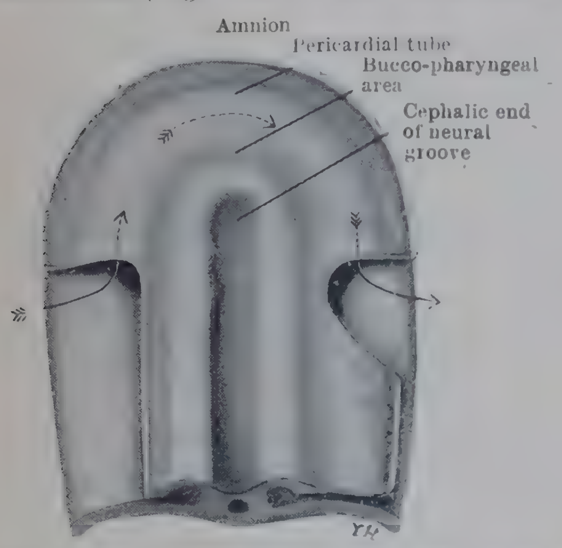


Fig. 107.—Schema of Intra-embryonic Cœlom seen from Dorsal Surface before folding of Embryonic Area. Portions of the somatopleure are cut away to show the continuity of the intra-embryonic cœlom of the two sides through the pericardial canal.

Extra-Embryonic Cœlom.—The formation of the extra-embryonic cœlom in the primary mesoderm has already been considered (p. 42). It is entirely obliterated when the outer surface of the expanding amnion fuses with the inner surface of the chorion (compare Figs. 96 and 97).

Intra-Embryonic Cœlom.—The intra-embryonic cœlom appears as a series of cleft-like spaces in the margin of the embryonic mesoderm (Fig. 68). The spaces fuse together to form a ∩-shaped cavity which divides the peripheral part of the embryonic mesoderm into a parietal or somatopleuric layer and a visceral or splanchnopleuric layer (p. 50). The bend of the ∩-shaped cavity is in the margin of the cephalic part of the embryonic region, and it has no direct communication with the extra-embryonic cœlom, but the greater part of each limb of the cavity, on account of the disappearance of its lateral wall, soon opens, laterally, into the extra-embryonic cœlom (Figs. 65, 107).

The transverse portion of the ∩ is the **pericardial cavity**. The adjacent parts of the limbs are best named at this stage **pericardio-peritoneal canals** (Frazer, 1940); they are invaded later by the growing lungs and are transformed into the *pleural cavities*. The remaining portions of the two limbs unite ventrally, as the umbilical orifice closes, to form the single **peritoneal cavity**.

As the head-fold forms, the pericardial part of the cavity is carried ventrally and caudally into the ventral wall of the fore-gut (Figs. 70, 71, 108). The mesoderm which originally formed its peripheral boundary then lies in the cephalic boundary

of the umbilical orifice; it becomes thickened to form an important mass called **the septum transversum** (Figs. 75, 86).

At the cephalic end of its dorsal wall, on each side, the pericardial cavity is still continuous with the pericardio-peritoneal canals which lie dorsal to the pericardium, between the fore-gut medially and the body-wall laterally.

Separation of Pericardial, Pleural, and Peritoneal Parts of Cœlom.—In the lateral wall of each pericardio-peritoneal canal, near its cephalic end, lies the duct of Cuvier, passing towards the heart; and between the canals the lung-buds arise from the end of the trachea (Fig. 108). On each side the lung-bud indents the medial wall and bulges into the cavity of the canal which now becomes a **pleural cavity** (Fig. 109). At the same time the ducts of Cuvier, as they pass to the heart, raise ridges in the body-wall—*pleuro-pericardial folds*—which constrict the openings between pleural and pericardial cavities (Figs. 108 C, 109 A). As the lung-buds grow the pleural cavities increase in size, and each passes ventrally round the side of the pericardium towards the ventral wall of the body, until it is separated from its fellow of the opposite side by a median interval only (filled with mesoderm), which becomes the anterior mediastinum and the anterior part of the superior mediastinum (Figs. 109, 110). At the same time the pleural cavity and the growing lung-bud grow towards the head of the embryo (Fig. 110, A). As the growing lung passes upwards it lies to the lateral side of the duct of Cuvier, which is thus pressed against the pleuro-pericardial opening, compressing it towards the median plane until it is obliterated. When this occurs the pericardial cavity is entirely shut off from the remainder of the cœlom and it becomes a completely closed space. Very

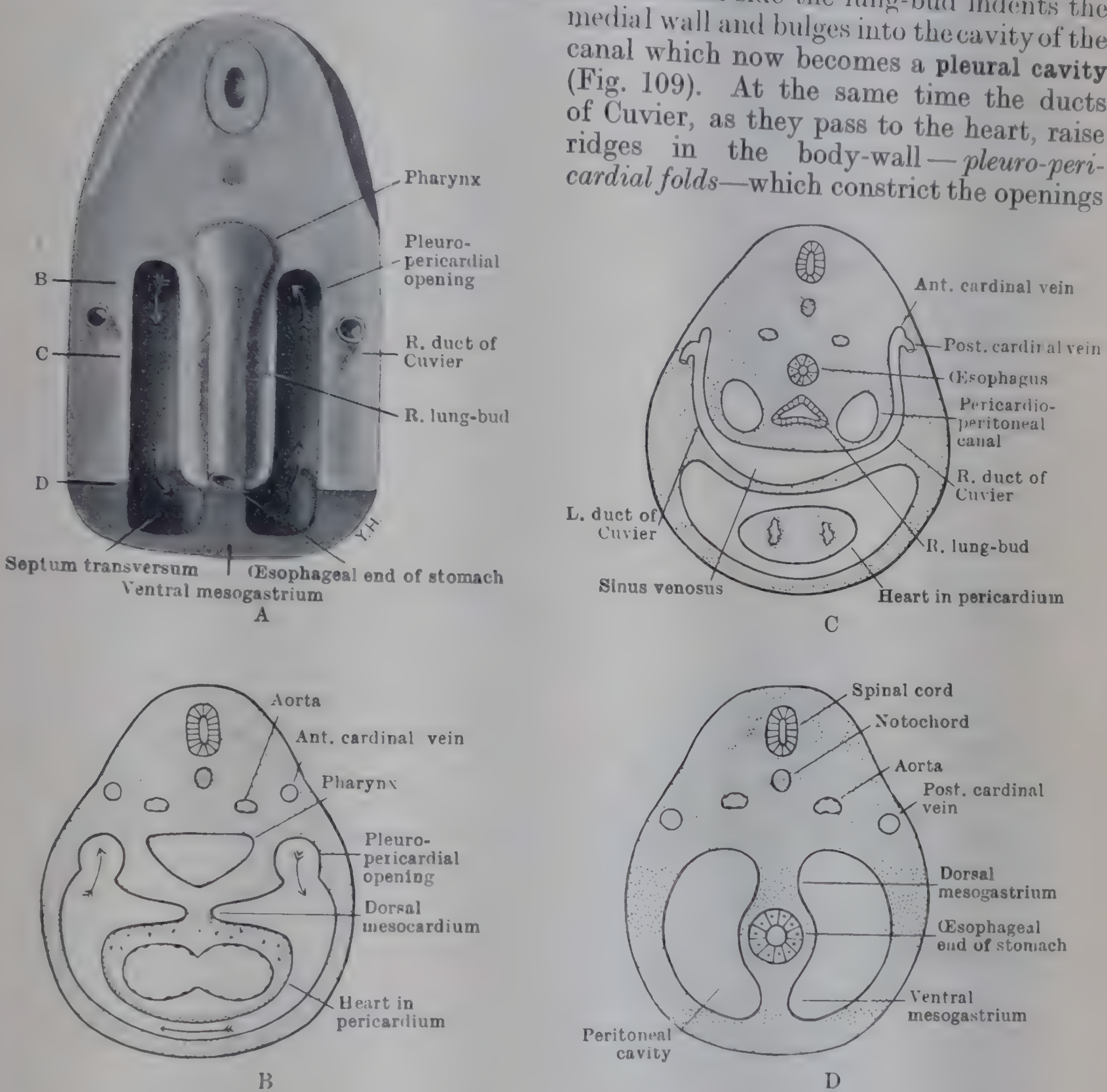
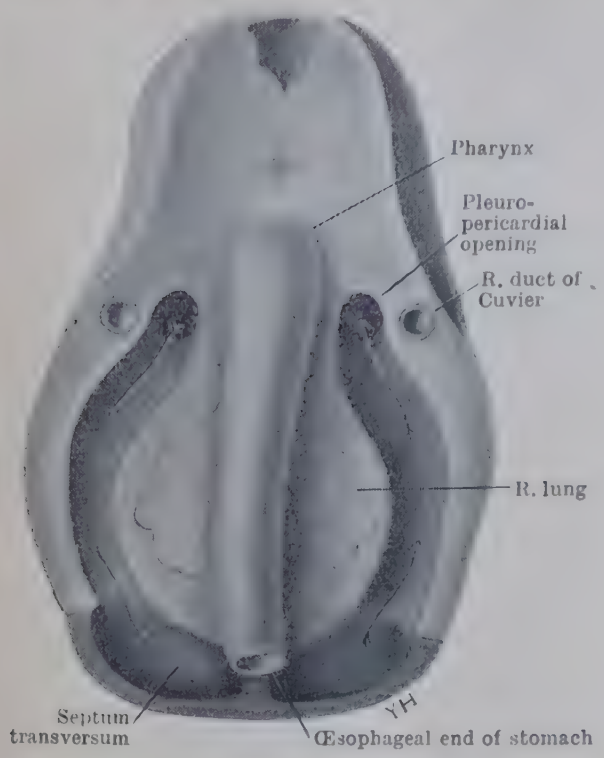


FIG. 108.—SCHEMATA OF EMBRYONIC CŒLOM AFTER FOLDING OF EMBRYONIC AREA BUT BEFORE THE SEPARATION OF THE VARIOUS PARTS. A: from dorsal surface; B, C and D (after Patten, 1946): at levels indicated in Fig. A.

rarely, as an abnormal condition, the pericardial cavity remains in communication on one or other side with a pleural cavity.

As the closure of the pericardial cavity is taking place a pair of wing-like folds of the mesoderm of the body-walls appear caudal to the lungs. These *pleuro-peritoneal folds* are the



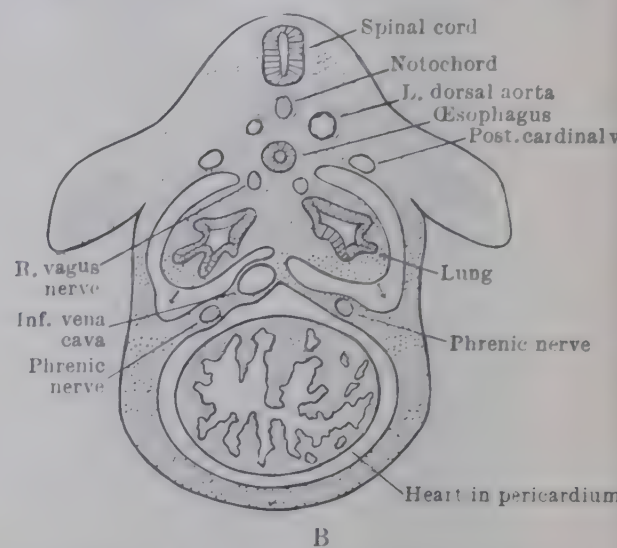
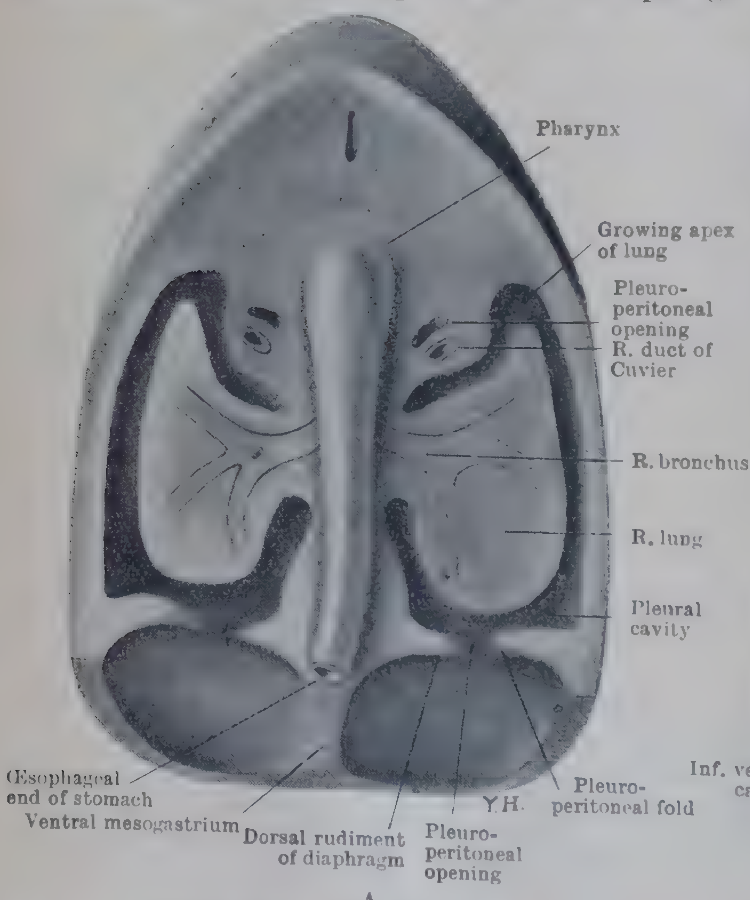


Fig. 109.—Schema of Later Stage of Differentiation of Cœlom. A: from dorsal surface. B (after Patten, 1946): transverse section cut at the level of lung-bud in A, showing commencing ventral extension of pleural cavities.

rudiments of the lateral parts of the diaphragm; they are connected ventrally with the septum transversum and grow medially until they fuse with the mesoderm of the side-wall of the fore-gut and with the dorsal mesentery (Figs. 109, 110). When this fusion is completed and the *pleuro-peritoneal opening* closed, the cavity of the portion of



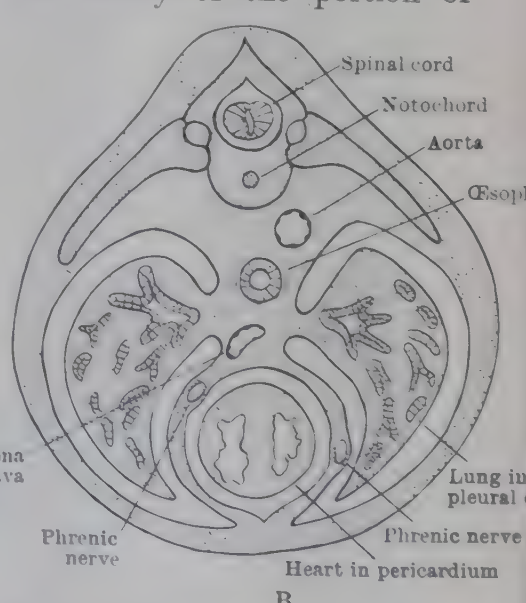


Fig. 110.—Schema of still later Stage of Differentiation of Cœlom. The pleuræ are separated from the pericardium, but still communicate with the peritoneum. A: from dorsal surface. B (after Patten, 1946): transverse section at the level of lung roots in A, showing ventral extension of the pleural cavities.

the cœlom surrounding the lung—the original pericardio-peritoneal canal—is

separated from the more caudal part of the cœlom, which now becomes the peritoneal cavity.

For some further details in the development of the pleural cavities see p. 724.

Formation of Diaphragm.—There are four main developmental parts of the diaphragm—a ventral, a dorsal, and a right and a left lateral.

The ventral part is formed from the *septum transversum*, which is gradually differentiated into a caudal, a middle, and a cephalic part. The caudal part is transformed into (1) the mesodermal tissue of the liver, which grows towards the abdomen, (2) the falciform and coronary ligaments, and (3) the lesser omentum. The cephalic part becomes the caudal or diaphragmatic wall of the pericardium. The middle part is transformed into the ventral portion of the diaphragm.

The dorsal part of the diaphragm is developed from the mesoderm of the dorsal mesentery of the fore-gut. Each lateral part is derived from the pleuro-peritoneal folds mentioned above. The two lateral portions grow towards the median plane till they fuse with the dorsal portion; but sometimes, especially on the left side, the fusion is not completed. The pleuro-peritoneal opening then remains unclosed (in the region of the *vertebro-costal trigone*, p. 452), and a portion of the abdominal contents may pass through it into the pleural sac, constituting a congenital *diaphragmatic hernia*.

For the origin of the muscular tissue of the diaphragm, see p. 555.

SUMMARY OF EXTERNAL FEATURES OF HUMAN EMBRYO AND FŒTUS AT DIFFERENT PERIODS OF DEVELOPMENT

First Month.—During the first **fourteen days** after fertilization the human ovum descends through the uterine tube, enters the uterus as a morula, and is transformed into a blastula which attaches itself to the uterine epithelium (Fig. 38) and penetrates into the decidua compacta (Fig. 39). The inner cell-mass differentiates into ectodermal and entodermal plates with which the amnion and the primary yolk-sac respectively become associated (Figs. 42-44); and when the secondary yolk-sac is formed the zygote consists of a large trophoblastic vesicle in which amnio-embryonic and yolk-sac vesicles are suspended by the mesoderm (p. 42). The embryonic area is indicated from the earliest stage by the contact of ectodermal and entodermal plates, but it is not until the 13th or 14th day, after the formation of the secondary yolk-sac, that it appears as a well-defined circular area about ·2 mm. in diameter (Figs. 47, 49, 50).

By the **fifteenth** or **sixteenth day** the caudal end of the embryonic area is indicated by thickening of the ectoderm and its fusion with the entoderm—the first stage in the formation of the primitive streak (Figs. 48, 50). About the **seventeenth day** the primitive groove, running caudally from the primitive node, has appeared; secondary mesoderm is spreading in the embryonic area from the primitive streak (now well-formed); and the allantoic diverticulum has grown into the body stalk (Fig. 111).

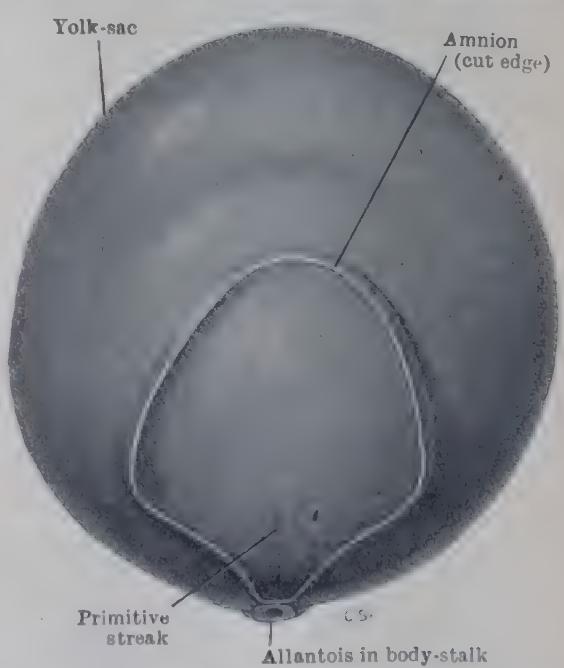


FIG. 111.—DORSAL VIEW OF HUMAN EMBRYO (MATEER) OF 17 DAYS. (After G. L. Streeter, *Carnegie Contrib. Embryol.*, 1920.) × 35. The amnion is cut away to show the embryonic area from above. The primitive streak is seen in the caudal part of the area and beyond that is a section of the body-stalk with the allantoic diverticulum in it.

By the **eighteenth** or **nineteenth day** the area, though variable in both size and shape, may be from 1 to 1·5 mm. long and 1mm. or less in breadth (Figs. 53, 112). The primitive streak is now fully developed with a very distinct primitive groove on its surface. The head-process is growing headwards from the primitive node and is progressively tunnelled by the archenteric canal. The tail-fold is carrying the primitive streak over the

caudal margin of the embryonic area, and the body-stalk, containing the allantois, appears to be bent dorsally at right angles to the region of the cloacal membrane (Fig. 54). There may be an indication of the formation of neural folds (Fig. 112).

By the **nineteenth** or **twentieth day** the embryonic area is still variable in size, but the length (1·5-2 mm.) is then definitely greater than the breadth. The floor of the archenteric canal has broken down, leaving the notochordal plate in the roof of the entodermal vesicle; and the neurenteric canal pierces the area towards its caudal end, with its dorsal opening between the caudal ends of distinct neural folds. The tail-fold is very evident; the head-fold has begun to form, and the pericardial region lies in the ventral wall of the rudimentary fore-gut (Figs. 60, 61, 70, 113).

By the end of the **third week** the head-fold and tail-fold are distinctly formed, the neural folds are well developed especially in the head-region, the neural groove is still completely open or just beginning to close, and the formation of mesodermal somites has begun (Fig. 114). The length of the embryo may now be about 2mm., but there is some variation in the relation of length to state of development at this stage.

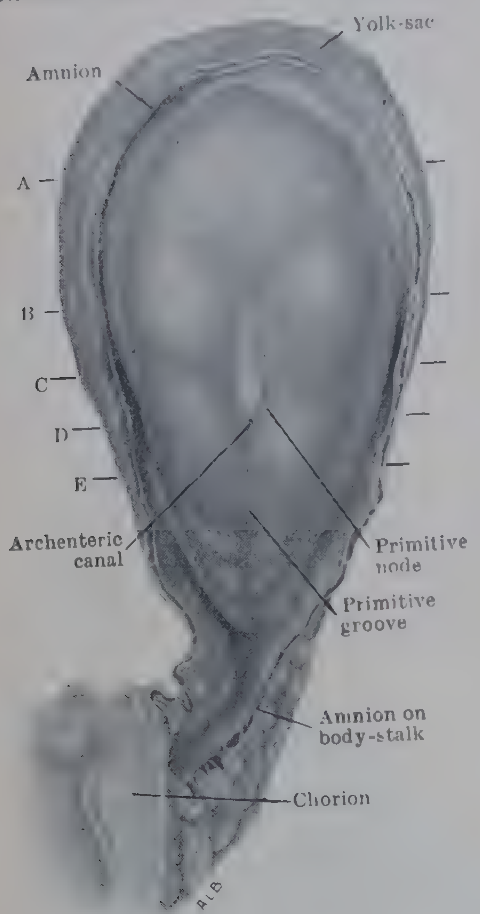


Fig. 112.—Dorsal View of Human Embryo of 18 Days. (After C. H. Heuser, *Carnegie Contrib. Embryol.*, 1932.) × 50.

The amnion is cut away to show the embryonic area now elongated (1·53 × 0·75 mm.) and with the caudal part slightly bent ventrally. The primitive node, with opening of archenteric canal, and primitive streak are seen in the caudal half of the area and there is an indication of commencing neural folds in the cranial half. Cf. Fig. 53; and for sections of this embryo, see Fig. 55.

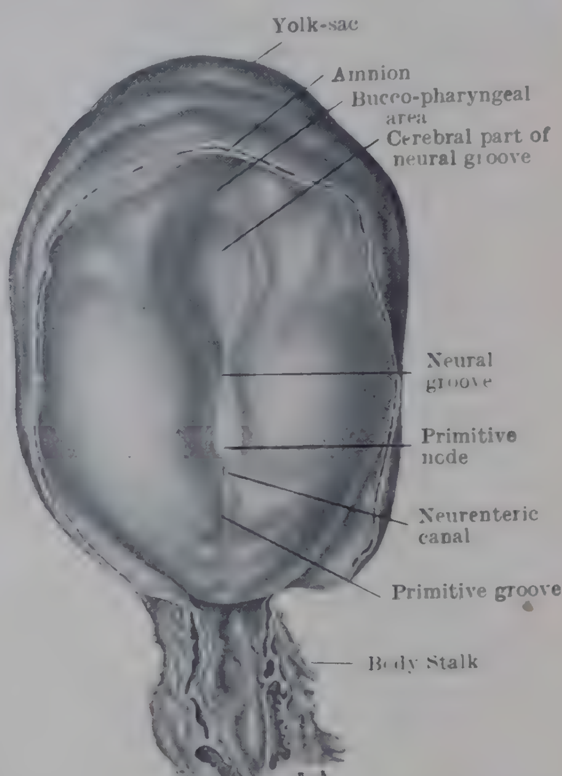


Fig. 113.—Dorsal View of Human Embryo of 19 Days. (After W. C. George, *Carnegie Contrib. Embryol.*, 1942). × 50.

The amnion is cut away to show the embryonic area (1·16 mm. long) with primitive node and streak, neurenteric canal and developing neural groove. Cf. Fig. 60.

In the next few days the primary parts of the brain begin to be evident, the neural groove closes except in the cephalic and caudal regions where the neuropores (p. 60) are seen, the mesodermal somites increase in number, and the cephalic region begins to bend ventrally as the cervical flexure forms (Figs. 115, 116).

By the end of the **fourth week** the length of the embryo is about 2·5-3 mm., the head is bent at right angles to the body, and appears flattened on account of the projection of the fore-brain. The number of somites increases to over twenty. The rudiments of the otic vesicles have appeared as slight depressions in the region of the hind-brain, and the cephalic and caudal neuropores are closed or closing. The yolk-sac is still relatively large and in free communication with the mid-gut. The pharyngeal arches and grooves are appearing in the wall of the fore-gut dorsal to the bulging pericardium (Figs. 75, 117).

Second Month.—During the **fifth week** the embryo attains a length of 5 to 6 mm.

The somites increase to thirty-eight or thirty-nine; the rudiments of the limbs appear and become quite distinct, the fore-limb in advance of the hind-limb; the otic vesicles sink into the interior of the head but remain connected with the surface by a narrow canal; the tail becomes a very definite appendage; and the bulgings caused by the optic vesicles are quite obvious on the surface of the head. The cervical flexure remains acute, and the head bends at right angles upon itself in the region of the mid-brain, forming the cephalic flexure, with the result that the frontal region is turned towards the tail (Fig. 118).

By the end of the **sixth week** the length of the embryo has increased to 11 or 12 mm.

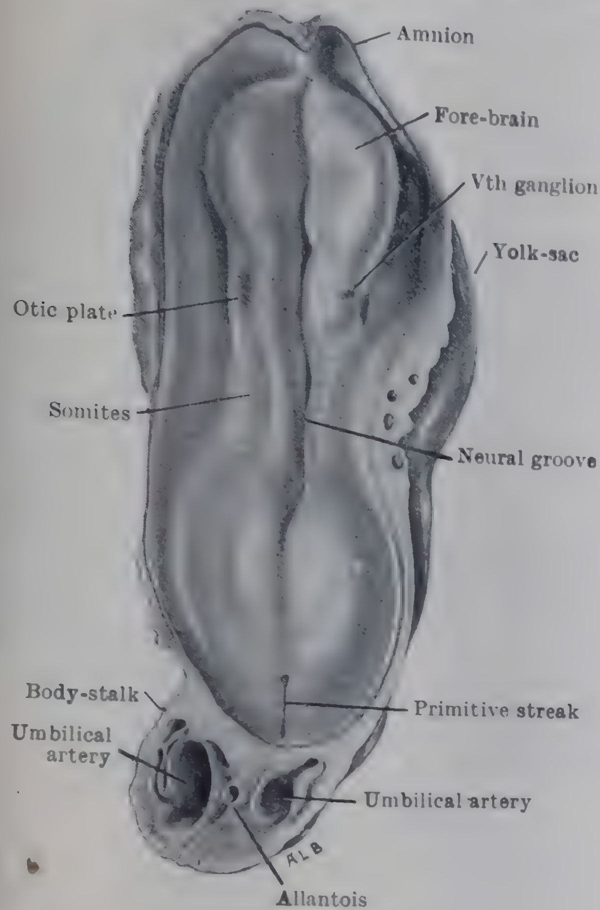


FIG. 114.—DORSAL VIEW OF HUMAN EMBRYO OF 21 DAYS. × 50. (After N. W. Ingalls, *Carnegie Contrib. Embryol.*, 1920.) The broad cephalic end of the neural plate is elevated with commencing formation of the brain. The neural groove is still open and its caudal end is enclosing the cephalic end of the primitive streak. The length of the embryonic area has increased to 1·4 mm. and somite formation has begun.

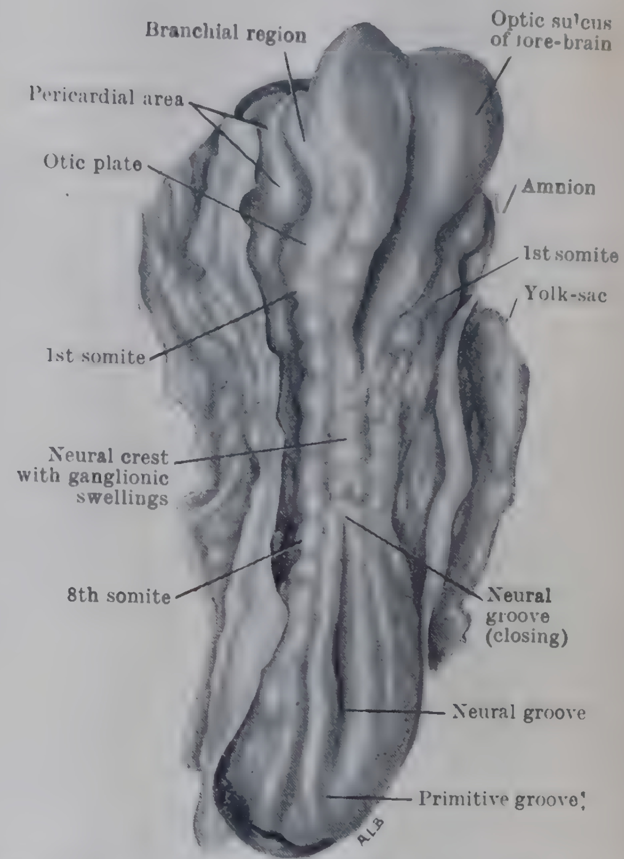


FIG. 115.—DORSAL VIEW OF 2·2 MM. HUMAN EMBRYO OF 22 DAYS. × 40. (After F. Payne, *Carnegie Contrib. Embryol.*, 1925.) The neural groove is closed in the future cervical region, the brain vesicles though still open are beginning to take shape, the site of origin of the optic vesicle is indicated, and there are 7 pairs of somites present.

(CR).[1] During this week the lens of the eye appears as a thickening of the surface-ectoderm, sinks into the interior of the eyeball, becomes a vesicle and separates from the surface. The three segments of the upper limb become visible, and the rudiments of the fingers appear. The lower limb is less advanced; the thigh segment is not distinct, and the rudiments of the toes are not yet visible. The third and fourth pharyngeal arches disappear from the surface and lie in the depths of the cervical sinus, overlapped by the caudal margin of the second arch (see p. 66) (Fig. 81). During the sixth week the head grows rapidly and becomes relatively very large in comparison with the trunk.

During this week also the olfactory pits appear between the median and the lateral nasal processes, and grow dorsally into the roof of the oral pit; the median process is divided into the two globular processes; and the maxillary processes of the mandibular arches, growing towards the median plane, fuse with the lateral nasal and the globular processes, so completing the lateral parts of the primitive upper lip (Figs. 76-77).

The nodular outgrowths which form the rudiments of the auricle appear on the margins of the first pharyngeal groove and begin to fuse together (Fig. 119).

By the **seventh week** the embryo has attained a length of 17-18 mm. (CR). The cervical

[1] CR indicates the crown-rump measurement which corresponds with the sitting-height (Mall, 1910).

flexure has begun to straighten. The rudiments of the eyelids have appeared. The globular processes have fused together, but there is still a distinct notch in the middle of the upper lip. The margins of the auricles are now well defined; the hands are folded medially; the tips of the fingers are free, and the palms rest on the upper part of the distended abdomen. The thighs and the toes have appeared, and the tail has begun to fuse with the caudal end of the trunk (Fig. 120).

At the end of the **eighth week,** when the embryo becomes a fœtus, it has attained a

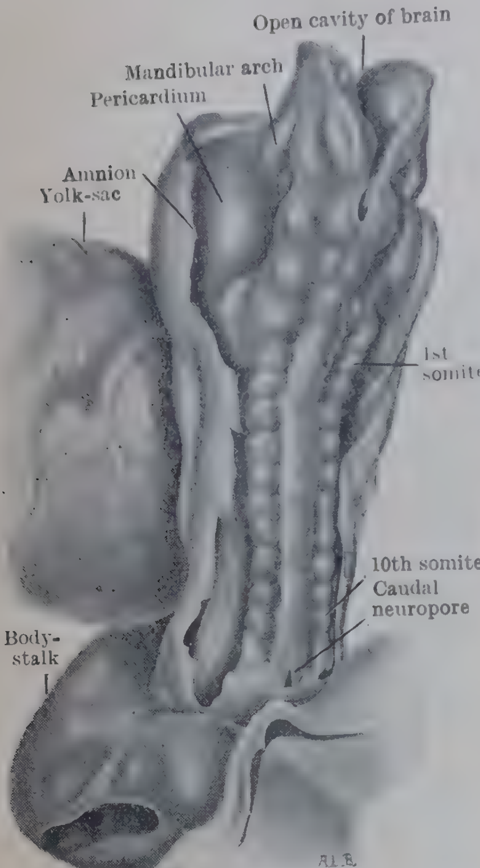


FIG. 116.—DORSAL VIEW OF 2·3 MM. HUMAN EMBRYO OF 23 DAYS. × 30. (After G. W. Corner, *Carnegie Contrib. Embryol.*, 1929.) The closure of the neural groove has advanced almost to the stage of cephalic and caudal neuropores. The three brain-vesicles are forming, the pericardium and the mandibular arch are evident, and there are 10 pairs of somites present.

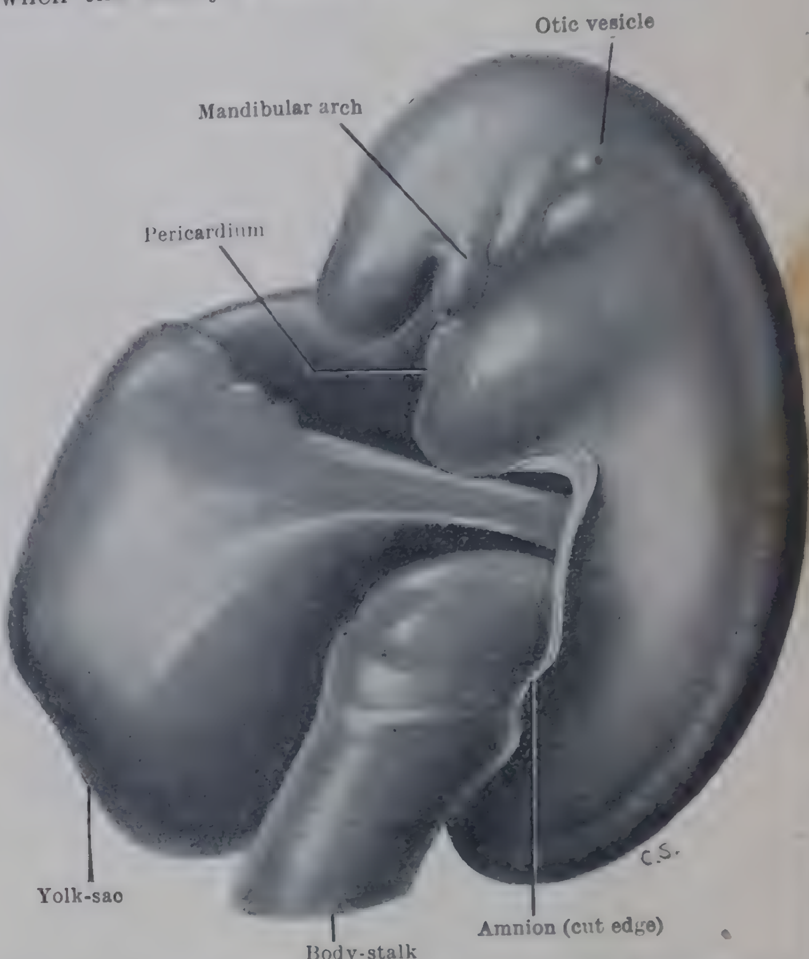


FIG. 117.—HUMAN EMBRYO, 2·5 MM. LONG, WITH TWENTY-THREE PAIRS OF SOMITES. × 34. (After Thompson, 1907.) The head is small and flattened; the optic vesicles project slightly from the fore-brain, and the position of the otic vesicle is indicated. The yolk-sac, still relatively large, is connected to the alimentary canal through the vitelline duct which, with the body-stalk, emerges from the umbilical orifice. The position of the somites is indicated by slight elevations of the surface. There is no trace of the limbs. For reconstruction of this embryo, see Fig. 75, p. 62.

length of about 25 to 30 mm. (CR). The auricles project from the sides of the head, the tail has almost disappeared from the surface, and the toes are free from one another. The external genital organs are developing and the genital tubercle is evident. The cervical flexure is now very slight, and although the head is still relatively large, the disproportion between it and the trunk has begun to decrease (Fig. 121).

Third Month.—The head grows less rapidly, and, though it is still large, it is relatively smaller in proportion to the whole body. The eyelids close, and their margins fuse together. The neck increases in length. The parts of the limbs begin to assume their proper proportions, and nails appear on the fingers and toes. The anal pit is formed and the external genital organs are sufficiently differentiated for the sex to be distinguished. The skin is a rosy colour, thin and delicate, and of firmer consistence than in the preceding stages. By the end of the third month the CR length of the fœtus is about 100 mm. (nearly 4 in.), and it weighs about 50 grams (2 oz.).

Fourth Month.—The skin is firmer, and fine, downy hairs (lanugo) are developed. The disproportion between the upper and lower limbs is less. A fœtus born at this period may live for a few hours. Its CR length is about 145 mm. ($5\frac{1}{2}$ in.), and it weighs 200 grams (7 oz.).

Fifth Month.—The skin becomes firmer, the hairs are more developed, and sebaceous

matter appears on the surface of the body. The lower limbs are still shorter than the upper, and the umbilicus is farther from the pubis. At the end of the month the CR length of the fœtus is 190 to 200 mm. (about $7\frac{1}{2}$ in.), and its average weight is 460 grams (about 1 lb.).

Sixth Month. — The skin is wrinkled and of a muddy, reddish colour. The hairs are stronger and darker. The deposit of sebaceous matter is greater, especially in the armpits and groins. The eyelashes and eyebrows appear. At the end of the month the CR length of the fœtus is 230 to 240 mm. (9-$9\frac{1}{4}$ in.), and its average weight is about 1 kilogram ($2\frac{1}{5}$ lbs.).

Seventh Month.—The skin is still a muddy-red colour, but it is lighter than in the previous month. The body is more plump on account of a greater deposit of subcutaneous fat. The eyelids have reopened. A fœtus born at this period is capable of living and may survive. Its CR length at the end of the month is about 250 mm. (11 in.), and its weight is about 1·5 kilograms (over 3 lbs.).

Eighth Month.—The skin is of a bright red tint and is completely covered with sebaceous deposit, which is thickest on the head and in the armpits and groins. The umbilicus is farther from the pubis, but it is not yet at the centre of the trunk. The CR length of the fœtus is 300 to 320 mm. (12-$12\frac{1}{2}$ in.), and its weight about 2 to 2·5 kilograms ($4\frac{1}{2}$-$5\frac{1}{2}$ lbs.).

Ninth Month. — The hair begins to disappear from the trunk, but it remains long and abundant on the head. The skin becomes paler, the plumpness increases, and the umbilicus reaches the centre of the trunk. During this month the nails reach

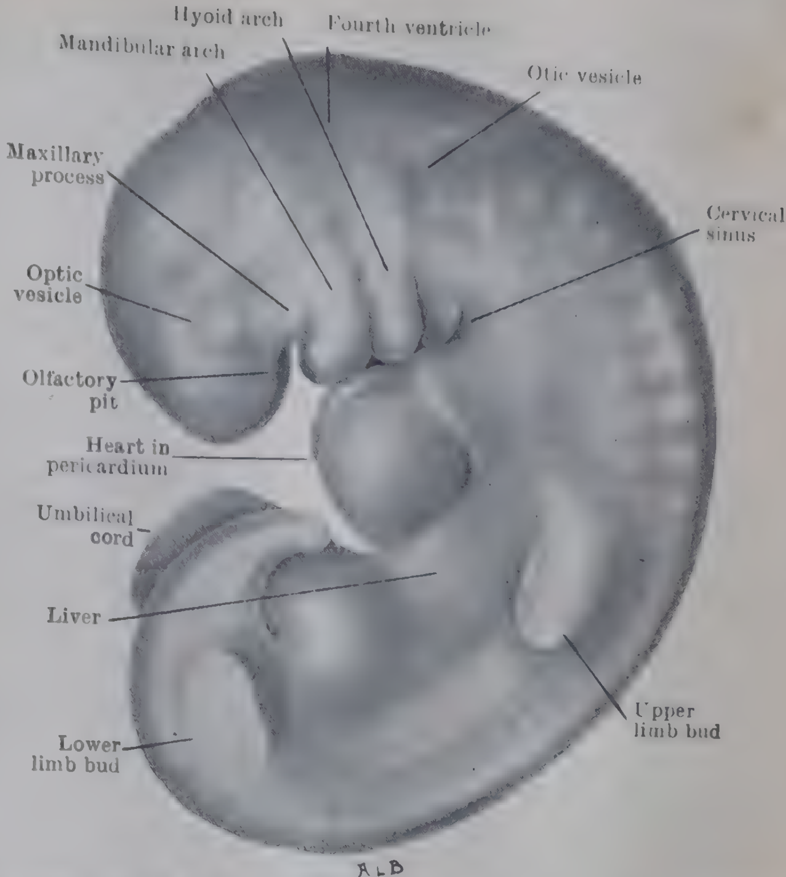


FIG. 118.—HUMAN EMBRYO, 5·5 MM. CR LENGTH. (After G. L. Streeter, *Carnegie Contrib. Embryol.*, 1945; Embryo No. 6830.) The limb-buds are now quite distinct (cf. Fig. 72, p. 58) and the upper limb is beginning to elongate and curve forward. The maxillary process has grown forward below the eye, and the cervical sinus is evident.

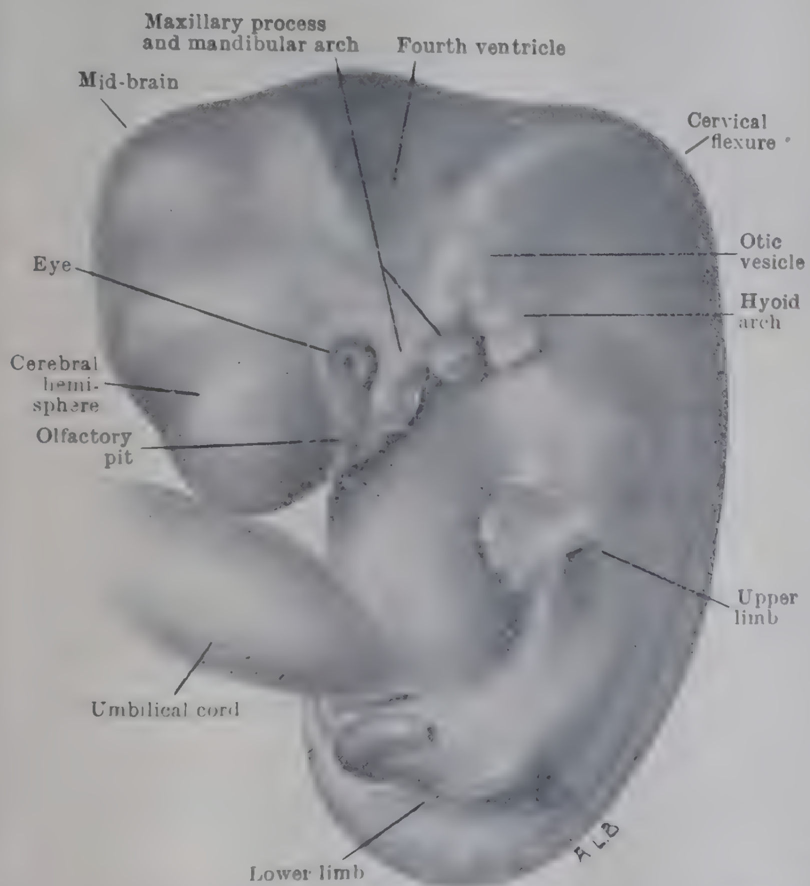


Fig. 119.—HUMAN EMBRYO, 13 MM. CR LENGTH. (After G. L. Streeter, *Carnegie Contrib. Embryol.*, 1948; Embryo No. 8101.) The limbs are bent ventrally and show differentiation into segments. The cervical sinus is closing and rudiments of the auricle of the external ear are present on the first and second arches. The pontine flexure of the hind-brain, the fourth ventricle and the olfactory pit are evident.

the ends of the fingers. At the end of the month, when the fœtus is born, its CR length is from 340 to 360 mm. ($13\frac{1}{2}$-14 in.), and it weighs from 3 to 3·5 kilograms ($6\frac{1}{2}$-$7\frac{1}{2}$ lbs.).

Age, Length, and Weight of Embryo and Fœtus.—The lengths and weights of embryos and fœtuses at increasing ages given in the foregoing summary are compiled from a number of sources. It must be understood, however, that they are only approximate, since embryos and fœtuses of the same length, or of the same weight, or even at the same stage of development, are not necessarily of the same age (Streeter, 1942). Moreover, it is usually impossible to calculate the *actual* age of an embryo (dating from the time of fertilization) and the age assigned (except in the case of some young embryos for which the data necessary for the calculation of fertilization-age are available) is then the *menstrual* age, dating from the first day of the last menstruation. Owing to the average time of ovulation in relation to the menstrual cycle, the menstrual age of the majority of embryos is probably at least fourteen days more than the actual age. The usual

Fig. 120.—Human Embryo, 18·5 mm. greatest length, about Seven Weeks Old. The abdomen is very prominent on account of the rapid increase of the liver. The digits of the hand and foot are distinct but not separated from one another. The margin of the auricle is completed. The eyelids have begun to form. Cf. Fig. 121a, p. 101.

Fig. 121.—Human Fœtus at the beginning of the Third Month. The cervical flexure is now slight. The upper limbs have assumed a characteristic position with the hands in front of the face, and the toes are free. The tail has almost disappeared, and the genital tubercle is evident.

method of calculating the duration of pregnancy by counting 280 days from the first day of the last menstruation gives in any case only the approximate date of parturition.

It should also be noted that the 'greatest length' of an embryo (excluding the lower limbs) depends upon the cervical flexure. While the head of the embryo is fully flexed the crown-rump measurement (CR) is less than the greatest length, but later the two measurements are the same.

Formulæ for the calculation of age from length have been devised, but it is more satisfactory to use tables and graphs (constructed from extensive data) from which the probable range of age can be read at a glance (Streeter, 1921).

FIG.—121A.—PHOTOGRAPH OF 21 MM. HUMAN EMBRYO IN AMNION AND CHORION. × 2·5.
For the form of the embryo, cf. Fig. 120; and note the position of the definitive yolk-sac between the expanding amnion and the chorion. (Carnegie No. 8537A; by special permission of Dr. George W. Corner.)

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PLATE I.—RADIOGRAPH OF EIGHT-MONTHS FŒTUS (EVISCERATED) TO SHOW THE STATE OF OSSIFICATION OF THE SKELETON. THE RIGHT FOREARM IS SUPINATED, THE LEFT PRONATED.

Note the absence of ossific centres for the Carpus and the presence of centres for the Talus and Calcaneum (cf. Plate XVIII, Fig. 1, p. 273, and Plate XXVIII, Fig. 1, p. 321). Minute centres of ossification for the lower epiphysis of the right Femur and the upper epiphysis of the left Tibia are also faintly visible.

PLATE II

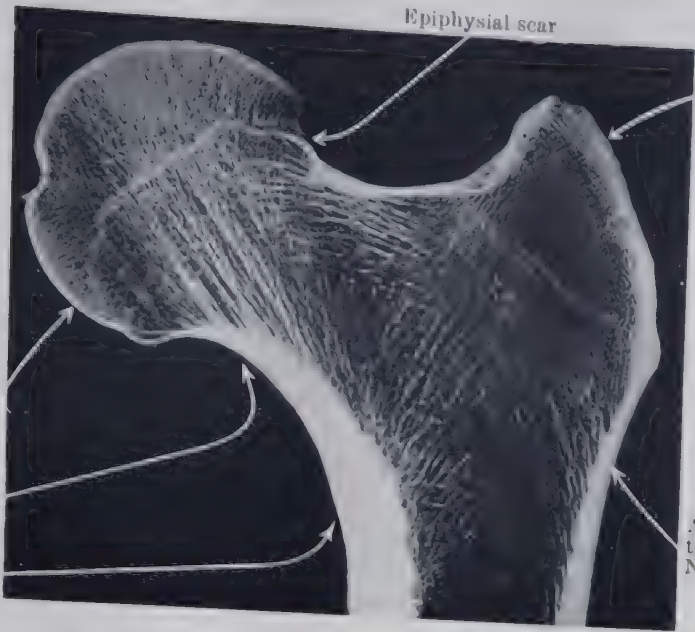
Fig. 1.—Photograph of Coronal Section of Upper End of Left Femur to show its Architecture.

Note how the compact bone of the Shaft thins out over the Greater Trochanter and the Head, and the manner of crossing of the different systems of lamellæ in the spongy bone.

Fig. 2.—Photograph of Sagittal Section of Calcaneum to show its Architecture.

Note the thin shell of compact bone and the arrangement of the lamellæ of the spongy bone in two main systems.

PLATE III



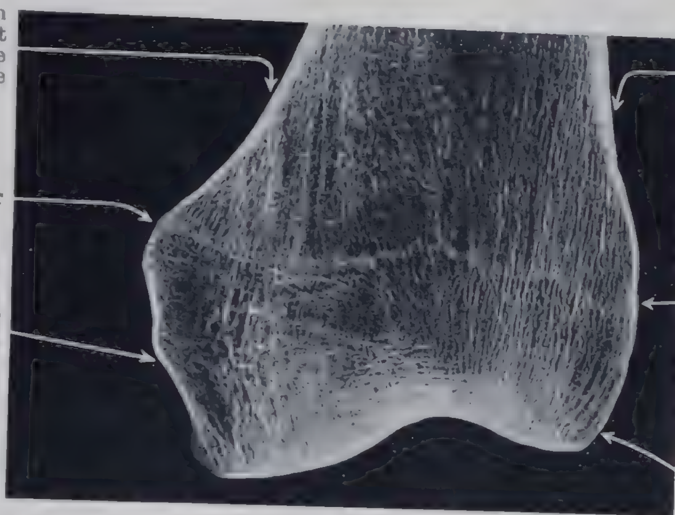


Plate III.—Radiographs of Coronal Sections of A. Upper End of Femur; B. Lower End of Femur; C. Upper End of Tibia, of a Woman aged 34.

Note the persisting epiphysial scars and the arrangement of the systems of lamellæ in the spongy bone.

PLATE IV

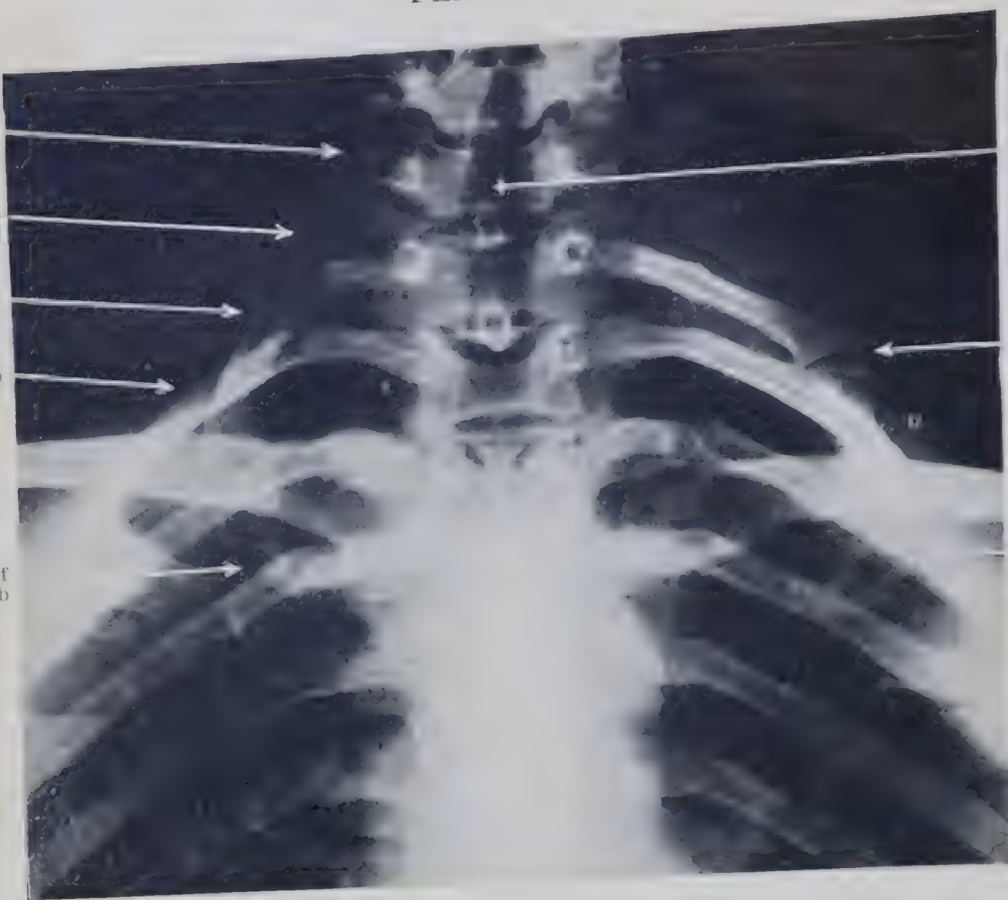


FIG. 1.—RADIOGRAPH OF CERVICO-THORACIC REGION OF WOMAN AGED 35, SHOWING A PAIR OF WELL-DEVELOPED CERVICAL RIBS.

Note the asymmetry of the cervical ribs and that the left one articulates with a projecting process of the first thoracic rib. For view of the right cervical rib on a larger scale see Plate LXVIII, Fig. 2, p. 721, which shows also more clearly the evidence of the presence of a " lobe of the vena azygos " in the right lung.

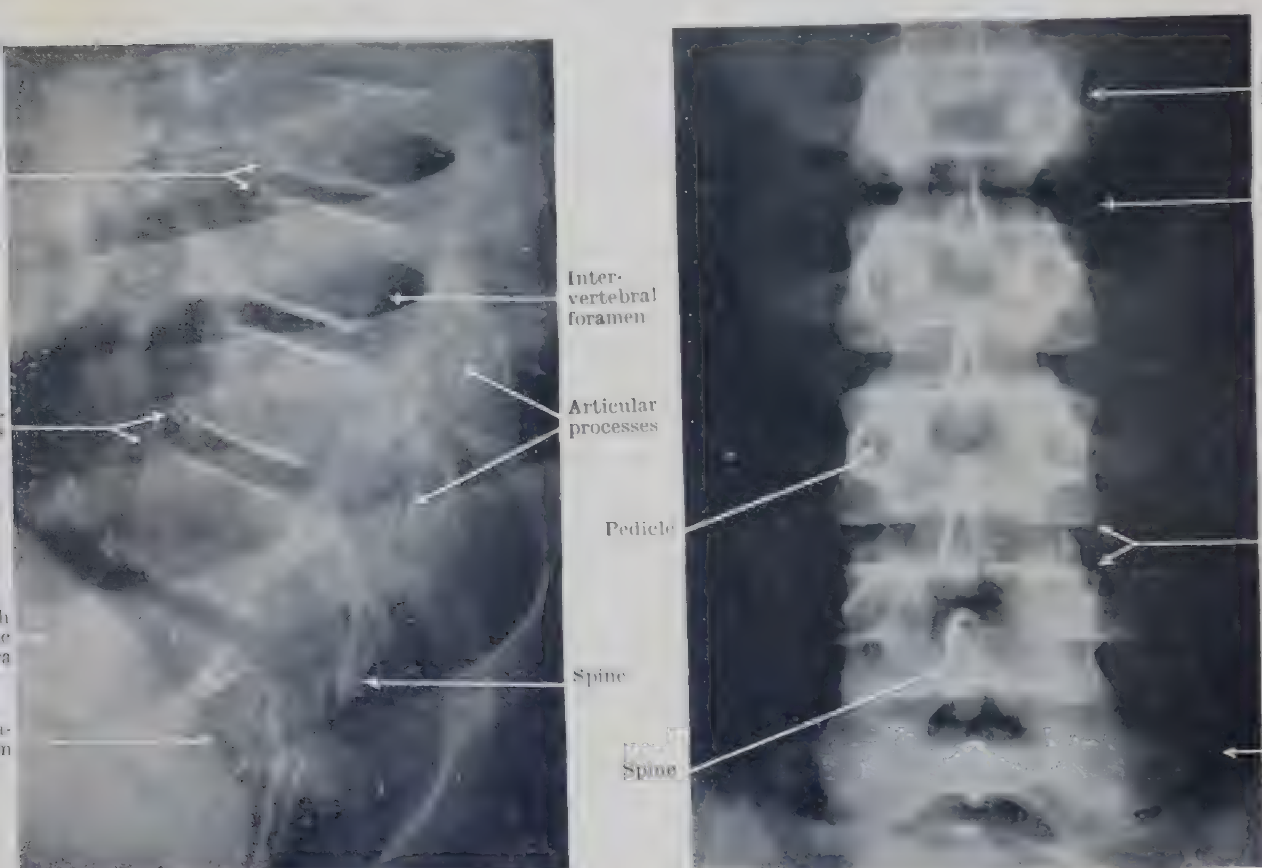


FIG. 2.—RADIOGRAPHS OF (A) THORACIC AND (B) LUMBAR VERTEBRÆ OF A GIRL AGED 12, SHOWING THE EPIPHYSES OF THE VERTEBRAL BODIES.

OSTEOLOGY

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INTRODUCTION

BONES AND CARTILAGES

The body is supported by an internal framework or *skeleton* of **bones** [σκελετός (skeletos) = dried]. This skeleton accounts for about one-seventh of the body-weight in a man and rather less in a woman; and the bones are supplemented in many places by gristle or **cartilage**—more so in a growing person than in an adult.

Uses of Bones.—Bones give support to the softer tissues which surround them and in some cases form protective boxes or cages for internal organs such as, for example, the brain in the skull, the heart and lungs in the chest and the spinal cord in the backbone. They also act as levers to which muscles or their tendons are attached and can transmit either tensile or compression stresses without appreciable deformation.

In addition, the spaces found inside bones are used for the production of blood-cells, for these spaces contain bone-marrow in which the blood-corpuscles develop, and the bone-substance itself is a store of lime-salts upon which the body may draw when necessary.

Articulation of Bones (see also the Section on Joints).—Since a continuous rigid framework would prevent movement, the bony skeleton is divided into separate bones joined by softer tissues which are, as a rule, sufficiently flexible to allow movement to take place.

The union between two or more adjacent bones is called a joint or *articulation* (*articulus*, diminutive of *artus* = a joint) and the bones so united are said to *articulate* with each other at the joint. The surface of one bone which comes into direct relation with another at a joint is its **articular surface** and, when the bones can glide or rotate on each other freely, an actual space is present between them; the articular areas are then covered with an adherent layer of smooth glistening **articular cartilage**. The bone underlying the cartilage is also smooth so that the articular part of a dried bone is easily identified even although the cartilage has been removed. In other cases, where less movement is required, the union of adjacent bones is made by some form of connective tissue, such as fibrous tissue or cartilage, when the articular surface will usually be rough; or else the union may be made complete by fusion of the two bones so that movement is prevented. Movements at joints are controlled or produced chiefly by muscles which are attached to the bones, but the bones are held together by all the tissues which surround them. In the majority of cases fibrous tissue runs from bone to bone as thickened bands or ligaments (*ligamentum* = a band or bandage, from *ligare* = to bind). These ligaments or other soft tissues maintain the continuity of the skeleton and transmit tensile stresses when required. Compression stresses cannot be transmitted through ligaments of this kind and the articular ends of long bones are likely to be enlarged so as to distribute such stresses and provide a good bearing surface in any normal position of the joint.

Constituents of Bone.—On analysis, bone can be broken down into approximately equal parts of solids and water. The solids are partly organic matter (31 per cent)

and partly inorganic (69 per cent). The *inorganic matter* consists of various *mineral salts*, the chief of which is calcium phosphate. This makes up over 80 per cent of the mineral or inorganic matter, though not necessarily in such a simple form, and, because of its abundance, bones are one of the sources of phosphorus. The *organic matter* is *white fibrous tissue*. It consists of:—(*a*) fine fibres embedded in a little amorphous material, called 'ground-substance', which unites the fibres into interlacing bundles; (*b*) connective-tissue cells, called *bone-corpuscles*, placed in rows among the bundles of fibres. The ground substance is completely impregnated with the mineral salts and a bone which has been burned to destroy the connective tissue element (calcined) still retains its form, though it becomes brittle and inelastic and may crumble. On the other hand, if the mineral salts are removed from a bone by soaking it in dilute acid, the bone again retains its form completely but becomes flexible. It can be cut with a knife and a sufficiently long and thin bone can be tied in a knot. Bones are therefore not only hard but, because of the fibrous tissue, are also tough and elastic. This combination of organic and inorganic substances makes bones almost unique in that resistance to compression and extension is nearly equal (D'Arcy Thompson, 1942). In old age bones become more brittle owing to diminution of the elasticity of the fibrous tissue and not to any increase in the salts.

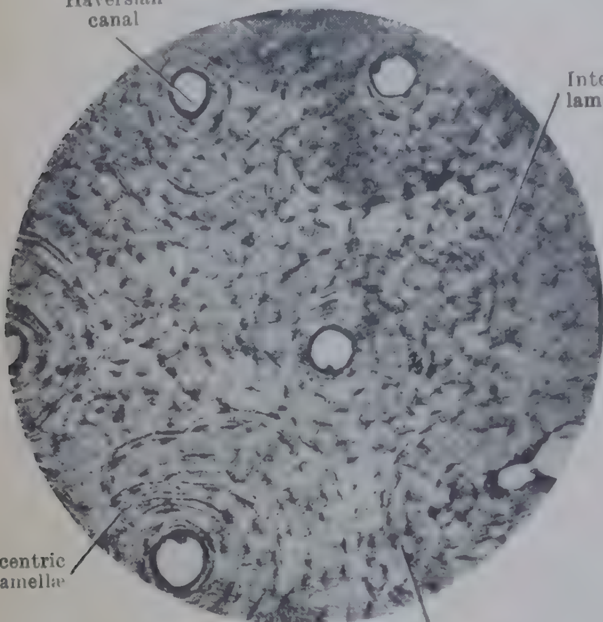


FIG. 122.—PHOTOGRAPH OF GROUND TRANSVERSE SECTION OF COMPACT BONE, showing Haversian systems (Haversian canal, concentric lamellæ, lacunæ, and canaliculi). × *c*. 75.

Structure of Bone.—There is only one kind of bone, but it may be either compact or spongy in texture (see Plate II, p. 104). **Compact bone** is hard and dense and forms the outer shell of a bone within its covering of periosteum (see p. 109). It is frequently thick and strong and is well seen when the shaft of a long bone, such as the thigh bone or femur, is sawn across. **Spongy bone** is also hard, but this is not so evident because it consists of thin intersecting lamellæ of bone substance with spaces between them, like a sponge (*lamella* or *lamina*—a leaf, blade, layer). This arrangement is well seen when the end of a long bone such as the femur is cut across. The spaces between the lamellae are filled with red marrow.

The **microscopical structure of bone** is essentially the same in the spongy and compact varieties and is closely associated with its mode of formation. Bone substance is laid down in two ways :—(a) Successive thin layers are formed under the periosteum. These lie approximately parallel with the surface and are called **periosteal lamellæ.** (*b*) Successive thin concentric layers are deposited around blood-vessels so as to form canals which therefore contain the blood-vessels as well as any lymph-channels, nerves and loose areolar tissue associated with them. The systems of tubular lamellæ so formed are called **Haversian systems** (after Clopton Havers who first described them in detail, 1691) and consist of three to ten or more concentric tubes, the **Haversian lamellæ**, which surround the central cavity named the **Haversian canal**. The cells associated with the laying down of bone are named **osteoblasts.** Numbers of them are trapped between the lamellæ during development and remain as **osteocytes** or **bone-corpuscles** in the substance of the bone. The minute cavities occupied by the bone-corpuscles during life are called **lacunæ** (*lacuna*—a pit, hole, or cavity) and, since the living cells are connected with each other by slender cytoplasmic processes, the substance of the lamellæ formed around them is penetrated by minute channels. These are called **canaliculi** and connect

neighbouring lacunæ with each other. The lacunæ of adjacent systems, however, seldom communicate. Bone is first laid down in its spongy form, but is thereafter continually changing its shape and structure by removal of bone already present and deposition of fresh bone arranged to suit new requirements. In consequence, the more recently formed Haversian systems have between them the remains of older Haversian systems or of periosteal lamellæ. These are termed **interstitial lamellæ**; periosteal lamellæ which lie nearer the surface and are unbroken by the Haversian systems are referred to as **circumferential lamellæ.** Bundles of collagenous fibres belonging to the surrounding fibrous tissue become incorporated in the periosteal lamellæ and calcified. These calcified bundles usually pass at right angles to the lamellæ, as though nailing them together, and are called the **perforating fibres** of Sharpey (1856).

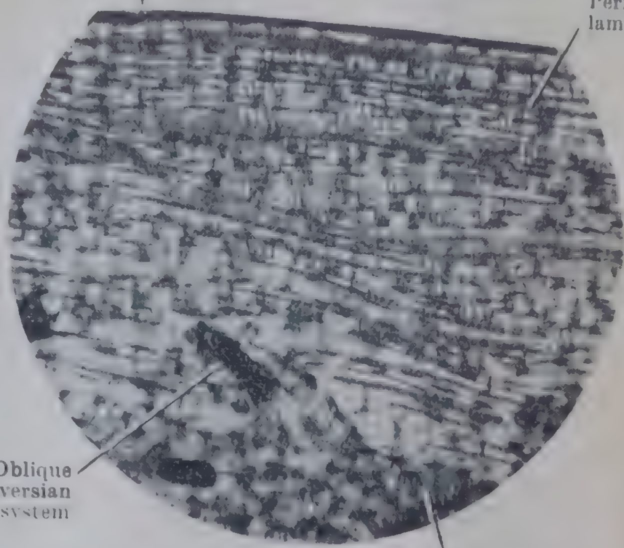


FIG. 123.—PHOTOGRAPH OF GROUND LONGITUDINAL SECTION OF COMPACT BONE, showing periosteal lamellæ parallel to surface above and Haversian systems cut obliquely below. × c. 75.

Architecture of Bone.—Although there is still doubt as to the actual mechanism—chemical, cytological, physical or mechanical, or a combination of these—which results in the absorption or deposition of bone, the resultant form and structure of any bone is peculiarly well adapted to its function of resisting mechanical stresses and is continually being modified to keep it so until ageing or decay leads to failure of the process.

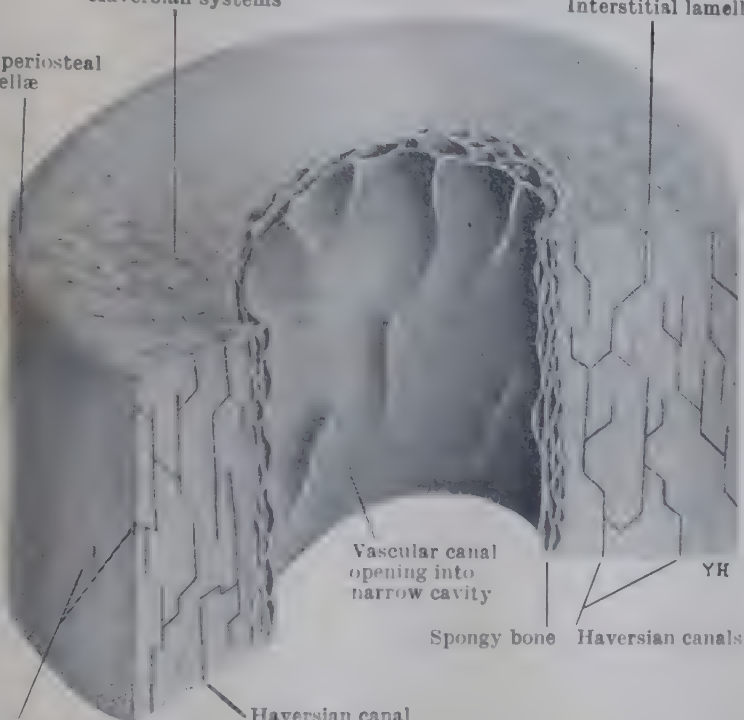


FIG. 124.—DIAGRAM TO ILLUSTRATE THE ESSENTIAL LAMELLAR STRUCTURE OF BONE. (After Le Gros Clark, 1945.) The Haversian systems are represented out of proportion in order to indicate schematically their arrangement in a long bone.

Two fundamental factors lead to strength and economy of material. The first of these is the intimate combination of mineral salts and fibrous tissue already mentioned. The other is the use of microscopic tubular lamellæ as basic units which resist bending equally in any direction and are hollow, to economize material where it is least required.

The sections of femur and calcaneum shown in Plate II, demonstrate the essential features of the architecture of bone. The bone-substance forms *macroscopic lamellæ*, or *trabeculæ*, running in definite directions suited to function. In the shaft of the femur (lower part of Fig. 1) the lamellæ are concentrated at the periphery and merge to form thick compact bone capable of resisting bending stresses while the interior is free of bone substance and constitutes the marrow-cavity. The upper end only of this cavity is shown in the illustration. In the upper end of the femur the lamellæ spring from the compact bone, diverge, and arch over to reach the head of the bone

and the greater trochanter. Other systems arch between the head and the trochanter or run from the surface of the head straight to the compact bone of the neck.

In the case of the calcaneum, or heel-bone, the heel is at the right lower corner of the illustration. Coarse lamellæ can be seen which transmit the weight of the body from the articular facets back towards the heel and forwards towards the ball of the foot. Other finer lamellæ curve forwards from the back of the heel to the lower part of the heel and to the front of the bone, intersecting the other systems and transmitting the pull of the tendon of the calf-muscles. In the space between these systems there is less stress and consequently a more open texture comparable to Ward's triangle in the neck of the femur (p. 298).

It must be emphasized that, to get a correct interpretation, the structural arrangements found in any bone must not be considered alone. Adjacent bones and soft tissues, particularly muscles, cause both tension and compression, which have to be taken into account. Also, it has to be borne in mind that conditions vary when joints are moved from one position to another (Carey, 1929) and effectively arranged lamellæ must be available for any normal position of the joint. The way in which lamellæ are arranged to transmit normal stresses from bone to bone is illustrated in Fig. 125 which may be compared with the radiographs in Plate III, p. 105. The classical example of bone-architecture is the arrangement found in the neck of the femur (see p. 297).

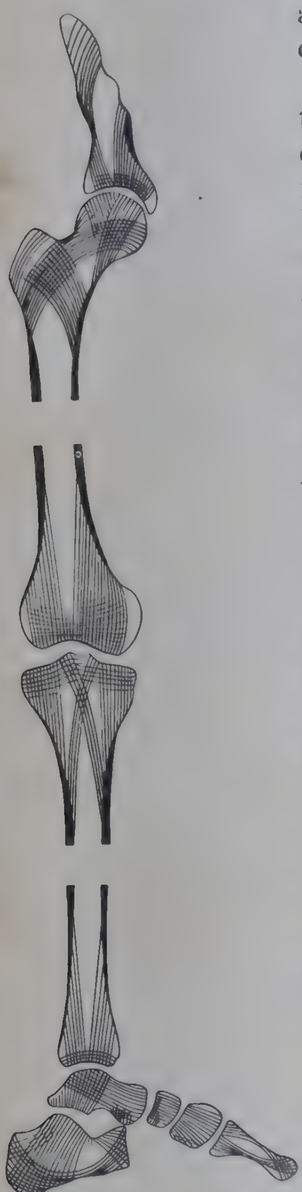


Fig. 125.—Diagram of the Architecture of the Bones of the Lower Limb. (After Meyer, 1867.)

Classification of Bones.—The bones are divided into four classes according to their shape: long, short, flat, irregular.

Long bones are found in the limbs, *e.g.*, the *humerus* or bone of the upper arm and the *femur* or thigh-bone. Small elongated bones, such as those of the fingers and toes, are called **miniature long bones**. Each long bone has a *shaft* and *two ends*. The **shaft** is a hollow, thick-walled rod of compact bone. The space inside is called the **medullary cavity**, and, when the bone is fresh, it is filled with soft, yellowish material known as *yellow marrow* [*medulla* = marrow]; the yellow colour is due to abundance of fat. Around the medullary cavity, inside the compact bone, there is a zone of coarse spongy bone. The medullary cavity serves not only for the lodgment of the marrow. Its presence saves bone-substance—with little diminution in strength, for up to a certain point a hollow cylinder is almost as resistant as a solid one of the same thickness and material. The shaft of a long bone is never quite straight but it is curved usually in more than one plane. To compensate for these curvatures there is a greater thickness of compact bony tissue in the concavities of the curves than elsewhere. The **ends** of a long bone are broader and thicker than the shaft. They consist of spongy bone covered with a thin layer of compact bone; the cavities in the sponge-work again economize in bone-substance and accommodate red marrow. The objects gained by the greater bulk of the end of the bone are :—(1) The surface for articulation is wider, and therefore movements at the joint can be regulated more precisely; (2) the chances of dislocation are diminished; (3) shocks received by the bone are diffused.

Short bones are more or less cubical in shape. They consist of spongy bone enclosed in a thin shell of compact bone. The short bones are the eight *bones of the wrist*, the seven *bones of the hinder half of the foot* and the *sesamoid bones.* A **sesamoid bone** is one which is developed in the substance of a tendon or sinew; the patella or knee-cap is by far the largest of these. They get their name from the resemblance that some of them have to sesame seeds.

Flat bones are such as the *ribs*, the *shoulder-blade*, and the bones of the *skull*

cap. They are thin rather than flat, for nearly all 'flat' bones are curved or bent. Each is made up of two plates of compact bone which enclose between them a layer of spongy bone. In the flat bones of the skull the layer of spongy substance is called the **diploë** [διπλόη (diploē) = a fold or doubling, a junction of two plates]; and in the diploë the marrow is largely replaced by venous blood-channels.

Irregular bones are of various shapes, and include all those that cannot be classed as long or short or flat. Many of the *skull-bones* are irregular, and so are the *vertebræ*. The thinner parts of irregular bones are like flat bones—two plates of compact substance with spongy substance between them. The bulky parts, especially in vertebræ, are like short bones, and consist of spongy substance surrounded with a layer of compact substance.

In the skull, most of the flat bones and many of the irregular bones have spongy substance between their two layers of compact substance, but in some of them the spongy tissue is invaded and replaced by cavities which contain air—the walls of the cavities being composed of compact bone. These cavities are **air-sinuses**; they give lightness to the bones and act as resonating chambers for the voice; they are extensions from the cavity of the nose, with which they are permanently in communication (Figs. 163-166) and their walls are lined on the inside with *muco-endosteum*, which is continuous with the muco-periosteum that lines the interior of the nose. Inflammation of the mucous lining of the nose in a "cold in the head" may extend to the lining of the sinuses and give rise to dull headaches. The air-spaces in the part of the skull called the mastoid temporal are extensions from the cavity of the tympanum or drum of the ear, and lie in the midst of spongy bone, replacing the marrow and some of the spongy substance. The bones of the skull which contain air-cavities are called **pneumatic bones** [πνεῦμα (pneuma) = wind or air].

Characters of Living Bone.—The following five points are to be noted with reference to a bone when it is living, or when it has been only recently removed from the body and has not been cleaned and dried.

(1) The articular parts of most bones are covered with a layer of **articular cartilage**; and, at those joints at which the bones are free to move, the articular cartilage is smooth to facilitate movement. But many of the bones of the skull, for example, have no articular cartilage: their articulating margins are rough and are united by fibrous tissue.

(2) The whole of the bone, except the articular part, is covered with a laminated membrane of fibrous tissue called **periosteum** [περί (peri) = around; ὀστέον (osteon) = a bone]. The periosteum is adherent to the bone owing to the number of blood-vessels and nerves which pass from the periosteum into the bone, and because numerous minute bundles of fibres, the *perforating fibres* of Sharpey, pass from the periosteum into the substance of the bone; within the bone the bundles are calcified like the rest of the bone, and 'nail' the bone-lamellæ together. The blood-vessels which carry blood to and from the bone and marrow lie in the periosteum before they enter the bone (arteries), and after they leave it (veins); if the periosteum is stripped off a living bone by accident or disease the underlying part of the bone may die owing to the loss of its blood-supply.

(3) The muscles, tendons, intermuscular fibrous septa [*septum* = a hedge, barrier, partition], and the ligaments are attached partly to the periosteum and partly to the bone directly. In muscles with fleshy attachments the muscle-fibres have microscopic tendinous ends which blend with the periosteum; some of the fibres of the tendons, the septa, and the ligaments blend with the periosteum, but a great many are prolonged into the bone as perforating fibres, and the tendons, etc., are therefore firmly attached to bone, being, in fact, in continuity with the non-calcareous part of it.

(4) The medullary cavity is filled with yellow marrow, and the cavities in spongy bone with red marrow.

(5) The cavities in spongy bone are lined with a delicate membrane of fibrous tissue called **endosteum** [ἔνδον (endon) = within]; and, in a long bone, the medullary cavity is lined with endosteum continuous with that in the ends of the bone. The endosteum is connected with the periosteum on the outside by means of the fibrous lining of the tunnels through which the blood-vessels pass.

Bone-Marrow.—Red and white blood-corpuscles are formed in the bone-marrow. After birth the marrow is the only normal source of the red corpuscles; and, in adults, the marrow

is the chief source of those varieties of white corpuscles that have distinctly stainable granules. Blood-platelets also are possibly formed in the marrow. In infants, red marrow pervades all bones. In the long bones, it is found not only in the spongy parts but also in the medullary cavity and even in the larger Haversian canals. It is gradually replaced by yellow marrow. At puberty the red marrow is found only in the spongy bone; and, as age advances, it is replaced by yellow marrow in the spongy bone of peripheral parts—distal ends of long bones and the lower part of the backbone (Piney, 1922). Red marrow persists in the sternum throughout life, and samples for examination are obtained clinically by *sternal puncture*. But, in certain diseases of the blood, the red marrow may increase, invade its former territories and replace the yellow marrow.

The **yellow marrow** is simple in structure. It is adipose tissue, and is the most purely fatty tissue in the body; but it still contains a few cells that give rise to blood-corpuscles.

The **red marrow** is the important blood-forming organ. It consists of a large number of cells contained in the meshes of a delicate sponge-work of reticular tissue in which numerous blood-vessels—chiefly veins—ramify and anastomose. The red marrow owes its colour to the red cells inside and outside the vessels. The cells are of different kinds:—(1) A large number of amœboid marrow-cells or myelocytes; (2) white blood-corpuscles; (3) erythroblasts; (4) red blood-corpuscles; (5) a few giant cells; (6) a few large fat-cells. The **marrow-cells** give rise to *white blood-corpuscles* by mitotic division. The **erythroblasts** are nucleated cells of two varieties—a larger and a smaller—and are reddish [ἐρυθρός (erythros) = red]. The larger give rise to the smaller by mitotic division. The smaller ones give rise to the *red blood-corpuscles* by losing their nuclei (probably by extrusion) and by becoming flattened discs. The **giant cells** resemble osteoclasts, and, indeed, are most numerous where bone is undergoing absorption, though they are not limited to such places.

The degenerated marrow found in the skull-bones of aged people is called *gelatinous marrow*.

The **blood-vessels** reach the yellow marrow through the canals in the thick, compact bone of the shaft, and they supply the bony substance on their way through it. To reach the red marrow they have to pierce only the shell of compact bone; they ramify in the red marrow, and send small twigs into the surrounding bone. Bone and fat are inactive tissues, requiring little blood; the blood-vessels in the part of the shaft that encloses the medullary cavity are therefore small and relatively few. Red marrow is an active tissue requiring a generous blood-supply; numerous blood-vessels of fairly large size therefore perforate the short and flat bones and the non-articular parts of long bones at and near their ends. The veins are larger and more numerous than the arteries; for the veins are the channels by which newly made blood-corpuscles are taken away from the marrow. Inside the spongy bone the veins are large blood-spaces enclosed by thin walls without muscular tissue.

The **nerves** that accompany arteries into the bone are probably *nervi vasorum*.

The **lymph-channels** of bone are cleft-like spaces in the areolar sheaths of the blood-vessels in the Haversian canals; and they end in the lymph-vessels of the periosteum. There are no lymph-vessels in the bone-marrow.

Appearances of a Dried Bone.—Bones used for study have been macerated and dried. In this process all structures attached to the bone, including periosteum and articular cartilage, are removed and the marrow and endosteum shrivel.

Though the articular cartilage is absent the **articular part** of a bone can still be identified. The articular cartilage that covers the upper and lower surfaces of the bodies of the vertebræ does not have a free surface but is adherent to a thick disc of fibro-cartilage (Fig. 313); and the part covered by the articular cartilage can be recognized by its peculiar appearance, which resembles unglazed porcelain. But in most bones the articular cartilage has a free surface which is smooth and glistening, and the bone covered by it is also smooth and polished; some other parts of the bone may be quite smooth but do not have the polished or glazed appearance. The numerous small apertures on the surfaces of a bone, except the articular surfaces, are the outer ends of the canals or tunnels through which the blood-vessels pass on their way to and from the bone-marrow and the substance of the bone. At the ends of a long bone, and on its shaft near the ends, these small foramina [*foramen*—a hole] are scattered, and are largest and most numerous near the margins of the articular surface. In the greater part of the shaft of a long bone the foramina are barely visible to the naked eye, but one is always relatively large and is called the **nutrient foramen**. Its position is fairly constant in different specimens of the same bone; the tunnel into which it leads is the *nutrient canal*; the vessels which pass through it are called the *nutrient artery* and *vein*, and they convey the blood to and from the yellow marrow and the substance of the shaft. The ends of a long bone have a double blood-supply—(1) from vessels that enter through their own non-articular surfaces; (2) from vessels that run into them from the adjoining parts of the shaft. In a dried bone, some of the foramina on the shaft near the end can be seen to be directed towards the end. It should be noted,

however, that no blood-vessels pass through the epiphysial plate of cartilage (see p. 116) from the shaft in the young bone (Harris, 1929).

On the exterior of bones there are many grooves and hollows, ridges, eminences, and projections. The depressions and elevations are chiefly for the attachment of muscles, tendons, and ligaments. The rough lines which often indicate the position of a muscle-attachment are made by fibrous tissue and, if present, show the position of its fibrous sheath or of fibrous septa within the muscle. For any one bone the markings vary in different bodies, but are sufficiently alike for a general description to be applicable to all. The **surfaces** of a bone are named usually from the direction in which they face; *e.g.*, a surface directed *forwards* is called the *anterior* surface. Sometimes surfaces are named according to their relative propinquity to a cavity; *e.g.*, the *outer* surface of a rib is the one farther away from the cavity of the chest. Some are named after neighbouring structures; *e.g.*, the *costal* surface of the shoulder-blade is the surface directed towards the ribs [*costa* = a rib]. The edge or ridge between two surfaces is called a **border** or margin, and is named from the direction in which it looks.

The depressions and elevations receive general names (most of which are in the list below) and special names according to their position or characters.

A student is often asked to say whether a given bone or other bilateral organ belongs to the right or the left half of the body. It is a ready means of testing whether he knows the broad, main features of the organ; for if a structure is held in the position it occupies in the erect body (*i.e.*, with its upper end upwards and its anterior surface facing forwards), then its lateral surface or end or border will look towards the side to which it belongs. If a student does not know enough about a structure to enable him to distinguish which is the upper part, which is the front, and which is the lateral part, there is little merit and no advantage in his knowing whether it is left or right.

Definition of Terms

The terms *median*, *medial*, *lateral*, etc., are explained on pp. 3 and 4.

Aditus. The entrance into a cavity. [*Aditus* = an entrance.]

Ala. A projection or a surface shaped like a wing. [*Ala* = a wing.]

Alveolus. A deep, narrow pit. [*Alveolus* = a small cavity.]

Antrum. A cavity or hollow filled with air and lined with mucous membrane in the interior of a bone. [Ἄντρον (antron) = a cave.]

Canal. A passage or tunnel; unlike the artificial watercourses of the same name, a canal has complete walls round about it.

Condyle. A smooth rounded eminence covered with articular cartilage. [Κόνδυλος (condylos) = a knuckle.]

Crest or *Crista.* A sharp, upstanding ridge of bone.

Epicondyle. A prominence or projection situated above a smooth articular eminence, though that eminence may not be called a condyle. [Ἐπί (epi) = above or upon.]

Facet. A small smooth area usually covered with articular cartilage. Nearly all smooth articular surfaces on bones are referred to at times as facets.

Foramen. A hole; it may be an aperture through which one can see, or it may be the end of a canal.

Fossa. A depression, usually broad and shallow. [*Fossa* = a ditch.]

Hiatus. A slit or gap.

Labium or *Lip.* The margin of a groove or a hollow; when a ridge or a border is thick its margins are called its lips.

Lamina or *Lamella.* A thin plate or sheet.

Ligula or *Lingula.* A projection shaped like a tongue.

Line or *Linea.* A low ridge, usually narrow.

Meatus. A short canal. [*Meatus* = a way, passage.]

Process. Any kind of projection or prolongation.

Sinus. A cavity in a bone lined with mucous membrane and filled with air; used with very different meanings in other systems. [*Sinus* = a curve, fold, interior, hiding place, bay, or gulf.]

Spina or *Spine.* A sharp-pointed projection.

Squama. A portion of bone shaped like a scale. [*Squama* = a scale.]

Sulcus. A groove or furrow.

Trochlea. A pulley or pulley shaped surface. [Τροχιλία (trochilia) = the sheave of a pulley.]

Tuber, *Tubercle*, and *Tuberosity* [*tuber* = a bump or swelling] are terms applied, without much distinction, to any kind of rounded swelling or eminence, large or small, smooth or rough. The term *tubercle*, with quite another meaning, is well known, owing to the endemic prevalence of disease caused by tubercle bacilli, but the origin of the term is the same. Tubercular diseases were so named because hard nodules or *tubercles* were found on the surface of affected organs.

Uncus. A part shaped like a hook. [*Uncus* = a hook or barb.]

Cartilage

Cartilage or gristle is present in many parts of the body. It is supplementary to bones, and in many situations it takes the place of bone. It is much

more abundant in a young animal than in an adult, for much of the cartilage present in the young animal is replaced by bone during the period of growth; but in many places cartilage persists throughout life. Cartilage is nourished by tissue fluids. Neither blood-vessels nor nerves have been found in the actual substance of cartilage, though blood-vessels are present in the clefts in the larger pieces. It is elastic, but is not hard like bone; for it consists of collagenous material impregnated with chondroitin sulphate, with only a trace of lime-salts. It is less yielding and pliable than tendons and ligaments, though it is cut more easily with a knife. Cartilage is covered with a fibrous membrane called **perichondrium**; the only exception is articular cartilage, which has a covering only on its margins. [Περί (peri) = around; χόνδρος (chondros) = cartilage.]

Classification of Cartilage.—There are three main varieties — hyaline cartilage; white fibro-cartilage; yellow fibro-cartilage.

Hyaline cartilage appears homogeneous to the naked eye and is glass-like in that it is bluish-white and translucent—hence the name 'hyaline' from ὕαλος (hyalos) = glass. It is, however, elastic and deformable by pressure and is easily cut with a knife or damaged by pressure over a small area. Hyaline cartilage is found mainly as a survival and continued growth of parts of the cartilage model which usually precedes bone in development (*vide infra*). This persistence of cartilage occurs, during growth, in *epiphyses* and between parts of a bone which ossify separately. It also occurs in the case of *articular cartilage*, which should not ossify, or else in parts which ossify late or not at all, such as the *xyphoid process* or the *costal cartilages*. Hyaline cartilage is found also in the respiratory system where it forms the cartilages of the *nose*, most of the cartilages of the *larynx* and the rings supporting the *trachea* and its branches, the *bronchi*. At birth a great deal of cartilage has been changed into bone already; but much of it still persists, especially at the ends of bones, and is gradually replaced by osseous tissue as growth goes on,

White fibro-cartilage consists of cartilage mixed with strong bundles of white fibrous tissue; it is therefore less homogeneous than hyaline cartilage and is tougher and more flexible; the fibrous tissue in it is most evident at its attachments to bone. It is found in the following situations:—(1) As *sesamoid cartilages* in a few tendons. (2) As *articular discs* in the joint between the lower jaw and the skull, the joint at each end of the collar-bone, and at the wrist joint. (3) In the shoulder joint and the hip joint, as a ring-like *labrum* attached to the rim of the articular socket of the shoulder-blade and the hip-bone. [*Labrum* = labium = a lip.] (4) In the knee joint, as two crescentic bodies called *semilunar cartilages*. (5) In the backbone as thick *intervertebral discs*, one between the bodies of each two vertebræ and attached firmly to both of them, uniting them together; these discs account for most of the white fibro-cartilage in the body; they are easily recognized between the bodies of the vertebræ on the sawn surface of a sirloin of beef. (6) A similar plate unites the two hip-bones at the *pubic symphysis*—that is, the joint in the median plane at the lower part of the front of the abdomen.

Yellow fibro-cartilage consists of cartilage containing bundles of yellow elastic fibres, but little or no white fibrous tissue. It is found in the *external ear*, in the *pharyngo-tympanic tube* (that is, the passage between the drum of the ear and the throat), and in some of the cartilages of the *larynx*.

Development of Bone

Bone is mesodermal in origin (p. 55) and develops as a sequel to the deposit of mineral salts in connective tissue, or in cartilage. The initial deposition of mineral salts is termed **calcification** which is to be distinguished from **ossification**, a term used to mean the process by which true bone is formed with its characteristic structure. When bone is formed directly in connective tissue it is referred to as **membrane bone** because of the membranous character of the tissue in which it develops. More frequently a preliminary foundation or model of cartilage is formed; this cartilage goes through the stages of calcification and ossification and is then referred to as **cartilage bone** to indicate its mode of development.

Formation of Cartilage Bone.—The first visible step is a closer aggregation of the mesodermal cells where the bone will develop. This aggregation of cells is the **rudiment** of a bone and the cells assume an appearance intermediate between fibrous tissue and cartilage, forming **pro-cartilage** which is gradually transformed into true hyaline cartilage. Each of the cells in the interior of the bone-rudiment enlarges, and as it does so it makes a thick *capsule* or envelope round about itself and then divides into two; each of the two enlarges, makes a capsule and divides; and so on—two new capsules being formed inside each older one. In that way the rudiment increases in size until a mass of tissue is formed consisting of cells—now called *cartilage-cells*—which are embedded in a dense substance of fused capsules made by the cells themselves and forming the **cartilaginous periblast** (or *matrix*—an unsuitable name.) The outermost part of the bone-rudiment is retained as the **perichondrium**, which consists of an outer layer mainly fibrous, and an inner layer mainly cells and blood-vessels. [Περί (peri) = around; βλαστάνω (blastanō) = grow; χόνδρος (chondros) = cartilage.]

Appearance of Ossific Centres.—The process of ossification begins at different dates in different bones, but nearly all the bones begin to be ossified during the second month of

intra-uterine life, and the date is fairly constant for any one bone in different subjects. The point in a bone where ossification begins is called a **centre of ossification**, and the centre is said to *appear* at such and such a date. Many of the bones are ossified from more than one centre. When several centres of ossification appear in a developing bone at widely separated dates, the first to appear is called the **primary centre** and the others are called **secondary centres**. By far the largest part of a bone is ossified from the primary centre. When ossification starts at more than one point in a bone about the same time, each is called a primary centre.

Ossification in Cartilage.—Ossification begins usually about the *middle* of a cartilage-bone. At that point there is a great *increase* both in the size of the cartilage-cells and in the amount of the substance around the cells; and the next step is the *deposition of lime-salts* in that substance. As the process spreads from the centre the *cartilage-cells* immediately ahead of the calcifying region *multiply* rapidly and become arranged in characteristic columns (Fig. 126); in that way the size of the 'bone' as a whole is increased—the multiplication and increase in a long bone taking place chiefly lengthwise. The deposit of lime-salts goes on till, in a little while, the

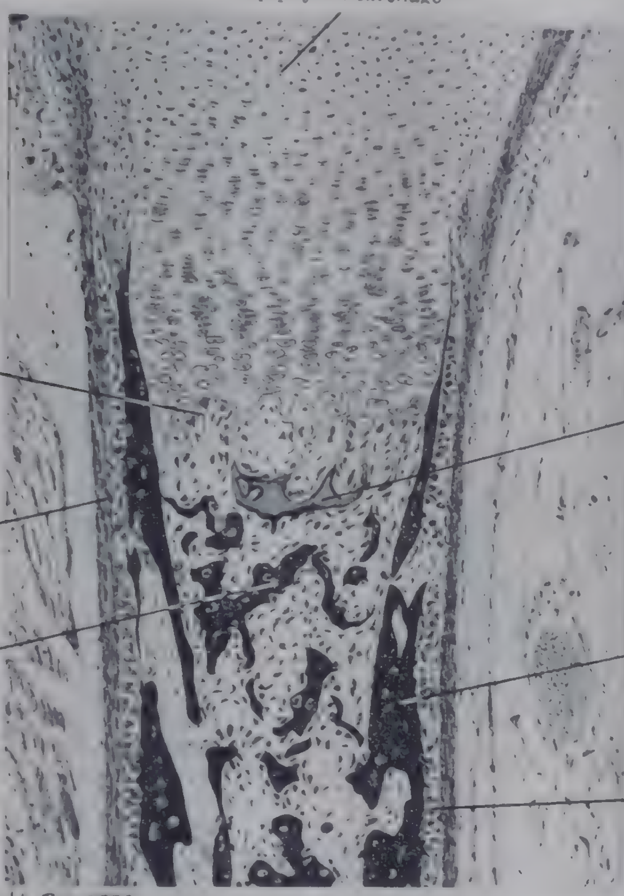


FIG. 126.—OSSIFICATION IN CARTILAGE (Le Gros Clark, 1945).
Longitudinal section of metatarsal bone of fœtal kitten. Note the arrangement of the zones described in the text.

cartilage-cells become imprisoned inside the calcareous walls built around them, and, having their supply of nutriment cut off at the same time, they die and shrivel, leaving the *spaces* they occupied *nearly empty*.

This calcified cartilage is not bone, though calcification is part of the process of ossification; but while these changes have been taking place in the centre a similar change, which leads to the *production of true bone*, has been taking place on the outside of the cartilage. The cells of the deeper layer of the perichondrium have formed a clear *ground-substance* round about themselves; fibres have been laid down in that, and **bone** is produced by the deposit of lime-salts in the ground-substance between and among the cells and fibres, and, possibly, within the fibres themselves. The calcified cartilage in the interior is thus encased in bone formed by the perichondrium; the perichondrium, since it now surrounds bone, is called periosteum, and that bone is called **subperiosteal bone**.

The calcified cartilage is short-lived. Blood-vessels grow in from the deeper layers of the periosteum, and they are accompanied by more than one kind of cell. Some of these cells are called **osteoclasts** [κλάω (claō) = break, destroy]. They eat their way through the subperiosteal bone, making passages through it for the blood-vessels they accompany to run along; and when they come to the calcified cartilage they consume a great part of it and so enlarge the spaces in the interior. Other cells that accompany the blood-vessels are called *osteoblasts* or **bone-forming cells** [βλαστάνω (blastanō) = grow, produce]. They are the same kind of cells around which, and under the influence of which, the bone is formed underneath the periosteum; they form layers of bone on the calcified cartilage that the osteoclasts have so far left untouched, and

thus enclose the enlarged spaces with bony walls; the spaces become filled with marrow by the multiplication of fat-cells and other cells that accompany the blood-vessels. The remains of the calcified cartilage on which these layers of bone are laid down become in time destroyed by the osteoclasts, until no vestige of cartilage or cartilage-cells is left in the interior.

Both under the periosteum and in the interior some of the bone-forming cells are left in small lacunae between succeeding layers of bone; these lacunae are connected together by *canaliculi* through which nutritive material reaches the cells in them; the cells therefore survive, under the name of *bone-corpuscles*, as long as the bone lives.

It is not only the calcified cartilage that is destroyed by osteoclasts. The cavities in spongy adult bone are much larger than the cavities in newly-formed bone. This is because osteoclasts have removed a great quantity of the first-formed bone, so that several of the original cavities or spaces run into one. The strength of the bone, however, is maintained and increased because bone-forming cells lay down additional layers of bone on what remains of the original bone, and in that way the walls of the enlarged cavities are thickened. And it is not only in the bone which is formed in the cartilage that those changes occur; the original subperiosteal bone also is largely destroyed and is replaced by a second osseous deposit. If the horizontal diameters of the body of a vertebra of a new-born child are compared with the diameters of the body of an adult vertebra, it will be clear that only a small part in the centre of the adult bone is pre-formed in cartilage. The greater part in those diameters is formed by layer after layer deposited under the periosteum. In that subperiosteal bone the same process has gone on as in the centre—ingrowth of blood-vessels, excavation by osteoclasts, and a rebuilding and a strengthening of the remains by bone-forming cells; and that strengthening is especially marked in the last-formed layers in the adult bone so as to produce the compact bone at the surface.

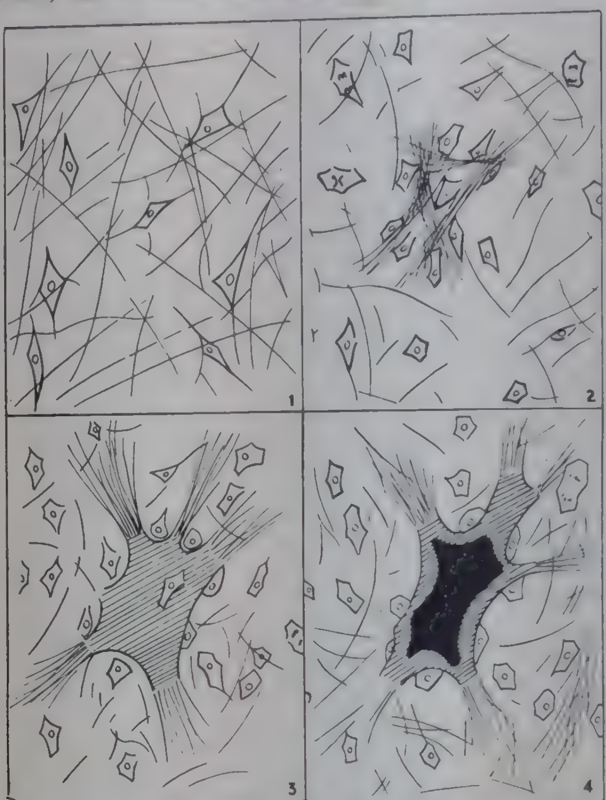


FIG. 127.—OSSIFICATION IN MEMBRANE (Leriche and Policard, 1926).

Schematic representation of the stages of formation of bone without the pre-formation of cartilage.

1. Oedema of connective tissue.
2. Multiplication of fibrils.
3. Deposit of pre-osseous ground-substance.
4. Deposit of lime-salts.

Some of the tissue which grows in with the blood-vessels from the periosteum becomes converted into the perforating fibres of Sharpey.

In bones that have a medullary cavity the osseous tissue which succeeds the calcified cartilage is entirely removed during the formation of the cavity; and, further, while new bone is being formed on the outside under the periosteum, osteoclasts are continually eating away the bony tissue next the medullary cavity in order to enlarge the cavity, both in length and width, until it attains adult size. In a bone like the femur none of the bony tissue present at birth and none that was created during early life is left at all, for the medullary cavity of the adult femur is larger than the whole femur of a child. Absorption of bone takes place also at the surface, especially at the ends of long bones—modelling them in order that their proper shape may be maintained as they grow.

The **Haversian systems** are produced in the following way:—Blood-vessels from the periosteum grow into the original subperiosteal bone, and the osteoclasts create long and relatively wide spaces around those vessels. The bone-forming cells then multiply and arrange themselves round the inside of the wall of the space, and produce layer after layer around the space, forming a series of concentric tubes, the innermost one enclosing the original space, now called the Haversian canal. As successive layers are produced, bone-forming cells are left between them as bone-corpuscles in lacunæ. Among the Haversian systems a few of the original layers of the subperiosteal bone or the remains of earlier Haversian systems survive as *interstitial lamellæ*; while, at the surface of the bone, the last-formed layers of subperiosteal bone are left unaltered as *circumferential lamellæ*.

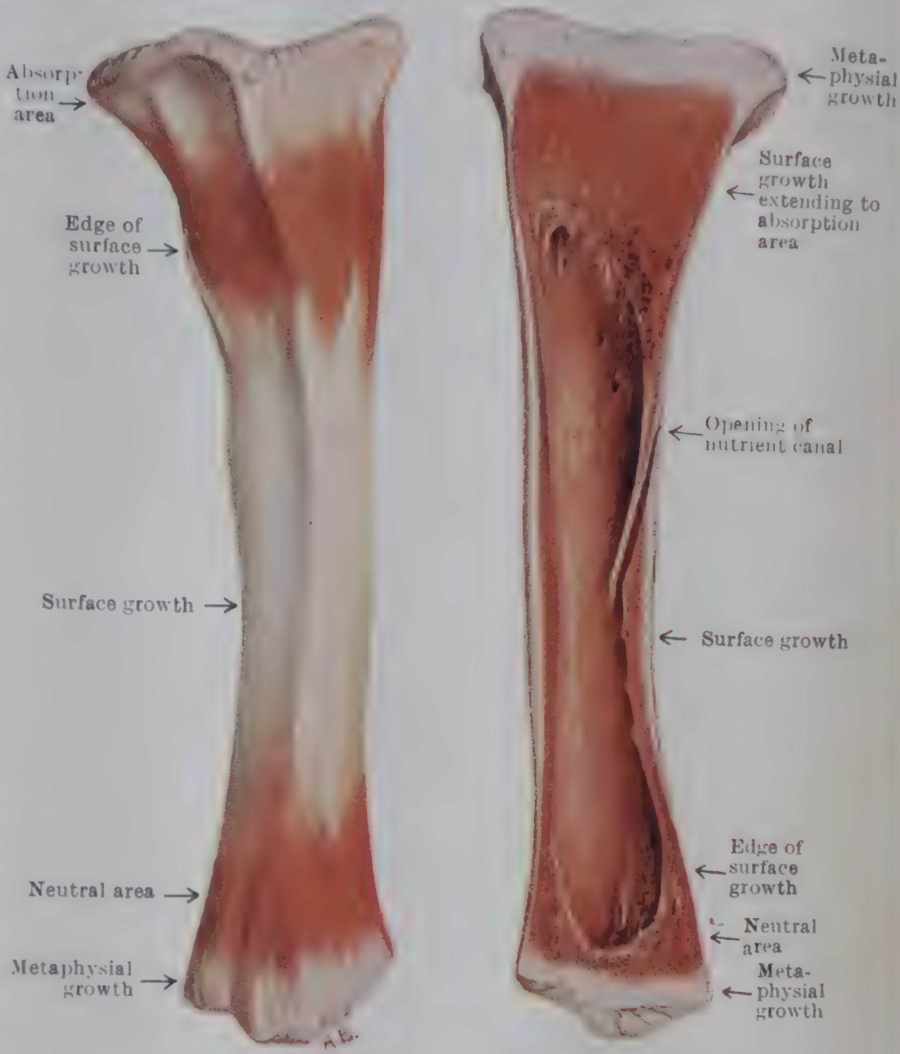
Ossification in membrane occurs in certain skull-bones, in the lower jaw-bone and in part of the collar-bone. The cartilaginous stage is missed out; in other respects the process of ossification is the same as in a cartilage-bone (Fig. 127). Osseous tissue is deposited in or underneath the outer layers of the sheet or membrane of mesoderm, which thereupon becomes periosteum; that is followed by excavation by osteoclasts and rebuilding by bone-forming cells—in the same sequence as in ossification under the periosteum of a bone pre-formed in cartilage.

Formation of Joints.—The mesodermal tissue between two developing bones becomes

converted into the structures that bind the two bones together, and these structures vary according to the class of joint. In a synovial joint—in which there is a cavity in the joint and the bones are free to move—the outer layers of the condensed mesoderm become converted into the *articular capsule* of the joint; the cells in the interior disappear and the *joint-cavity* is formed (Fig. 312). In certain joints the cells inside do not all disappear; those that remain give rise to the fibro-cartilaginous plates and the ligaments found in the interior of certain synovial joints. (See Section on Joints, p. 339.)

Growth of Bone.—The absorption of bony substance in some places and deposition of new bone in others which occur during development is continued thereafter to provide for growth. The process may be observed in bones taken from animals fed for suitable periods on substances, such as madder, which colour new bone as it is laid down (Figs. 128, 171). This continuation of controlled growth and absorption permits alterations in the shape of bones, alterations which are necessary if proper proportions and the correct relative position of individual parts of the bone are to be retained during growth.

The principles involved, with a review of the work of others as well as his own, are stated by Brash (1934) in his 'Struthers' Lecture and the student is referred to this and to the recent work by Lacroix (1949) for fuller discussion. One essential feature is that bone is laid down on or absorbed from a surface, whether this be an outer surface, the surface of a cavity, or the surface of a lamella in spongy bone. It can be seen that, if bone is laid down on one side of a given part of a bone and absorbed on the opposite side, the effect will be to move the part bodily in one direction. This will hold good whether the part is a projection or a hollow, the wall of a cavity such as the skull, or the whole thickness of part of a long bone.



A. Posterior aspect. B. Longitudinal section.

FIG. 128.—DIAPHYSIS OF TIBIA OF MADDER-FED PIG TO ILLUSTRATE THE MODE OF GROWTH OF A LONG BONE. (After Brash, 1934.)

The animal was $40\frac{2}{7}$ weeks old, and the madder had been omitted from the food for 30 days. The new bone added during that period is white, in contrast to the old, red bone.

The principle of surface-accretion as the only method by which a bone grows in size implies that there is *no interstitial growth* of bone as distinguished from interstitial changes in density which are constantly taking place. The proof that interstitial growth does not occur is threefold. (1) The experiment of inserting two metallic marks in the long bone of a living animal, as performed by John Hunter (1772) and others, shows that these remain the same distance apart as the bone grows in length; and metallic rings placed around the bone under the periosteum become embedded in the bone by surface-accretion and may be found later in the marrow cavity as that is enlarged by absorption. (2) If the long bones of a child show "lines of arrested growth"—transverse planes of greater density due to heavier calcification at the ends of a bone growing at a slower rate during an illness—repeated radiographic observation at increasing ages shows similarly that these remain the same distances apart as the bones grow in length (Harris, 1933). (3) The indirect madder method—colouring the bones completely and then omitting the dye for a definite period—leads to the same conclusion, since the increase in length is accounted for by the new white bone which appears at the ends and the increase in girth by the subperiosteal deposit (Fig. 128).

All three methods thus demonstrate that growth in length of a long bone occurs at the ends only; and measurements, which can be used to calculate the *rates* of growth (Payton, 1932), show that growth is greater at one end which, therefore, is termed the 'growing end' of the bone (p. 117).

Most bones grow in two dimensions by deposition of osseous tissue under the periosteum, and in the third dimension by transformation of cartilage into bone. For example, the body of a vertebra grows in breadth and in thickness by sub-periosteal deposit of bone, and in height by increase of cartilage at its upper and lower surfaces. A long bone grows in girth (*i.e.*, breadth and thickness) under the periosteum, and in length by increase of the cartilage at its ends. As growth takes place at the junction between bone and cartilage the bone which has been laid down is left behind to become part of the shaft. It has, however, been formed at a wide part of the bone and 'modelling absorption' must take place on the surface if the proper form of the bone is to be maintained.

Failure of modelling absorption may occur, rarely even in bones that appear to be normal in other respects (see Harris, 1933; Brash, 1934). Usually associated with abnormal bone-growth (Keith, 1920), the result is a characteristic club-shaped appearance of the ends of the bones; and it seems to have a genetic basis (Grüneberg, 1935). For a remarkable case in a child associated with "marble-bones" (Albers-Schönberg disease), see Lightwood and Williams (1939). In bones such as those of the skull which are developed in membrane, growth takes place under the periosteum mainly by deposition of new bone on the outer surface and absorption from the inner surface. Absorption or accretion will occur, however, wherever they are required to maintain the proper proportions of the bones.

Some short bones and some flat bones are ossified wholly from the **primary centre** of ossification. They continue to grow: (1) in the case of flat bones developed in membrane, until the bone-forming cells in the periosteum and in the tissue which separates the margins of bones cease to function as bone-forming cells; and (2) in the case of bones developed in cartilage, until the subperiosteal bone-forming cells cease to function and the cartilage-cells in the cartilaginous covering of an articular surface cease to multiply. At the articular part of a bone the multiplication of cartilage-cells and the process of ossification cease before the cartilage is all used up; a layer of articular cartilage is thus left, and it survives till death or until destroyed by disease.

All long bones and many others acquire **secondary centres** that appear in outlying cartilaginous parts into which ossification from the primary centre does not extend. Nearly all the secondary centres appear after birth, and the method of ossification from them is the same as from primary centres, except that the whole of the bone is formed within the cartilage, which, until growth ceases, enlarges by multiplication of its cells.

The part of a bone ossified from the primary centre is called the **diaphysis**. A part ossified from a secondary centre is called an **epiphysis**, and a secondary centre is therefore often called an *epiphysial centre*. ['Επίφυσις from ἐπί (epi) = upon, φύω (phyō) = make to grow.]

Ossification in the cartilage proceeds from the primary and secondary centres till only one part or two parts of the cartilage are left: (1) A thin plate, called the **epiphysial cartilage**, persists for a time between the diaphysis and the epiphysis (Fig. 306 A, p. 335); its edge at the surface of the bone forms the **epiphysial line**. (2) In a bone where the epiphysis is the articulating part the articular layer of cartilage survives.

So long as the epiphysial cartilage lasts the bone continues to grow on each side of it—that is, both diaphysis and epiphysis continue to grow—the rate of growth being much more rapid in the diaphysis than in the epiphysis, possibly owing to absorption of the epiphysis on its diaphysial side which counteracts the growth under the articular cartilage (Payton, 1933). The diaphysis continues to grow at the expense of the epiphysial plate, and this enlarging part of a diaphysis is sometimes called the *metaphysis*. To maintain the existence of the plate, the cells farther away from the diaphysis go on multiplying; but a time comes when they cease to do so, and the ossifying process in the diaphysis—invading the cartilage—uses it up. The diaphysis and epiphysis are then said to have joined or *fused*, and the bone ceases to grow in that situation. The epiphysis grows at the expense of the peripheral cartilage, whose cells multiply to maintain it; so growth goes on in the epiphysis until they cease to multiply—at about the same date as cessation in the epiphysial plate. If the epiphysis is on a non-articulating part of the bone—*e.g.*, iliac crest—the cartilage is all replaced by bone; but in bones where the epiphysis is articular, its outermost layer of cartilage remains.

Healthy periosteum, or endosteum, retains the faculty of producing new bone when required and absorption of bone continues to take place where necessary. Broken bones can accordingly be repaired and bones can be remodelled to meet increased exercise, or atrophy from lack of it. Harris (1933) points out that during growth in a long bone the longitudinal or primary trabeculæ are consolidated before the transverse or secondary trabeculæ are laid down and, in cases of atrophy, the transverse trabeculæ are in great measure absorbed before any changes occur in longitudinal trabeculæ. The length of the bone and the function of the joints and muscles are thus preserved.

Epiphyses (Figs. 229, 263).—The shaft of a long bone is developed from a primary centre, and the shaft is therefore the diaphysis. Every long bone has an epiphysis at one end; most of them have epiphyses at both ends; in some bones there are more than one epiphysis at the end, *e.g.*, the distal end of the humerus, the proximal end of the femur. When a long bone has an epiphysis at only one end, it is at the end at which there is the more movement. Most epiphyses are ossified from one centre, but some are ossified from more than one, and the different parts ossified from these separate centres coalesce before the union with the diaphysis, *e.g.*, the proximal end of the humerus. When there are more than one epiphysial centre at the end of a bone, and the parts ossified from these centres do not coalesce but join the shaft separately, each part is called an epiphysis, *e.g.*, the parts at the proximal end of the femur.

According to Parsons (1904, 1905, 1908) secondary centres of ossification fall into three classes :—(1) 'Pressure epiphyses', (2) 'traction epiphyses', related respectively to pressure at the articulating ends of long bones and to the pull of muscles, and (3) 'atavistic epiphyses' representing bony elements which have lost their independence in the course of evolution, *e.g.*, the secondary centres of the ischium and pubis and of the coracoid process of the scapula. The epiphyses of the trochanters of the femur are typical 'traction epiphyses'; but it should be noted that they do not necessarily depend upon the stimulus of muscle-action during the growth-period of an individual (Appleton, 1925).

Ossification of Epiphyses.—Post-natal changes in epiphyses of the long bones in the limbs may be separated into three main stages. (*a*) Secondary centres of ossification appear from the time of birth to 5 years of age. (*b*) Ossification continues to spread from these centres until the age of about 12 years in girls or 14 years in boys. (*c*) This is followed by a period from 12 or 14 years to 25 years during which the epiphyses fuse with the diaphyses and growth in length ceases as fusion occurs. This process is speeded up in girls at five years, and again at ten years (Wingate Todd, 1933, 1937), so that after these periods in particular the female is in advance of the male and the dates of epiphysial fusions in general are earlier.

Exceptions of some practical use include the appearance of a centre in the distal end of the femur in the last month of fœtal life. The proximal end of the tibia often develops a centre late in this month and the upper end of the humerus also may do so. A child is assumed to be at full-time if one of these centres is present. At the other end of the scale the clavicle, or collar-bone, has an epiphysis at its medial end which is exceptional in that its centre appears late (18-20 years) and fusion is delayed until between 25 and 30 years. A clavicle with an epiphysis present but unfused would be from a person between 18 and 30 years old.

As a general rule, when a centre of ossification in an epiphysis appears early the epiphysis fuses late and vice versa. The humerus, for example, is notable for the long period over which its stages of ossification are spread. A centre is present in the head shortly after birth and fusion of the epiphysis does not occur until the age of 18 to 21 years. The intermediate stages are marked by the comparatively late appearance of centres at the lower end of the bone and their correspondingly early fusion.

The end of a bone bearing an epiphysis which fuses late (or a single epiphysis for that bone) grows for a longer time and also grows more rapidly than the other end. It therefore contributes more to the length of the bone and is sometimes referred to as the "growing end". This differential rate of growth affects the course of the nutrient canals which are directed away from the growing end. This is because a nutrient artery maintains its position relative to the bone as a whole and, since the canal is formed by new bone laid down round the artery, the outer opening of the canal likewise retains its relative position. As growth proceeds at the "growing end", the nutrient artery and, with it, the nutrient foramen are displaced away from the slow-growing or stationary end of the bone and from the inner opening of the canal which itself is displaced in the same direction by absorption. The canal, therefore, becomes oblique as it grows, slopes away from the "growing end" and continues to point approximately to the site of the primary ossification centre.

Most of the epiphysial centres in the vertebræ and ribs and in the shoulder and pelvic girdles do not appear till puberty and fuse about the age of 25; this does not apply, however, to the fusion of the separate parts entering into the formation of the shoulder and hip joints. These conform more with the arrangement at the ends of long bones adjacent to them.

No student should ever attempt to memorize lists of dates of appearance of epiphysial centres or of fusion with the diaphysis, but a general knowledge is necessary. It is, for example, simple enough to group the dates of fusion of epiphyses in the long bones of the limbs. Using the figures given in this text and taking them according to their proximity to joints, the figures for the male are as follows :—Hip and ankle joint regions, 18 years; knee and elbow, 18-19 years; shoulder and wrist, 21 years. Fusion will take place earlier by two or three years in the female.

The most important of the epiphyses of a vertebra are those that cover the upper and lower surfaces of its body. In lower animals these epiphyses are thin plates; in Man they are flattened rings. These ring-like epiphyses do not fuse with the body of the vertebra till the full adult stage is reached, and that stage may not be reached till the 25th year or later; the back, therefore, goes on growing for a longer time than the limbs do, for the limb-bones have usually all ceased to grow before the 21st year.

For any one epiphysis, the date of appearance of its centre varies in different children by weeks or months, and sometimes by one or two years. The date of union varies even more, especially in the backbone; it is common knowledge that some people reach their full height in their teens while others do not do so till after the age of 25. The sequence of the dates of union and the intervals between them remain proportionately the same in different people (see Stevenson, 1924) and, therefore, if the first to join do so at an earlier age than usual, ossification throughout the body will be completed at an early age. Centres appear and union takes place earlier in girls than in boys. The dates given under the individual bones are approximate averages; those for most of the limb-bones are taken from the table compiled by R. S. Paterson (1929), but see also the tables compiled by Wingate Todd (1930) and H. Flecker (1932).

Separation of Epiphyses.—The cartilages and the opposed surfaces of diaphyses and epiphyses have pronounced elevations and depressions which fit into one another, so that the bones can withstand knocks and jars and twists. None the less, an epiphysis sometimes is broken off. When a limb of an adult is subjected to violence, a bone may be broken or put out of joint, but while the bones are growing there is an added danger: an epiphysis may be damaged or

break away. When that happens, the epiphysial cartilage is often injured so that the bone ceases to grow at that part after diaphysis and epiphysis have reunited. When a bone is broken near one end in a young person, it may be either an ordinary fracture or a separation of the epiphysis. It is important to recognize at the outset which it is; and it is important, therefore, to remember the period at which epiphyses usually join. Moreover, in a negative radiograph of a young person an epiphysial cartilage appears as a dark line, and that line may be mistaken for a line of fracture if it is forgotten that there is an unjoined epiphysis in the region. (In an adult, even though the epiphysis fused long ago, the position of the epiphysial line may still be indicated in a negative radiograph by a thin, white line known as the "*epiphysial scar*"—Pl. III.)

Epiphyses can be seen in radiographs and in the skeletons of relatively young people and young animals in museums. They can be seen at home also: epiphysial plates of vertebræ can be seen in a sirloin of young beef; epiphyses of limb-bones can be found in a leg of lamb.

THE SKELETON

The human body is divided into the following parts: the **head** and **face**; the **neck**; the **trunk**, subdivided into the chest or *thorax* and the belly or *abdomen*; a pair of **upper limbs**; and a pair of **lower limbs.** The abdomen is further divided into a larger upper part called the *abdomen proper*, and a smaller part called the *pelvis*, situated below and behind the abdomen proper, between the two hips. The bones in the head, face, neck, and trunk are 80 in number in the adult and constitute what is called the *axial skeleton*. Excluding the small sesamoid bones, which are inconstant in number, there are 32 bones in each adult upper limb and 31 in each adult lower limb, and they constitute the *appendicular skeleton.*

The bones in the adult **axial skeleton** are—(*a*) the backbone or vertebral column; (*b*) the breastbone or sternum; (*c*) 12 pairs of ribs; (*d*) the skull, including the lower jaw-bone or mandible; (*e*) the hyoid bone; and (*f*) 3 pairs of tympanic ossicles.

The **vertebral column** is the fundamental part of the skeleton; it is common to all the great *vertebrate* class of animals, namely, fishes, amphibians, reptiles, birds, and mammals. It is situated in the median part of the back of the body and extends through the whole length of the neck and the trunk. The **sternum** lies in the median part of the front of the thorax. The twelve **ribs** make up the framework of the side and front and back of each half of the thorax. The **skull** is the skeleton of the head and face, and the **mandible** supports the lower part of the face. The **hyoid bone** lies in the front of the neck below the mandible and the tongue. The **tympanic ossicles** are little bones situated in the drum of the ear or tympanic cavity.

The bones of the **appendicular skeleton** are summarized in the sections on limbs.

VERTEBRAL COLUMN

The vertebral column or backbone is a long, curved pillar (Fig. 140) composed of a number of units, called **vertebræ,** which are placed in a series one above the other and are connected together by discs of fibro-cartilage and by ligaments. The bulky part of each vertebra is its anterior part and is its *body* (Fig. 131). The most posterior part of a vertebra is a projection called its *spine*, whence arose the names 'spine' and 'spinal column' used as synonyms for backbone. The spines can be felt in the floor of the median furrow that begins at the nape of the neck and ends between the buttocks.

In the **child** there are 33 separate vertebræ, but in the **adult** vertebral column there are only 26 separate bones, for the lowest nine vertebræ are fused together to form two single bones; the upper one is the *sacrum* and consists of 5 fused vertebræ; the lower is the *coccyx* and consists of 4 fused vertebræ (Fig. 141). The vertebræ are classified in five groups from above downwards:—

Child.		*Adult.*		
Cervical vertebræ	7	Cervical vertebræ	7	True or movable vertebræ
Thoracic ,,	12	Thoracic ,,	12	
Lumbar ,,	5	Lumbar ,,	5	
Sacral ,,	5	Sacrum	1 = 5	False or fixed vertebræ
Coccygeal ,,	4	Coccyx	1 = 4	
	33		26	

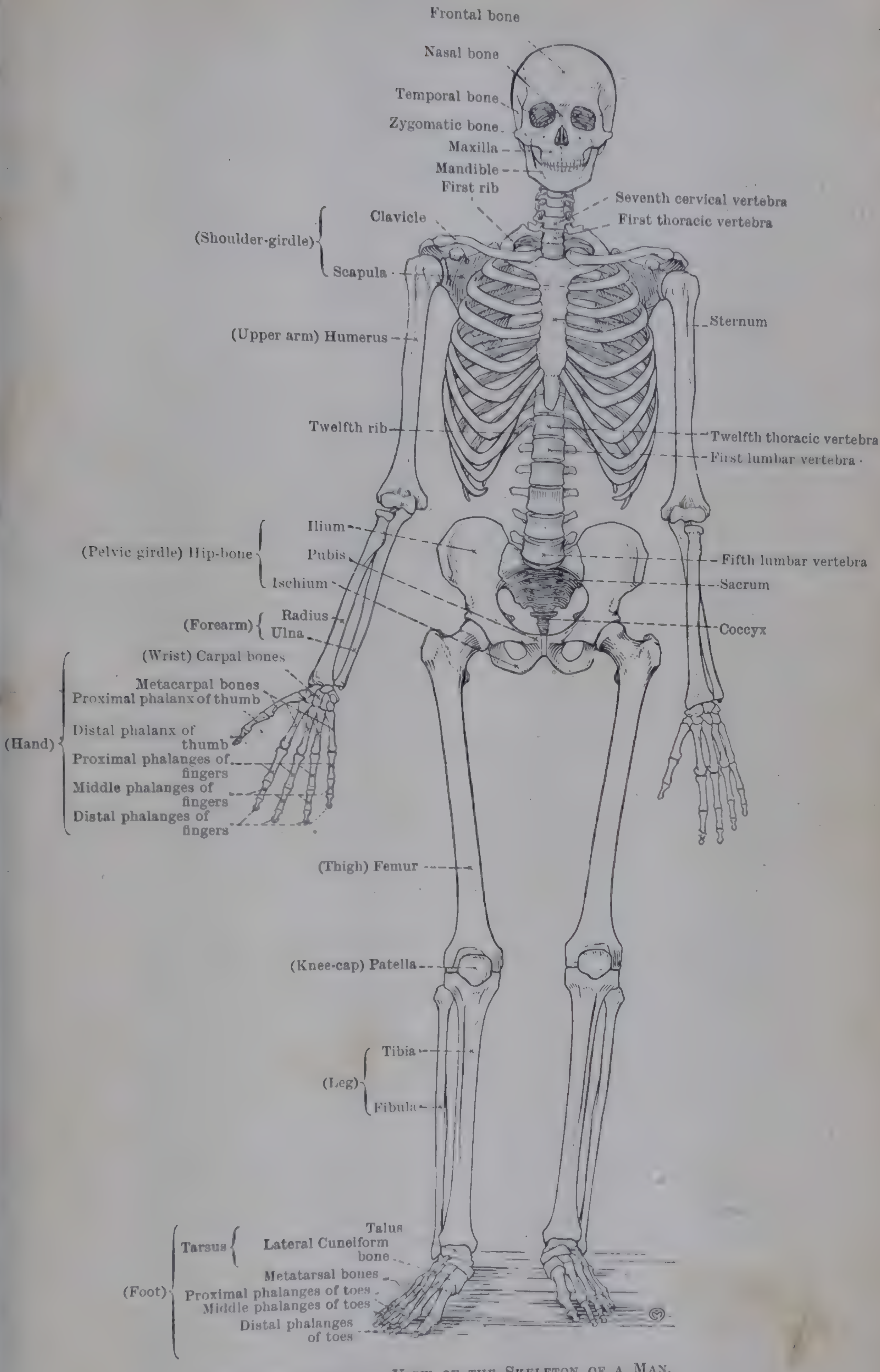


FIG. 129.—ANTERIOR VIEW OF THE SKELETON OF A MAN.
The bones of the left forearm and hand are in the position of pronation.

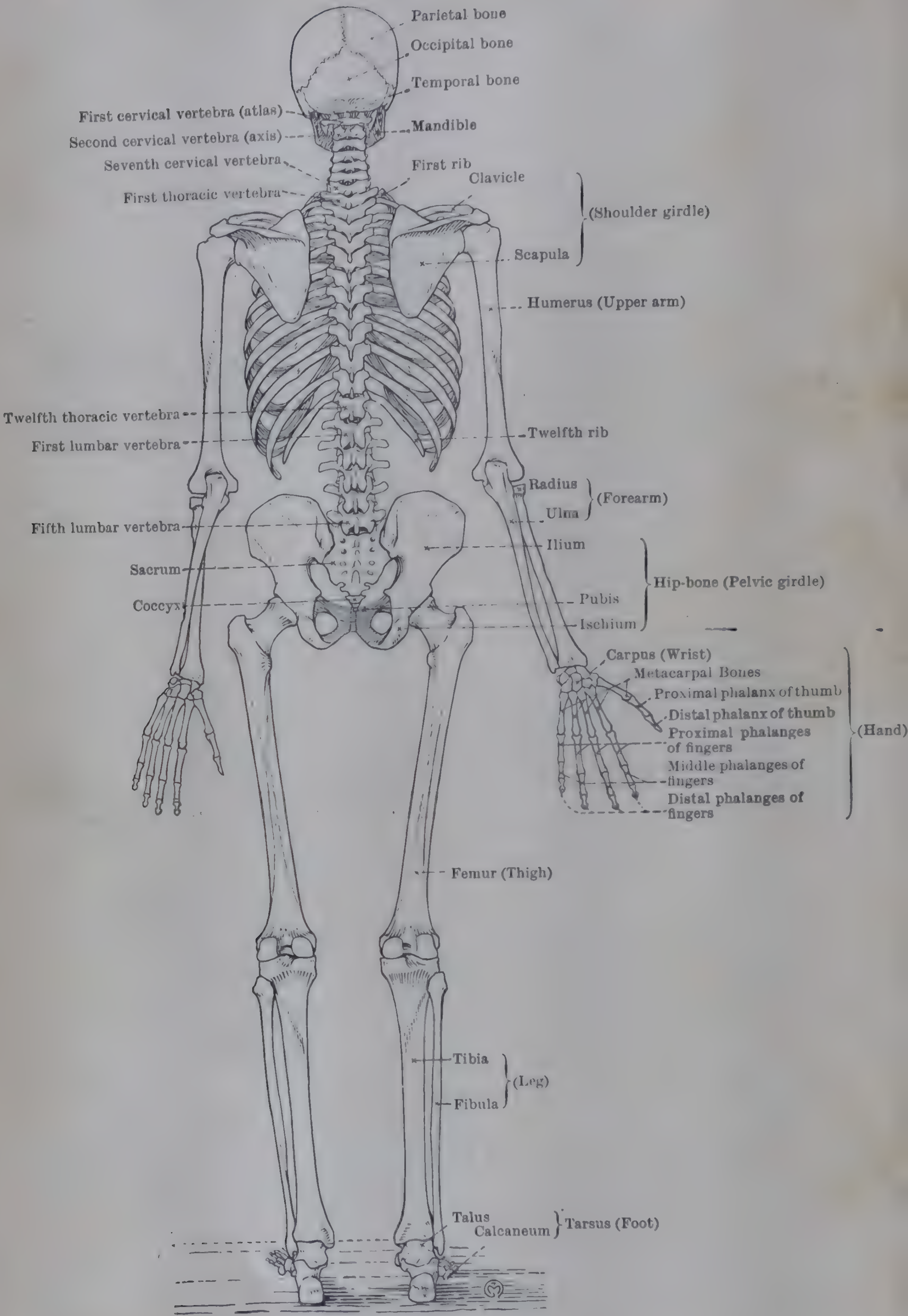
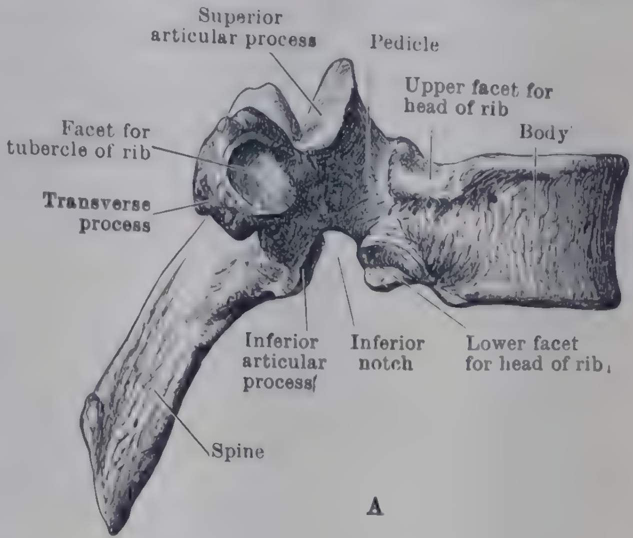


Fig. 130.—Posterior View of the Skeleton of a Man.
The bones of the left forearm and hand are in the position of pronation.

Vertebræ belong to the class of *irregular* bones. Most of them have characters in common, but the vertebræ of each group have also special characters that distinguish them from those of the other groups; and, while each vertebra has the distinctive characters of its own group, many of them have their own special features by which they can be recognized at a glance.

A Typical Vertebra (Fig. 131).—It is usual to select a vertebra from the *middle* of the *thoracic* region as a type. The beginner can pick out a thoracic vertebra from among the others because it has articular *facets* on the sides of the body. Only a thoracic vertebra has these facets; and those in the middle of the thoracic region have long spines. The main parts of a vertebra are a *body* and an *arch* which enclose a large hole called the *vertebral foramen*. Various processes jut out from the arch, namely, the *spine*, a pair of *transverse processes*, and two pairs of *articular processes*—superior and inferior.

The **body** is the bulky, anterior part. The **vertebral foramen**, behind the body, is large enough to admit a finger; when the vertebræ are in column the series of vertebral foramina makes a long tunnel, or *vertebral canal*, for the lodgment of the spinal cord. The **vertebral arch** consists of four essential parts which bear the processes named above. These parts are a pair of *pedicles* at the sides of the foramen, and a pair of *laminæ* at the back; the two laminæ fuse together in the median plane. When the vertebræ are in column there is, on each side, a row of holes, called the *intervertebral foramina*, between the pedicles; a spinal nerve passes through each intervertebral foramen. The **spine** projects backwards and downwards from the junction of the two laminæ; its downward slant enables the beginner to distinguish the upper part of the vertebra from the lower; the tip of the spine is the only part of a vertebra that is *easily* felt in the living person, and, owing to the slope, it is at the level of the body next below. The other processes are at or near the junction of the pedicles with the laminæ; the **transverse processes** are the large projections that jut out from the sides of the arch; **superior articular processes** project upwards from the side of the arch; the **inferior** pair project downwards and articulate with the superior pair of the vertebra next below; in the thoracic vertebræ they are less distinct than the superior pair and are on the laminæ near the pedicles.



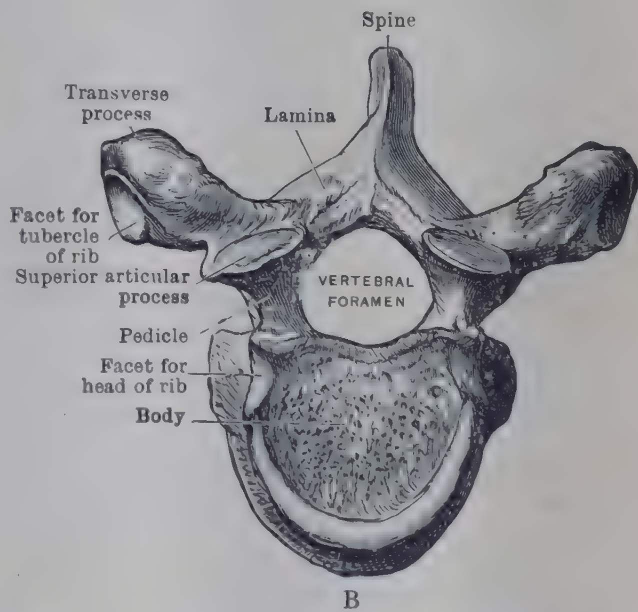


FIG. 131.—FIFTH THORACIC VERTEBRA, (A) as viewed from the right side, (B) as viewed from above.

The **body** has an *upper* and a *lower* surface; a *posterior* surface, which forms the anterior boundary of the vertebral foramen; an *anterior* surface, which merges into the *right* and *left* sides, so that the three form a continuous surface which is highly convex from side to side and slightly concave from above downwards. The upper and lower surfaces are separated from the bodies of the vertebræ immediately above and below by thick *discs* of fibro-cartilage (which, at the same time, bind the bodies together); and two long fibrous ribbons, called the *anterior* and *posterior longitudinal ligaments*, lie on the front and the back of the bodies and are attached to them and to the discs throughout the series of movable vertebræ.

The **pedicles** of the arch project backwards from the back of the body and are continuous with the laminæ posteriorly. The upper and lower borders of each pedicle are slightly concave, forming the floors of notches called the **superior** and **inferior vertebral notches**; in the thoracic and lumbar regions the superior notch is very shallow, for the pedicle springs from the upper part of the body. The pedicles are the only parts of two contiguous vertebræ that are not united by ligaments; they are separated by the **intervertebral foramen**, which is bounded *above* and *below* by the pedicles, *posteriorly* by the articular processes of the two vertebræ, *anteriorly* by the upper of the two bodies in the thoracic and lumbar regions and by both bodies in the cervical region. These foramina form a linear series on each side, transmitting the spinal nerves and vessels on their way from and to the spinal cord.

The **laminæ** are plates of bone that slope towards each other from the posterior ends of the pedicles and fuse together in the median plane behind the vertebral foramen. [*Lamina* = a plate, a leaf.] Their posterior surfaces are covered with muscles. Laminæ of contiguous vertebræ are united by flat, fibro-elastic bands, the *ligamenta flava* [*flavus* = yellow] which are attached to their borders, to the rough lower parts of their anterior or inner surfaces and to the upper parts of their outer surfaces.

The **vertebral canal**, formed by the series of **vertebral foramina**, is bounded *anteriorly* by the bodies of the vertebræ, the discs, and the posterior longitudinal ligament, *posteriorly* by the laminæ and the ligamenta flava, *at each side* by the pedicles—between which there are the intervertebral foramina. The canal *contains* the spinal cord and its membranes, the roots of the spinal nerves, vessels which supply the spinal cord and the vertebræ, and a quantity of loose, semi-liquid fat. The canal is widest in the regions where the vertebral column is most movable—the neck and the loins.

Each **spine** has a median ridge superiorly, but widens out inferiorly into a surface bounded by a pair of ridges; and each ridge may end in a little tubercle at the tip. The spines are united by *interspinous ligaments*, which lie in the interval between each two, and *supraspinous ligaments*, which pass from tip to tip, forming a continuous band from the sacrum to the neck; in the neck they form a wide sheet called the *ligamentum nuchæ* [*nucha* (derivation uncertain) = the nape of the neck]. The ligamentum nuchæ is set as a median partition between the muscles of the two sides of the back of the neck and is attached superiorly to a median ridge, the external occipital crest, on the posterior part of the base of the skull. Numerous muscles are attached to the spines.

The **transverse processes** give attachment to numerous muscles, and are connected with those of the vertebræ above and below by weak fibrous bands called *intertransverse ligaments*. In a typical thoracic vertebra each transverse process articulates with a rib and has a facet on the front of its free end for that articulation. It is connected to ribs by ligaments.

The **articular processes** project upwards and downwards from a pair of *articular masses* which are thickened parts of the pedicles and laminæ at and near their junction. The **superior processes** have smooth articular surfaces on their posterior aspects. The **inferior processes** are not so prominent; they are surfaces rather than processes in cervical and thoracic vertebræ, and look forwards to articulate with the superior pair of the vertebra below. The margins of the articulating surfaces give attachment to the *joint-capsules*; and the non-articulating parts give attachment to muscles.

Structure.—All parts of a vertebra consist of spongy bone enclosed in compact bone. The compact bone is thinner in the body than in the other parts; it is thickest at the notches, the inner tables of the laminæ and the upper edge of the spine. The cervical vertebræ are denser in structure than those of the other regions. *Vascular foramina* are very small in the arch and processes; they are numerous and large on the front, sides, and back of the body; the largest is on the back and transmits a vein.

Cervical Vertebræ

Cervical vertebræ constitute the bony axis of the *neck* and form a very flexible part of the vertebral column [*cervix* = neck]. By their small size and uneven surface-contours they can be identified as cervical at a glance; but their special distinctive character is that each of them has three holes in it—the large **vertebral foramen** in the middle, and a smaller hole at each side, called the **foramen transversarium** because it is partly bounded by the transverse process. The foramina transversaria form a vertical series on each side, and the *vertebral artery* runs through the upper six of them. In most cervical vertebræ the **transverse process** has two tubercles at its free end called the *anterior* and *posterior tubercles* of the transverse process. The free ends are little more than an inch from the median plane, and can be felt as an uneven bony resistance when pressure is made on the side of the neck. The lower border of the *third* vertebra is at the level of the upper border of the thyroid cartilage—the prominence in the front of the neck known as the laryngeal prominence or "Adam's apple". The *sixth* vertebra is at the level of the cricoid cartilage—the rounded bar felt in the front of the neck below

the thyroid cartilage; the anterior tubercle of its transverse process is called the *carotid tubercle* because the carotid artery can be compressed against it.

The first and the second vertebræ are greatly modified to allow free movement of the head, and the seventh also has special characters, but the other four are very much alike and are regarded as typical cervical vertebræ.

A Typical Cervical Vertebra.—The **body** is small and is wider from side to side than from before backwards in the proportion of 3 to 2. It is lipped up at the sides on the upper surface and correspondingly bevelled off on the lower surface; between the lip and the bevel of contiguous vertebræ there is a small synovial joint at the side of the intervertebral disc. The posterior surface is flat, and it is pitted near its centre by holes for veins. The anterior surface is flat in the middle for the attachment of ligaments, and depressed at its side for muscular attachments; its lower part juts downwards and overlaps the disc below; the upper margin of the surface may be slightly bevelled.

The **vertebral foramen** is triangular with rounded angles; and it is large in order that the spinal cord shall not be compressed in the movements of the neck, and also because the cord is thicker in the neck than it is lower down. The **pedicles** are short and rounded; they project sidewards as well as backwards, and that contributes to the width of the vertebral foramen and to its triangular outline. The superior and inferior **vertebral notches** are nearly equal in depth.

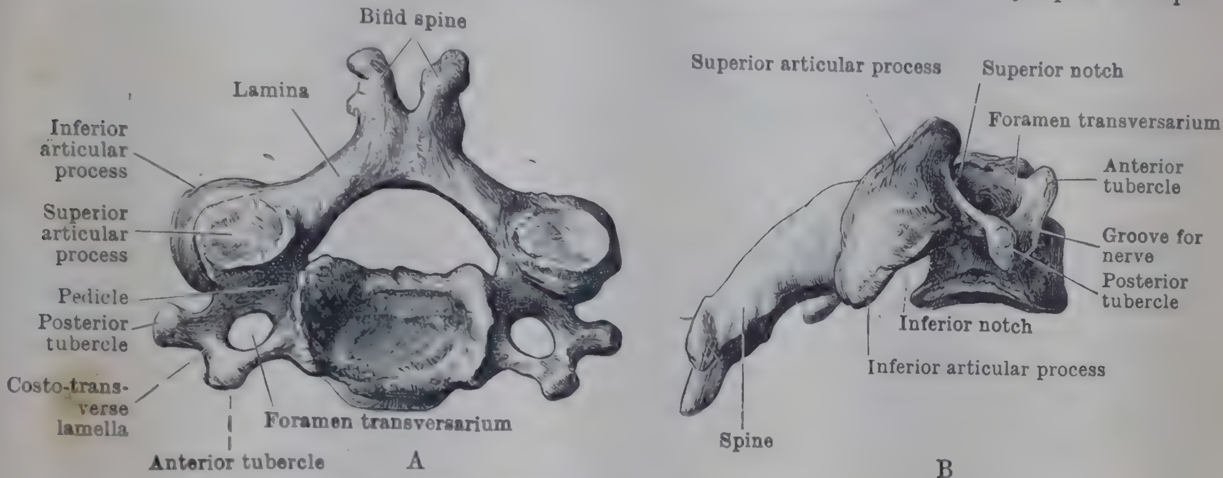


FIG. 132.—FOURTH CERVICAL VERTEBRA, (A) from above, and (B) from the right side.

The **laminæ** are thinner than in other regions, longer in their horizontal measurement, and narrower from above downwards.

The **spine** is short, and it overlaps the spine below; it is compressed from above downwards, and the median ridge is blunt and ill-defined; the free end is bifid, because the pair of lateral ridges end in prominent spurs for the attachment of muscles—the spurs of the sixth being, however, short or absent.

The **articular masses** are large, and the series of them are built up to make a pair of rounded pillars behind the transverse processes; shallow, horizontal grooves on the sides of the third and fourth are for the accommodation of the posterior primary rami of the corresponding cervical nerves. The **articular processes** are merely the upper and lower parts of each articular mass; their articular surfaces are sloping and are nearly flat; the upper pair look backwards and upwards; the lower pair look in the opposite direction.

The **transverse processes** are short and inclined slightly downwards and forwards. Each has two distinct parts or roots—an anterior and a posterior. The *anterior root* corresponds to a rib and is sometimes called the *costal process*; it springs from the side of the body and ends laterally as the *anterior tubercle*. The *posterior root* is the true transverse process; it springs from the arch at the front of the articular pillar, and it ends laterally as the *posterior tubercle*. Near their free ends the lower margins of the two roots are united by a curved bar of bone called the *costo-transverse lamella*. The posterior tubercle is farther from the median plane than the anterior tubercle is—jutting beyond the plane of the lateral surface of the articular pillar. The upper border of the anterior root is about the level of the upper surface of the body, and may be even higher. In the third it is at a higher level than the posterior root, and the costo-transverse lamella therefore slants downwards and backwards. In the fourth the anterior root is higher at its upper border and its costo-transverse lamella also is oblique, but the lower border is almost at the same level as the lower border of the posterior root. In the fifth and sixth the roots are nearly at the same level, and the lamella is therefore horizontal, but in the sixth the roots are farther apart and the lamella therefore longer.

The **foramen transversarium** is bounded by the side of the body, the pedicle, the two roots of the transverse process and the costo-transverse lamella; in some vertebræ it is divided into two by a spicule of bone. Except in the seventh, it transmits the vertebral artery surrounded by a network of veins and a plexus of sympathetic nerves derived from the inferior cervical ganglion. The cervical nerves, on emerging from the intervertebral foramina, lie behind the vertebral artery, where each one divides into an anterior and a posterior primary ramus; the posterior

ramus turns backwards above the posterior root of the transverse process across the side of the articular pillar; the anterior ramus runs laterally and lies on the costo-transverse lamella.

The **atlas** or **first cervical vertebra** is a ring of bone. It has no body and no spine; for the median part of the body has been detached from it and is fused with the upper surface of the body of the second vertebra, and a spine has not been developed on it because it would hamper the backward movement of the head. The two bulkier parts of it are called the **lateral masses**; they are united by an **anterior arch** and a **posterior arch**, of which the posterior is much the longer. A **transverse process**, enclosing a **foramen transversarium**, projects sidewards from each lateral mass. The transverse processes are farther apart than those of other cervical vertebræ; the tip of each is an inch and a half from the median plane, and is the bone felt by the finger pressed into the hollow below the ear. The lateral masses rest upon the second cervical vertebra, and they support the skull—hence the name "atlas". Their upper and lower surfaces are readily distinguished, for the *lower* facets are fairly flat, while the facets on their *upper* surfaces are kidney-shaped and concave. The upper facets articulate with the occipital condyles at the sides of the foramen magnum of the skull (Fig. 156).

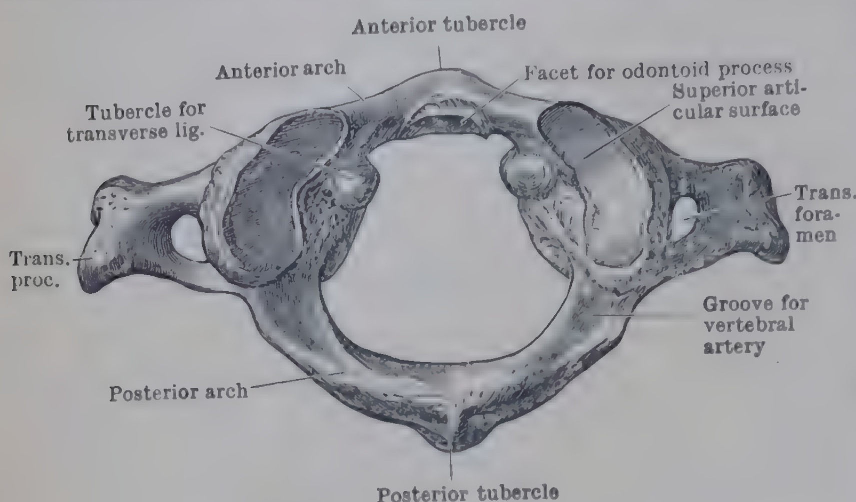


Fig. 133.—The Atlas from above.

The **anterior arch** is short and is compressed from before backwards. The facet seen on the middle of its posterior surface is for articulation with a part of the second vertebra called the odontoid process. On the middle of its anterior surface the **anterior tubercle** of the atlas forms a smooth eminence which gives insertion to the upper ends of the longus cervicis muscles. A continuation of the anterior longitudinal ligament is attached to the *lower margin* of the arch. The anterior atlanto-occipital membrane stretches upwards from the *upper margin* to the anterior margin of the foramen magnum (p. 172).

The **posterior arch** is twice as long as the anterior arch, and it is tilted slightly upwards. It springs on each side from the back of the lateral mass and the posterior root of the transverse process, and it represents the pedicles and laminæ of a typical vertebra. On the middle of its posterior surface the **posterior tubercle** of the atlas forms a small projection, which corresponds to a spine and gives origin to a pair of small muscles named the recti capitis posteriores minores. On the *upper surface* of the arch, close to each lateral mass, there is a broad, oblique groove in which the vertebral artery lies as it runs from the first foramen transversarium to the foramen magnum. The first cervical nerve lies in the groove below the artery. The remainder of the upper surface or border gives attachment to a thin fibrous posterior atlanto-occipital membrane which stretches upwards to the posterior margin of the foramen magnum and also upwards and laterally to fuse with the capsule of the joint between the lateral mass and the skull. The infero-lateral margin of the membrane therefore bridges across the groove for the vertebral artery and is sometimes ossified, converting the groove into a foramen. The *lower margin* of the arch is connected with the laminæ of the second vertebra by the first pair of ligamenta flava.

The **transverse processes** are longer and stronger than those of other cervical vertebræ, for they give attachment and leverage to the muscles that rotate the head. The free end—though often tuberculated and sometimes bifid—corresponds only to the posterior tubercle of a typical cervical transverse process. The anterior root and tubercle have been absorbed into the front of the lateral mass (where they may be identified as a slight swelling), and the bar of bone that bounds the foramen anteriorly corresponds to a costo-transverse lamella. The free end is a little below the tip of the mastoid process of the temporal bone, but is slightly medial to and in front of that process. The prominent, anterior part of the tip is the bone felt in the hollow below the ear. Each process gives origin to the following muscles—the rectus capitis lateralis, the obliquus capitis superior and slips of the levator scapulæ and scalenus medius—and insertion to the obliquus capitis inferior and a slip of the splenius cervicis.

The **lateral masses** correspond to the pedicles and to the lateral parts of the body of a typical vertebra—the parts that bear the synovial joints. Owing to the shortness of the anterior arch, the lateral masses are closer together in front than behind; and their upper and lower

surfaces slope so markedly that the medial surface is of much less depth than the lateral surface. The *lower surface* of each is oblique, nearly circular, and is slightly concave when denuded of cartilage; it articulates with the second cervical vertebra, and the capsular ligament of that joint is attached to the rough, slightly grooved circumference of the lateral mass above the articular margin. The *upper surface* articulates with the occipital condyle. Almost the whole upper surface is occupied by the articular facet, but there are narrow, depressed areas laterally and medially—the medial part usually presenting a vascular pit; posteriorly, it juts as a prominent tubercle that overhangs the groove for the vertebral artery. The facet, like the whole lateral mass, is nearer its fellow in front than behind. To fit the occipital condyle, it is kidney-shaped, concave (especially antero-posteriorly), and slopes downwards from the lateral to the medial edge. The 'hilum' or notch is on the medial side; but it may be notched on both sides, and is sometimes divided into two parts. The capsular ligament of the joint is attached well beyond the articular margins—to the front of the lateral mass, to the overhanging tubercle at the back, and to the outlying margins of the rough depressions at the sides. The *anterior surface* is slightly undulating, and gives origin to the rectus capitis anterior; it merges into the front of the anterior arch and the transverse process, and, near the transverse process, it presents a diffuse, low tubercle or swelling that represents the anterior root and tubercle of the typical cervical transverse process. The *lateral surface* gives origin to the transverse process, and is slightly excavated by the vertebral artery. The *posterior surface* is connected with the posterior arch; it is convex from side to side and grooved horizontally by the vertebral artery above the arch and by the anterior primary ramus of the second cervical nerve below the arch. The *medial surface* is small and uneven, and is seldom sharply marked off from the upper surface; its most conspicuous feature is a smooth, round *tubercle* for the attachment of the *transverse ligament* of the atlas, which stretches from one lateral mass to the other across the back of the odontoid process and keeps it in place against the anterior arch. The hole surrounded by the lateral masses and the arches is divided by the transverse ligament into two parts—an anterior, which holds the odontoid process, and a posterior, which is the vertebral foramen and contains the spinal cord and its membranes.

The **second cervical vertebra** is called the **axis** and is the thickest and strongest of the cervical vertebræ. It is easily distinguished, because a thick process called the **odontoid process** stands up from the upper surface of the body. The **spine** is thick compared with other cervical spines; it can be felt two or three inches below the *external occipital protuberance, i.e.*, the knob in the median line where the back of the head joins the neck. The spine is the first bony resistance encountered by the finger drawn downwards from the protuberance.

The **axis vertebra**, when looked at from the front, is relatively long in its vertical measurement, because of the upstanding odontoid process and because the lower part of the front of the body juts downwards very considerably. The **odontoid process** [ὀδούς (odous,

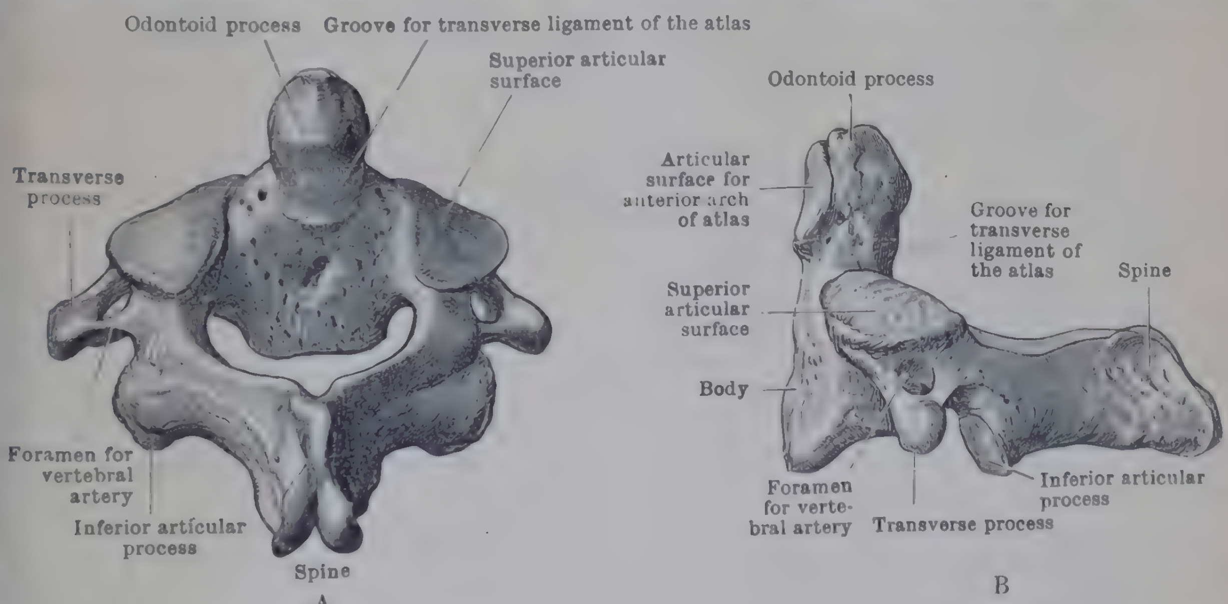


FIG. 134.—AXIS VERTEBRA: (A) from behind and above, (B) from the left side.

genetive odontos = dens = a tooth] is the median part of the body of the atlas fused with the body of the axis. When the first two vertebræ are fitted together the odontoid process lies in the anterior compartment of the ring of the atlas, and, if the atlas is looked at from above, the whole of what is really its body is then seen—its own pair of lateral masses and the odontoid process of the axis. The upper part of the anterior surface of the odontoid process is smooth for articulation with the back of the anterior arch of the atlas; its posterior surface near its

root also is smooth and even grooved for contact with the transverse ligament. Its top is pointed. A weak band of fibres, the apical ligament, stretches from the apex to the anterior margin of the foramen magnum; and a pair of strong bands, the alar ligaments, stretch from the sides of the apex to tubercles on the sides of the foramen magnum. When the head is turned from side to side, the atlas, carrying the skull, pivots round the odontoid process (hence the name *axis*), and the movement is limited by the alar ligaments.

The **inferior vertebral notches** are deep; the **superior** are absent; the **laminæ** are thick. The **spine** is deeply grooved on its lower surface and keeled on its upper surface. It is thick and broad because of the number of muscles attached to it. The most important of these muscles are the rectus capitis posterior major and obliquus capitis inferior (which move the head) and a great part of the semispinalis cervicis, which is inserted into it and bends the neck backwards. The **transverse processes** are the smallest of the series, the free end representing only the posterior tubercle. The anterior root is absorbed into the anterior surface of the upper articular part of the bone, and the anterior tubercle is either absent or is only a slight roughness near that surface. If the second and third vertebræ are placed together and looked at from the side, the change in the transverse process is obvious. The anterior boundary of the **foramen transversarium** is then seen to be chiefly the bar of bone that corresponds to the costo-transverse lamella of the third vertebra. The foramen is a short canal directed laterally as well as upwards, because the transverse process of the atlas is more laterally placed. The **inferior articular surfaces** are situated on typical *articular processes*. The **superior articular surfaces** are not situated on processes at the junction of the pedicles and the laminæ, but are placed on the body and the pedicles; they articulate with the lower surfaces of the lateral masses of the atlas, and through them the weight of the head is transmitted from the lateral masses to the bodies of the vertebræ below. The joints between them and the lateral masses of the atlas, and also those between the lateral masses and the occipital condyles correspond to the small joints between the bodies of the cervical vertebræ at the sides of the intervertebral discs; the first and second cervical nerves issue therefore behind the joints that connect the atlas with the skull and with the axis, while other spinal nerves issue through the intervertebral foramina in front of the joints formed by the articular processes.

The **seventh cervical vertebra** is distinguished from the others because its **spine** is long, and is not bifid but is thickened at its free end; the end of the spine is the upper of the two prominences at the root of the back of the neck, and on that account the seventh vertebra is called the *vertebra prominens*. The *posterior root* of the **transverse process** is a relatively wide triangular plate whose base or medial attached edge may reach almost as high a level as the top of the superior articular process, and its free end (*i.e.*, the posterior tubercle) is in line with the tip of the first thoracic transverse process. The *anterior root* is slender and the *anterior tubercle* is often absent; but the anterior root is sometimes large and separate, forming a **cervical rib** (Pl. IV, p. 105, Fig. 1). The **foramen transversarium** is usually small, for it does not transmit the vertebral artery; it transmits the posterior of the two vertebral veins when there are two of these veins instead of one; on one or both sides it may be double.

Thoracic Vertebræ

Thoracic vertebræ lie in the posterior wall of the chest with 12 pairs of ribs attached to them [θώραξ (thōrax) = a cuirass]. They are of medium size, and increase in size from above downwards; their distinctive character is that they all have facets on their sides for articulation with the heads of ribs (see Figs. 131 and 135). The **body** of each of the upper eight articulates with two pairs of ribs—the pair with which it corresponds numerically and the pair below. For example, the body of the **first** articulates with the heads of the *first* pair of ribs and the upper part of the *second* pair; the **second** body with the lower part of the heads of the *second* pair and upper part of the *third* pair; and so on to the **eighth** body, which articulates with part of the *eighth* pair of ribs and part of the *ninth* pair. The bodies of the lower four articulate only with the ribs with which they correspond numerically.

The upper ten have a facet on each **transverse process** for articulation with the tubercle of the corresponding rib (see Fig. 147). The lower two do not have facets on the transverse processes. The thoracic transverse processes are thick, their posterior surfaces lie under cover of the muscles of the back, and their tips are a little more than one inch from the median plane. The **spines** are long and sloping, especially in the middle of the series, where the slope is so steep that the spine is almost vertical. In the upper and lower vertebræ the spines are shorter and slant very little in comparison. The lower can be distinguished from the upper by the

large size of the bodies. The tip of the spine of the *first* thoracic vertebra is the lower of the two knobs felt at the root of the back of the neck. The spine of the *third* is at the level of the spine of the scapula where it joins the medial border, and that point is easily found in the living body. The spine of the *seventh* is at the level of the inferior angle of the scapula (Figs. 130, 151).

The first two thoracic vertebræ and the lower four have special characters by which they can be distinguished individually; the other six belong to a common type; but when the whole series are from the same skeleton they are easily placed in their proper order, if the gradual changes in appearance are noted.

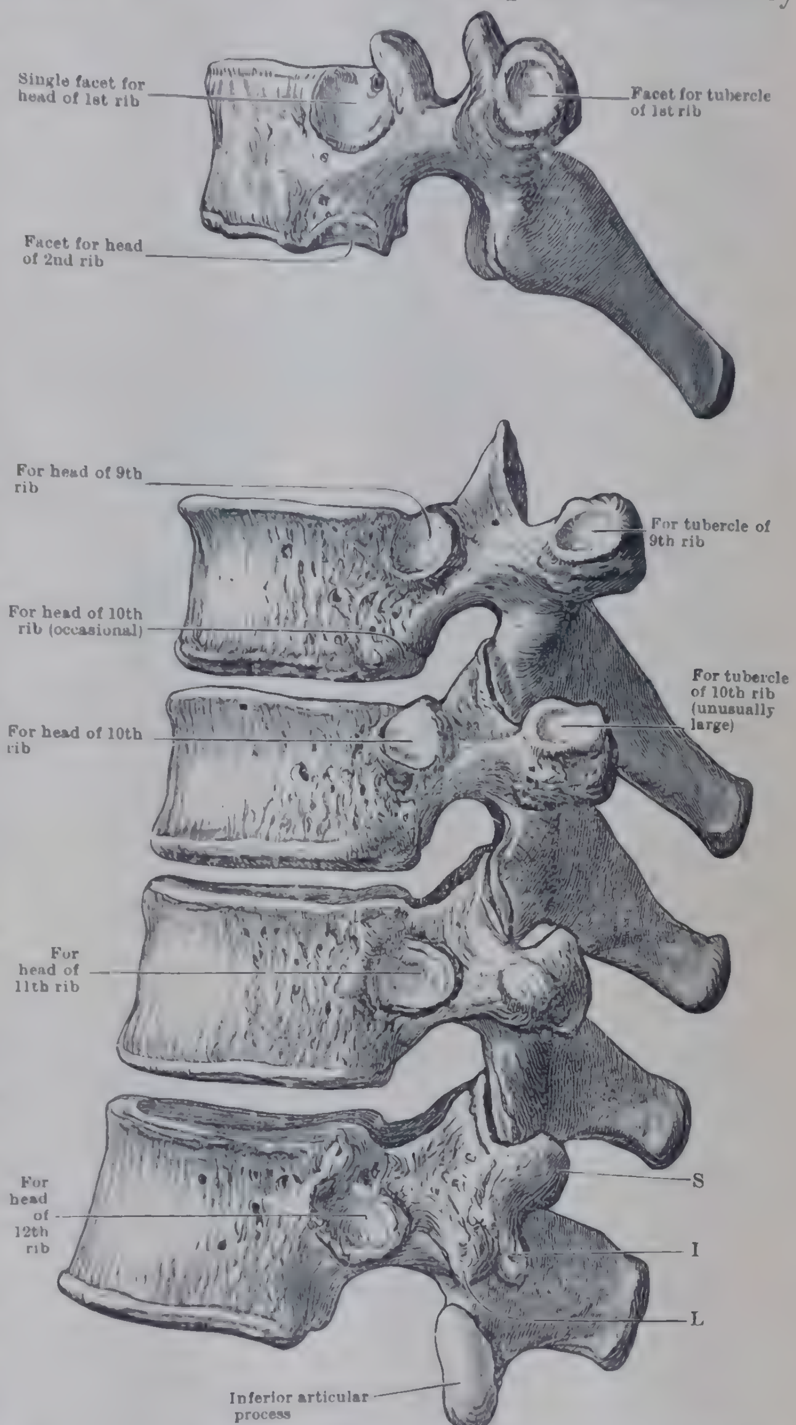


Fig. 135.—Left Side of the First, Ninth, Tenth, Eleventh, and Twelfth Thoracic Vertebræ.

S. Superior, I. Inferior } tubercles correspond to { Mamillary, Accessory } of lumbar.
L. Lateral tubercle = posterior part of root of Transverse

A Typical Thoracic Vertebra (Fig. 131).—The *upper* and *lower surfaces* of the **body** are almost flat, and are heart-shaped in outline. The *posterior surface* is slightly concave from side to side; it is slightly deeper than the *anterior surface* to conform with the curvature of the backbone in the thoracic region (p. 135). There are two unequal *facets* set far back at the widest part on each side of the body, the larger one at the upper border and the smaller at the lower border. The lower facet of one vertebra is directly above the upper facet of the vertebra next below; the two facets, together with the side of the intervertebral disc, make a socket for the head of the rib that corresponds numerically with the lower of the two vertebræ.

The **pedicles** increase in thickness from above downwards. Each is compressed from side to side; it passes more directly backwards than in the cervical and lumbar regions, and is inclined upwards. It springs from the body nearer the upper border than the lower; the **superior vertebral notch** is therefore shallow, and the **inferior** is deep. Owing to the direction of the pedicles, the **laminæ** are narrow, but they are deep and overlap the laminæ below; such overlapping is called *imbrication* [*imbrex* = a tile]. The **vertebral foramen** is smaller than in the cervical and lumbar regions, as there is less movement and less danger of compressing the spinal cord. The small size of the foramen and its circular outline are due to the direction of the pedicles and the narrowness of the laminæ.

The **spine** is long, slender, and three-sided, and its ridges converge on its free end, which is slightly thickened; it slopes so as to overlap the spine below. The **transverse processes** are long, thick, and rounded, and are inclined backwards and upwards. The free end of each is clubbed, is roughened for muscular and ligamentous attachments, and bears on its anterior surface a *facet* for articulation with the tubercle of the rib of corresponding number; owing to the backward inclination of the process, the facet looks sidewards rather than forwards, and in the lower members it looks upwards as well; the process is connected with the corresponding rib by a

joint-capsule and by the lateral and inferior costo-transverse ligaments. It is connected with the neck of the rib below by the superior costo-transverse ligament. The *superior articular surfaces* are flat, and look backwards and slightly upwards and sidewards; they are situated on distinct **articular processes**. The *inferior articular surfaces* are situated partly on the lower parts of the laminæ near the pedicles, and partly on short **articular processes** that jut downwards from the laminæ. Their direction is the opposite of that of the superior surfaces and the articular surfaces lie concentrically so as to allow movement round the axis of rotation of the bodies as well as flexion and extension

The *body* of the **first thoracic vertebra** resembles that of a lower cervical vertebra in general outline, and also in that the postero-lateral part of the upper surface is raised up as a prominent lip which makes the superior vertebral notch deeper than that of any other thoracic vertebra. The body departs from type in its costal facets also; it has a complete, full-sized facet on each side near the upper border for the whole of the head of the first rib, and a small facet at the lower border for the upper part of the head of the second rib. The superior articular processes are wider than those of a typical vertebra and are less upright, and they encroach on the upper surfaces of the transverse processes.

The **second** often resembles the first, but the large facet at the upper border is not quite complete, and its superior vertebral notch and articular process conform to type.

The **ninth** has only one facet on the body; it is at the upper border—encroaching on the pedicle—and is incomplete; it is for articulation with the lower part of the head of the ninth rib. There may be a small facet at the lower border also, in which case the ninth would be a typical vertebra, and the tenth would resemble a ninth. Occasionally, the facet on the ninth is complete; in that case the eighth would resemble a ninth, and the ninth would not be readily distinguished from a tenth unless it was known that they both belonged to the same skeleton. The facet on the transverse process is on its upper surface rather than on the front.

The **tenth, eleventh**, and **twelfth** have *large bodies* resembling those of lumbar vertebræ, and each of them has only one pair of facets for the heads of ribs. The facet is large and complete, and is more on the pedicle than on the body; it is for articulation with the head of the rib of corresponding number. The facet on the *tenth* is near the upper border, while that on the *eleventh* is lower down; the tenth has a small facet on the upper surface of the transverse process, and the eleventh has none; those two, therefore, can usually be distinguished, though it is not always easy when they are from different skeletons. The **twelfth** is easily identified. Its *transverse processes* are each replaced by three small tubercles. Its costal facet is on the middle of the pedicle—or lower. The articular surfaces of the *inferior articular processes* look in a lateral direction, while in other thoracic vertebræ they look forwards. In some skeletons the inferior articular processes of the eleventh resemble those of the twelfth, but the transverse processes of the eleventh are not replaced by tubercles. The inferior articular facets, which face laterally, will limit rotation of the vertebral column by locking against the superior facets of the vertebra below.

Lumbar Vertebræ

Lumbar vertebræ lie in the loins or "small of the back" [*lumbus* = the loin]. They are the only bones that belong exclusively to the *abdomen proper* which is less supported by bone than any other part of the body. Their *large size* distinguishes them at a glance from cervical vertebræ and most thoracic vertebræ; the *thin transverse processes* and *hatchet-shaped spine* distinguish them (all except the fifth) from the bulky lower thoracic vertebræ. The negative distinctive characters common to all lumbar vertebræ are the *absence* of a foramen in the transverse process and the *absence* of facets for ribs.

The **bodies** are about an inch in depth; they are almost two inches wide at their widest part, and structures that lie alongside the bodies are therefore about an inch from the median plane; and the tips of the **transverse processes** are rather more than an inch and a half from the median plane. The **umbilicus** is opposite the disc between the bodies of the *third* and *fourth*. The *fourth* is at the level of the *highest* part of the **iliac crest** (Fig. 150), and the *fifth* is at the level of the *tubercle* of the **iliac crest**. The **laminæ** droop considerably below the level of the pedicles, so that, though the spine is nearly horizontal, its posterior edge is at the level of the lower part of the body of its own vertebra and the upper part of the body next below. The laminæ do not overlap (Fig. 151); there is an interval between the spines and laminæ of two contiguous lumbar vertebræ through which an instrument can be passed into the vertebral canal in a living person—the operation being called *lumbar puncture*. Lumbar vertebræ measure about three inches from the posterior border of the spine to the front of the body, and therefore account for a large part of the antero-posterior diameter of the trunk about the level of the umbilicus.

The fifth lumbar vertebra has distinguishing features of its own; the others belong to a common type, though there are minor differences among them.

A Typical Lumbar Vertebra.—The **body** is large; its *upper* and *lower surfaces* are nearly flat and have a slight resemblance to a kidney in outline; the *posterior surface* is slightly concave, and, in the lower three, is less in depth than the *anterior*, in conformity with the curve of the lumbar part of the backbone, which is convex forwards; the greater part of that convexity is, however, accounted for by the fact that the intervertebral discs are thicker in front than behind.

The **pedicles** are short, thick, and horizontal, with a slight lateral inclination, and are compressed sideways. They spring from the upper part of the body; therefore the **superior vertebral notches** are shallow and the **inferior** are deep. The **laminæ** are thick and uneven; they droop considerably below the level of the pedicles but do not imbricate. The **vertebral foramen** is triangular in outline with rounded corners; it is larger than in the thoracic region owing to the larger size of the body, but smaller than in the cervical region as the pedicles are less oblique.

The **spine** is large and hatchet-shaped, and, owing to a great exaggeration of the median ridge, is almost horizontal. The **superior articular processes** are broad and uneven. The posterior border of each process is smooth, rounded, and slightly enlarged, and is called the *mamillary process* [*mamilla* = a nipple]. The articular surface is on the medial side, is concave from before backwards and faces medially and slightly backwards so as to prevent much rotation. The **inferior articular processes** project downwards from the lower part of the laminæ, and are pointed at their lower ends. They fit in between the superior processes of the vertebra below; they are therefore closer together than the superior pair, and the articular surfaces look in a lateral direction and are convex. The line of the joint is therefore almost in a sagittal plane; but sometimes, in the lower members, the articular surfaces have a lessened convexity and look forwards as well as sidewards; the superior processes of the next vertebra are correspondingly altered, and the result is that the line of the joint is oblique or nearly transverse, and the inferior processes are nearly as far apart as the superior.

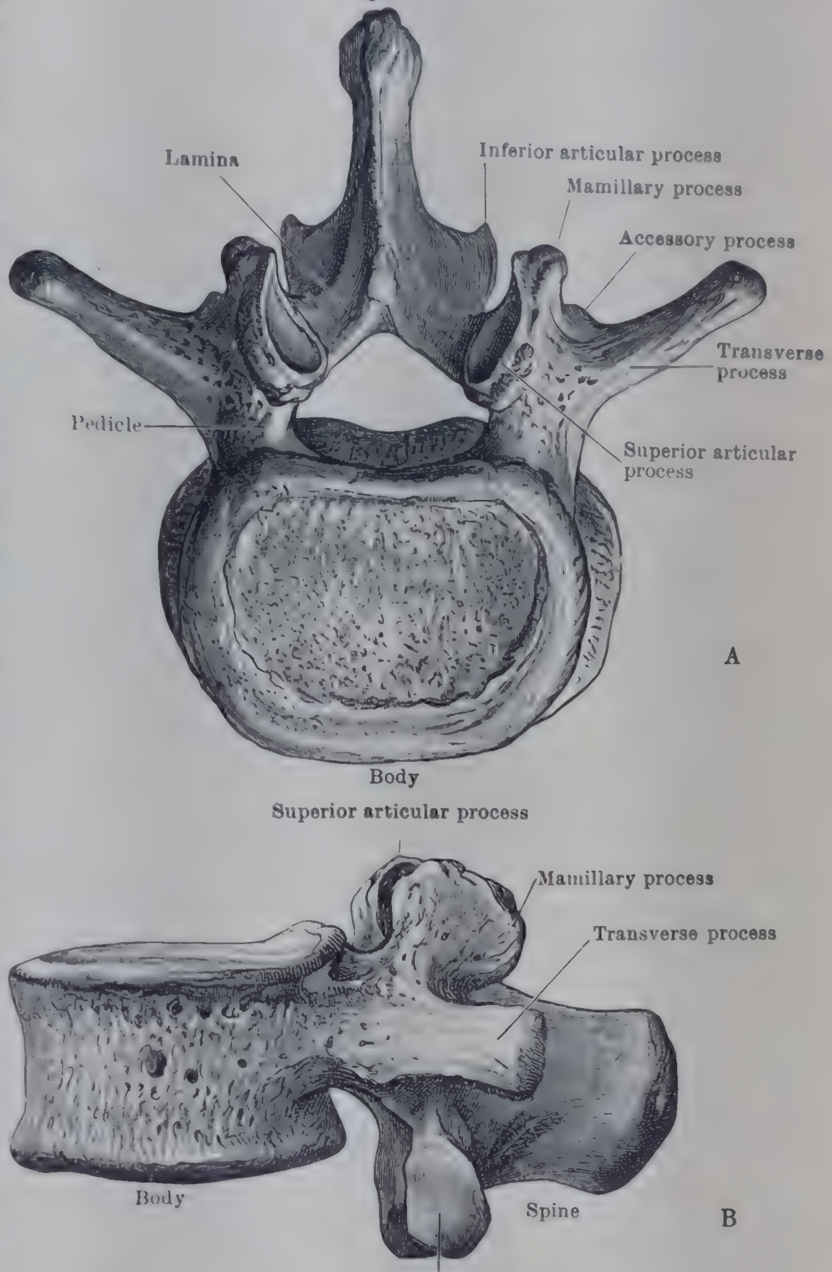


FIG. 136.—THIRD LUMBAR VERTEBRA, (A) from above, and (B) from the left side.

The **transverse processes** are long, thin and compressed from before backwards, and they incline slightly backwards and upwards. In the lower vertebræ they spring from the pedicle as well as from the junction of pedicle and lamina, and the superior vertebral notch extends as a shallow groove on to the root of the process. On the back of each root there is a little tubercle called the *accessory process*. The mamillary and accessory processes and the posterior part of the root of the transverse process correspond to the transverse process of a thoracic vertebra, as may be seen if the last two thoracic vertebræ and the first lumbar vertebra are placed together in order; almost the whole of the transverse process of a lumbar vertebra is the homologue of a rib, and occasionally the first one is separate as a **lumbar rib**.

Certain minor differences among lumbar vertebræ may be noted. The body of the first may be deeper behind than in front, and these measurements may be equal in the second, while the others are deeper in front than behind. The third transverse process is usually the longest, and the others are shorter in this order 4th, 2nd, 1st, 5th. But these differences are inconstant, and it may be impossible to attach a number to one of the upper four unless the

others are present. Progressive differences are then obvious. From above downwards, the bodies widen, the pedicles thicken, the articular processes are farther apart, the mamillary processes become less prominent, and the length of the whole articular column is reduced. The spines increase in depth to the third and then diminish.

The **fifth lumbar vertebra** is usually the largest of the lumbar vertebræ, though its body is usually of less depth than the fourth. The front of the **body** is usually much deeper than the back. The **spine** is small, and its corners are rounded off. The transverse process is short, thick, and conical; its root is attached to the junction of lamina and pedicle and also to the side of the pedicle or even to the side of the body. A strong ilio-lumbar ligament stretches from its tip to the adjoining part of the iliac crest. The **inferior articular processes** are as wide apart as the superior, or even wider, for they have to articulate with the widely separated superior articular processes of the sacrum. Their articular surfaces are less convex than in a typical vertebra and look forwards as well as sidewards—sometimes more forward than sidewards.

Sacrum and Coccyx

The **sacrum** is a large bone made up of the five sacral vertebræ, which are fused together in order to increase the stability of the pelvis [*os sacrum*; the "sacred" bone—called *luz* in ancient times—supposed to resist decay and to be the seed from which the body was to be resurrected]. It lies below the small of the back, almost horizontally, in the dorsal wall of the pelvis between the two hip-bones where it can be felt as an uneven bony surface. It forms by far the greater part of the dorsal wall of the cavity of the pelvis and is held in place by exceedingly strong ligaments. Shaped like an inverted triangle, it possesses a wide upper end or **base**, a small lower end or **apex**, right and left **borders**, a rough, uneven **dorsal surface**, and a relatively smooth **pelvic surface**.

The **pelvic surface** is concave and looks downwards and forwards; it presents a large median column of bone separated from a smaller mass on each side by a vertical series of four holes. The median column consists of the **bodies** of the five sacral vertebræ and the ossified intervertebral cartilages all fused together. The block of bone on each side is the **lateral mass** of the sacrum. The four pairs of holes are the **anterior sacral foramina** and the anterior primary rami of the upper four pairs of sacral nerves issue through them. When the coccyx has fused with the sacrum there are five pairs of foramina.

The **base** is directed forwards and upwards. In the middle there is the upper surface of the **body** of the first sacral vertebra; its prominent anterior border forms the *promontory* of the sacrum. On each side of the body there is a wide, spreading surface called the **ala** of the sacrum; it is the upper end of the lateral mass. The promontory and the anterior borders of the two alæ form the posterior part of the brim of the true pelvis. The **vertebral foramen** is the large opening behind the body and leads into the *sacral canal*. The **superior articular processes** are the pair of upstanding projections at the sides of the vertebral foramen.

The **apex** is the lower surface of the body of the fifth sacral vertebra.

Each side or **border** of the sacrum is very thick above and much thinner below. The upper part is a sharply defined area that has some resemblance to an ear and is therefore called the **auricular surface**; it articulates with a corresponding auricular surface on the hip-bone to form the *sacro-iliac joint*. The thinner, lower part of the border, as it is traced downwards, turns abruptly towards the body of the fifth vertebra, where it ends; the point where the change of direction takes place is called the **inferior lateral angle** of the sacrum.

The **dorsal surface** is very rough and uneven, and is convex. In the median plane there is a row of **spinous tubercles**; they are the spines of the sacral vertebræ, and may be united by ossified ligaments into a median crest. The second spine or spinous tubercle is opposite the middle of the sacro-iliac joint, and, when the body is erect, it is at the same level as the promontory of the sacrum and the posterior superior iliac spine of the hip-bone. About an inch lateral to the median plane there is a vertical row of four **posterior sacral foramina**; they are opposite the anterior foramina, and transmit the posterior primary rami of the upper four sacral nerves. The posterior parts of the vertebral arches of the lower two or more sacral vertebræ are absent; the row of spines therefore does not reach the lower end. The lowest complete vertebral foramen is the lower end of the sacral canal;

it is an oblique opening; and its margins are prolonged downwards to the fifth vertebra and end as two blunt projections called the **sacral cornua**.

The chief contents of the **sacral canal** are the roots of the sacral and coccygeal nerves, the filum terminale and the lowest parts of the dura mater and arachnoid mater. The lower end of the sacral canal gives exit to the fifth pair of sacral nerves, the pair of coccygeal nerves and the filum terminale. (Dura mater and arachnoid mater are the names given to the outer two of the three membranes that surround the spinal cord; they are continued downwards around the roots of the nerves as far as the second piece of the sacrum. The innermost membrane is called the pia mater; the filum terminale is a long, slender glistening thread continued

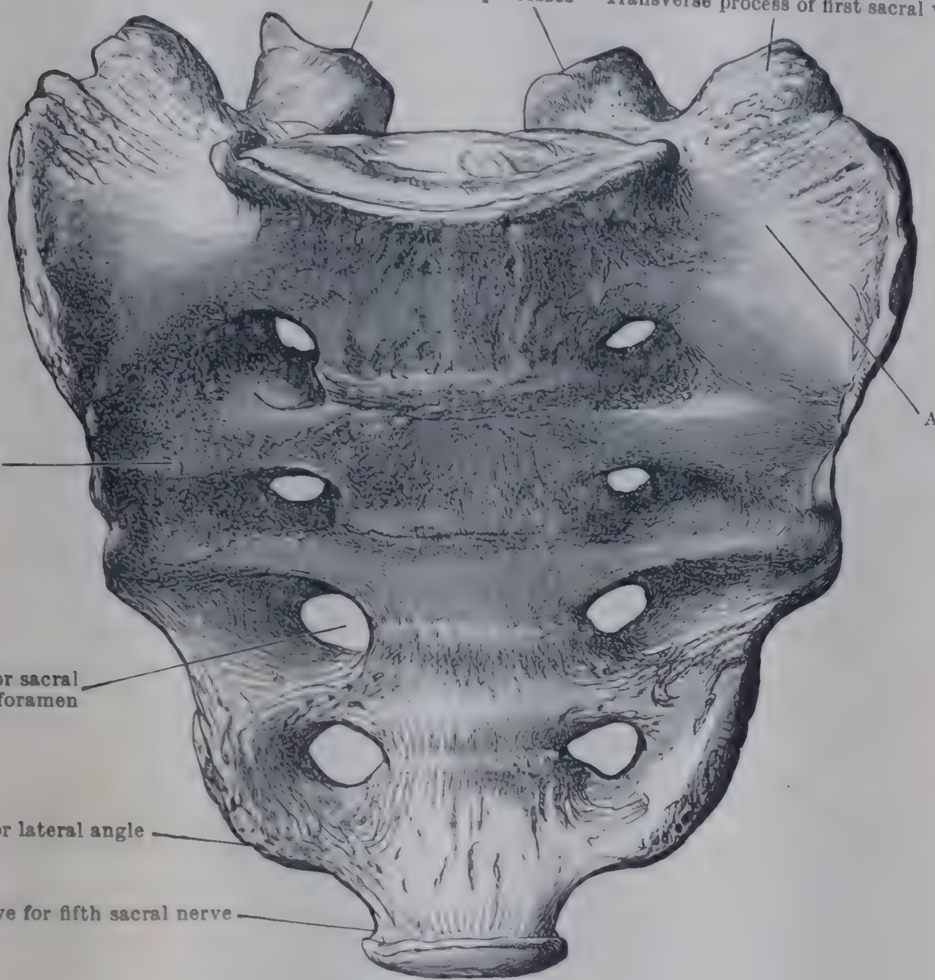


FIG. 137.—THE SACRUM (pelvic view).

downwards from the lower end of the pia mater and it ends by blending with the periosteum on the back of the coccyx.)

The **coccyx** is the lowest part of the backbone and has a fancied resemblance to the bill of a bird [κόκκυξ (coccyx) = a cuckoo] It lies in the floor of the groove between the buttocks a little above the anus, and, at the same time, in the dorsal wall of the pelvis below the sacrum. It is made up of four small incomplete vertebræ fused together, and, like the sacrum, it is triangular in outline with the apex below. It has a base, an apex, a pelvic surface, a dorsal surface, and a pair of borders. The **first vertebra** is much the largest; its *upper surface* is the **base** of the coccyx and articulates with the apex of the sacrum; from its **dorsal surface** a pair of processes called the **coccygeal cornua** project upwards; and from each border a **transverse process** juts out. The lower three vertebræ are mere nodules of bone, usually diminishing in size from above downwards. Occasionally the coccyx consists of three or of five pieces instead of four.

The **pelvic surface** of the **sacrum** is concave from above downwards, and slightly concave from side to side also, the degree of concavity varying greatly in different specimens. Four *transverse ridges*, which are the edges of ossified intervertebral discs, indicate that there are five

bodies in the median column. The bodies diminish in width and thickness from above downwards and to a varying extent in depth; and, if a sagittal section is made, the remains of the discs are found between them. The four pairs of **anterior sacral foramina** are at the ends of the transverse ridges; they also diminish in size from above downwards and a short, shallow groove extends from the foramen on to the lateral mass. Each foramen transmits the anterior primary ramus of a sacral nerve, a branch of a lateral sacral artery, and an accompanying vein. The **lateral mass** is made up of the *transverse processes* of one side all fused together, including, as in the cervical region, a *rib element* in front and a *true transverse process* behind. The costal elements make up the larger part of the lateral mass (Fig. 144), especially in the upper three segments which articulate with the ilium.

The median sacral artery with its companion veins, runs down the middle of the pelvic surface of the sacrum and ends on the pelvic surface of the coccyx. The sympathetic trunk runs down

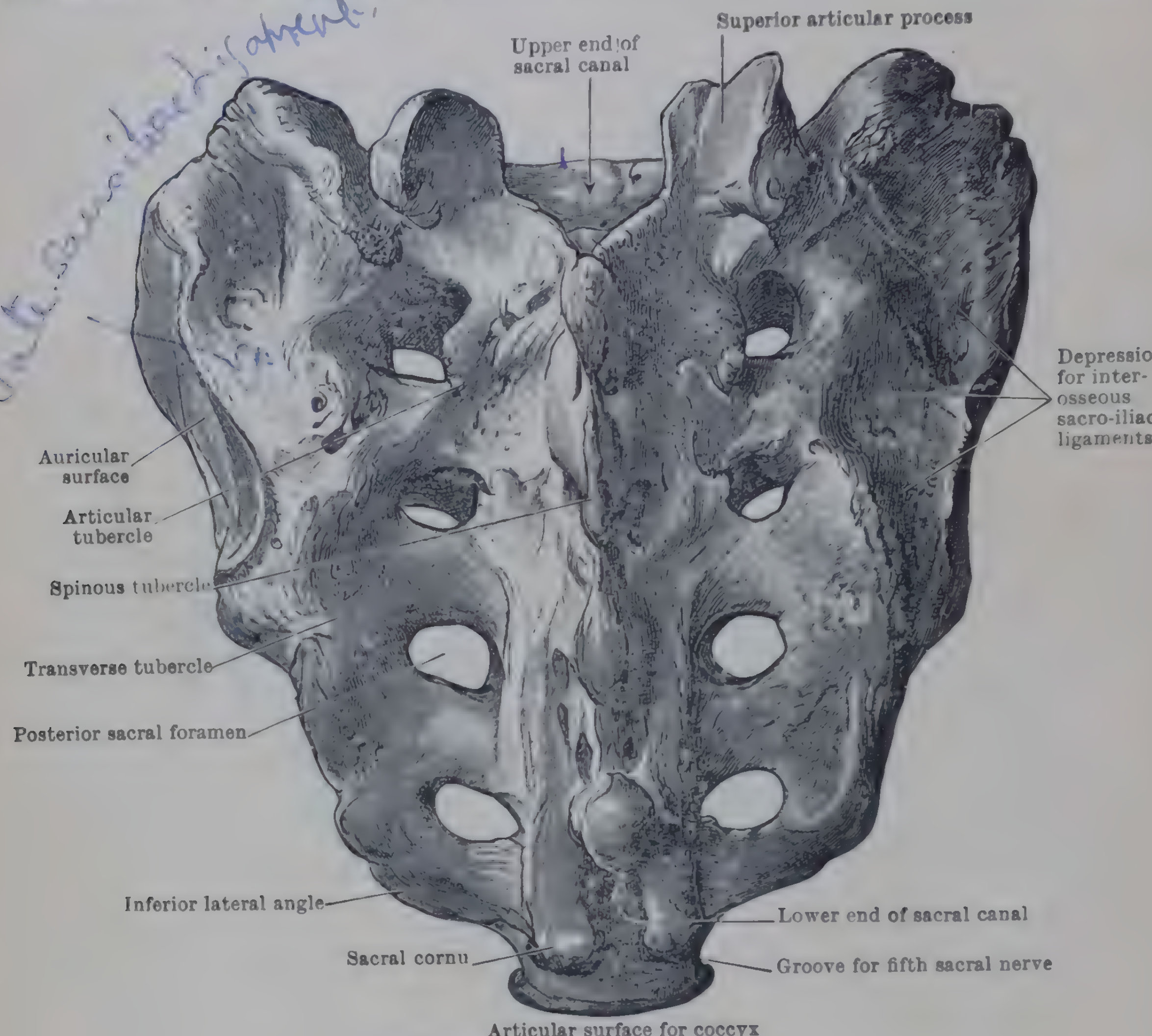


FIG. 138.—THE SACRUM (dorsal view).

across the medial parts of the anterior sacral foramina and joins its fellow of the other side on the front of the coccyx. The greater part of the piriformis muscle arises from the middle three pieces of the sacrum between the anterior foramina. The rectum is closely related to the pelvic surface of the coccyx and the lower half of the sacrum. The bodies above that are clothed with peritoneum.

On the **base** of the sacrum the constituent parts of the first sacral vertebra may be made out fairly clearly. The upper surface of the **body** resembles the body of the fifth lumbar vertebra in outline; it is bound to that body by the lowest intervertebral disc and the lower ends of the anterior and posterior longitudinal ligaments. The **vertebral foramen** is large, sloping, and triangular. The **superior articular processes** stand up from the sides of the vertebral arch. Their articular surfaces are concave; they look medially and backwards, and they articulate with the inferior articular processes of the fifth lumbar vertebra, to which they are bound by articular capsules. The **laminæ** are connected with the laminæ of that vertebra by the lowest pair of ligamenta flava. The **pedicle** is the part between the superior articular process and the body, and it may be marked off from the ala by a pit, or, in rare cases, by a foramen. It is the lower boundary of the intervertebral foramen through which the fifth lumbar nerve issues. The vertebral notch is on the root of the pedicle, and it is continuous with two grooves: the one groove is for the posterior primary ramus of the nerve, and it runs backwards between the articular process and the lateral mass; the other is for the anterior primary ramus and runs forwards to the side of the body, whence the anterior ramus, running downwards, forwards, and sidewards,

sometimes makes a shallow groove on the ala. The **ala** is the transverse process; its posterior part is the *true transverse process* and may be marked off from the rest by a slight depression; the postero-lateral angle of the ala is the tip of the true transverse process and may be marked off from the margin in front of it by a notch. The ala is continuous with the floor of the iliac fossa of the hip-bone when the bones are articulated; the lumbo-sacral ligament and some fibres of the iliacus are attached to it. Its lateral margin is the anterior or upper boundary of the auricular surface.

The **apex** is attached to the body of the first coccygeal vertebra by an intervertebral disc and by the anterior and the deep posterior sacro-coccygeal ligaments.

The **lateral border** is curved sinuously as it is traced from base to apex, for the third piece of the sacrum is rather wider than the second, and the border turns abruptly towards the body of the fifth piece. The **auricular surface** belongs to the upper two or three pieces; it is uneven and usually rough, though it is the articulating surface at a synovial joint; its inequalities fit into reverse inequalities of the auricular surface of the hip-bone, so that very little movement is possible at the joint. The anterior and lower parts of the joint-capsule are together called the anterior sacro-iliac ligament, which is attached to the convex margin of the auricular surface; the posterior or upper part is the interosseous sacro-iliac ligament, which is very thick and strong, and is attached to the concave margin of the surface and to the wide, uneven depression above and behind it. The pelvic surface of the upper part of the sacrum is wider than the dorsal surface, and the auricular surface slopes accordingly; in the articulated pelvis the sacrum is therefore the reverse of the keystone of an arch; the interosseous ligaments of the two sides are the principal factors in holding it in place.

The thinner, lower part of the lateral border gives attachment to part of the sacro-tuberous ligament; the upper parts of the sacro-spinous ligament and coccygeus muscle are attached to the side of the fifth piece in front of the sacro-tuberous ligament; and the **inferior lateral angle** is connected with the transverse process of the coccyx by the lateral sacro-coccygeal ligament.

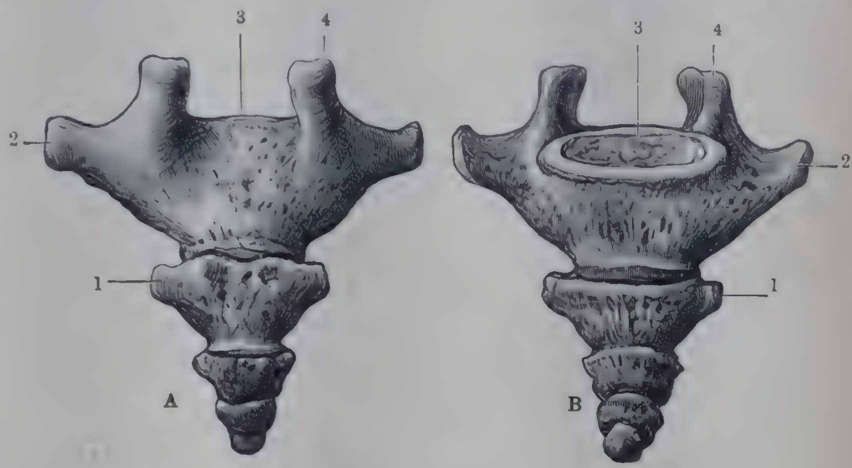


FIG. 139.—THE COCCYX.
A. Dorsal Surface. B. Pelvic Surface.
1. Transverse process. 2. Transverse process. 3. For Sacrum. 4. Cornu.

The **dorsal surface** is directed upwards and backwards. The ridge of **spinous tubercles** varies greatly in its degree of prominence; its upper end gives attachment to a supraspinous and an interspinous ligament that connect it with the lowest lumbar spine, and the lower part of the lumbar fascia is attached to each lip of the ridge. At each side of the root of the ridge there is a rough plate of bone made up of the laminæ united by ossified ligaments. Lateral to that plate there are the four **posterior sacral foramina**; they diminish in size from above downwards, and each one transmits the posterior primary ramus of a sacral nerve, accompanied by small terminal branches of the lateral sacral vessels. At the medial margin of each foramen there is a small projection which is called an **articular tubercle** because it represents the inferior and superior articular processes of two contiguous sacral vertebræ fused together. The lowest of the series is the **sacral cornu**, which represents an inferior articular process of the fifth sacral vertebra; the two sacral cornua are connected by ligaments with the coccygeal cornua. Lateral to the posterior sacral foramina, on the back of the lateral mass, there is a row of **transverse tubercles** which represent the tips of the fused true transverse processes. The sacro-spinalis muscle arises from the spinous and transverse tubercles, and the multifidus from the uneven surface that separates these two rows of tubercles. The short posterior sacro-iliac ligament is attached to the first and second transverse tubercles (the first being the postero-lateral angle of the ala); the long posterior sacro-iliac ligament to the third tubercle; part of the sacro-tuberous ligament to the fourth and fifth; fibres of the gluteus maximus arise from the back of the sacrum, but they spring from these ligaments and the lumbar fascia rather than from bone.

The **sacral canal** is the lowest part of the vertebral canal. It lies between the united bodies and the united laminæ. Its upper part is triangular; its lower part is flattened from before backwards. On each of its two margins there is a series of four large apertures that correspond to **intervertebral foramina**; they transmit the upper four sacral nerves, and each one divides into two parts which end as an anterior and a posterior sacral foramen. The canal *contains*: (1) a quantity of soft fat in which there lie small arteries and fairly large, thin-walled veins, (2) the roots of the sacral and coccygeal nerves, (3) the filum terminale, (4) the lower part of the spinal dura mater and arachnoid mater down to the level of the second spine. The lower part of the posterior wall of the canal is deficient owing to the absence of the laminæ and spine of the fifth vertebra and, very often, of the fourth also. The lower opening of the canal, or *hiatus sacralis*, is therefore very oblique. It is closed by a thick membrane, called the superficial posterior

sacro-coccygeal ligament, which extends from its upper and lateral margins to the back of the coccyx. The hiatus transmits the filum terminale and the primary rami of the coccygeal and fifth sacral nerves.

The coccygeal cornua correspond to pedicles and superior articular processes. In specimens in which the sacrum and coccyx are fused together the ligaments that connect the sacral and coccygeal cornua may be ossified, and so also may be the ligaments that connect the inferior lateral angles of the sacrum with the transverse processes of the coccyx; in such a specimen there are a *fifth pair* of intervertebral foramina and corresponding sacral foramina.

The back of the first piece of the **coccyx** gives attachment to the filum terminale, and a few fibres of the gluteus maximus. Its margin gives attachment to the lower parts of the sacro-tuberous ligament, the sacrospinous ligament, and the coccygeus muscle, in that order from behind forwards. The posterior fibres of the levator ani muscle are inserted into the side of the lower pieces; the sphincter ani externus and the ano-coccygeal body are attached to its apex.

Sexual Differences.—In the male the curve of the sacrum is fairly uniform and is deepest opposite the third piece. In the female the sacrum is flatter above and more sharply bent forwards below. In the female the auricular surface may be limited to the first two pieces; in the male it includes the third partly or wholly. The female sacrum is shorter and wider (in accordance with a shorter and wider pelvic cavity) and the alæ form nearly two-thirds of the width of its base. Its pelvic surface looks more downwards than in the male. The coccyx is more movable in the female and less liable to be fused with the sacrum, and the first piece of the coccyx more often fails to fuse with the second piece than in the male.

VERTEBRAL COLUMN AS A WHOLE

The **vertebral column** is about 28 inches (70 cm.) long in a man and 24 inches (60 cm.) in a woman; and it is said to diminish nearly half an inch during the day. The discs account for nearly one-fourth of its length. In a man, approximate measurements for the different regions are: cervical, 5 in.; thoracic, 11 in.; lumbar, 7 in.; sacrum and coccyx, 5 in. The length increases up to the age of twenty-five or more; it diminishes in old age owing to reduction of the thickness of the discs and to exaggeration of the curve in the thoracic region. The proportion of its length to the whole length of the body is—3 : 4 at the third week of intra-uterine life; about 3 : 7 at birth; and 3 : 7·5 in a young man.

The column can bear a weight of nearly 7 cwt. without crushing, and a tearing strain of nearly 3 cwt. Its weakest part is between the second and third cervical vertebræ but the part most liable to injury is at the twelfth thoracic, for at that level the column has the smallest transverse width (Fig. 141), and is acted upon by the longest leverage. The important factor, however, is that this region lies at the junction of relatively fixed and freely movable parts.

The vertebræ are joined together by the discs between the bodies and by the ligaments that connect the body, laminæ, and processes of one vertebra with corresponding parts of its two immediate neighbours, so making a strong column for the support of the trunk and neck and a pedestal for the head. It is a flexible and resilient column for, although the vertebræ are firmly bound together, a little movement is possible between each two (with the exception of the segments of sacrum and coccyx). The sum of the movements between each two over the whole movable part of the column is considerable. The vertebræ derive their name from the rotary movements between them. [*Vertere* = to turn.]

The column of **bodies** is the chief axis of support and the bodies increase in size with the increasing weight carried from above down to the sacrum where the body weight is transmitted to the pelvic girdle. Below that level the sacrum tapers rapidly. The **vertebral arches** close in the vertebral canal, in which the spinal cord lies in safety; the **articular processes** permit movement but also control its direction and help to limit its range; the **spines** and **transverse processes** are levers to which muscles are attached.

Curvatures.—**At birth** the column has two **primary curvatures**, both concave forwards. The lower one, made by the sacral and coccygeal vertebræ, begins to appear at the fifth month of intra-uterine life and accommodates the pelvic viscera. The upper one includes all the rest of the column, and is present from the earliest period. The **sacro-vertebral angle** is formed where the two curves meet, at the junction of the last lumbar vertebra and the first sacral. It is more acute in the female than in the male.

In the adult the assumption of an erect posture has produced two **secondary**

curvatures, convex forwards, in the cervical and lumbar regions. The alternating curves, in conjunction with the intervertebral discs and the muscles, provide considerable elasticity to the upright column. The original primary curve, concave forwards in both thoracic and lumbar regions, is a characteristic feature in the quadrupeds. The pronounced lumbar curve characteristic of the human vertebral column is associated with an erect posture during life and a pronounced alteration in the mechanics of the vertebral column. The curvatures are maintained partly by the shape of the vertebral bodies, partly by the shape of the intervertebral discs, and partly by the tension of the soft parts such as the ligaments and, particularly, the muscles. Any attempt to reconstruct the spinal curvatures from dried bones is rendered difficult or impossible by the absence of the intervertebral discs; but it must be remembered that an increased range of movement during life, or an habitual posture, may result in misleading conclusions. Habitual squatting, for example, may give rise to compression of the anterior parts of the vertebral bodies and suggest a flattening of the lumbar curve which did not exist during life except as a transient phenomenon.

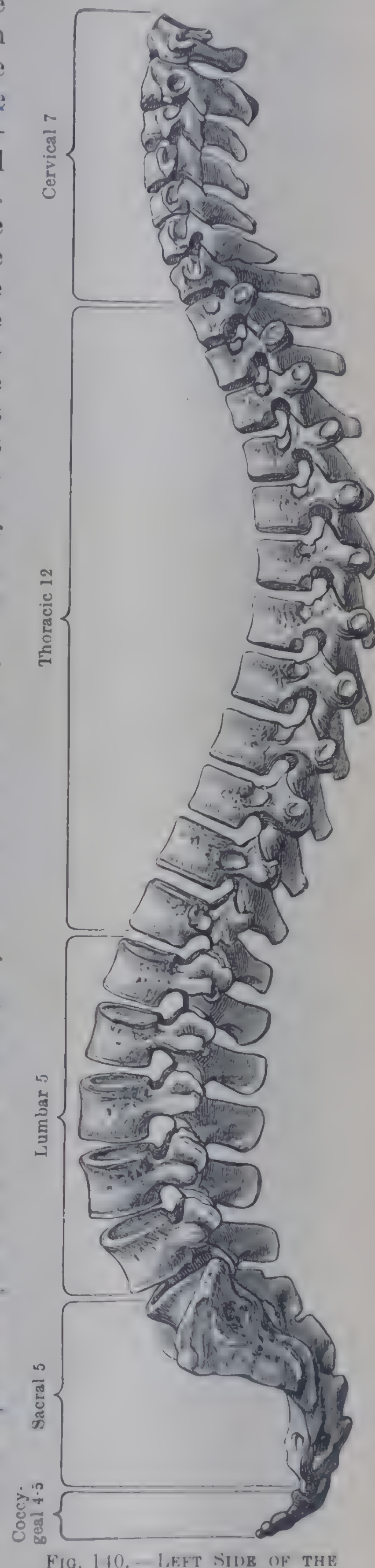


Fig. 140.—Left Side of the Vertebral Column.

The **cervical curvature** is convex forwards. It begins at the atlas, culminates at the fifth cervical, and, at its lower part, merges into the thoracic curve; the lower border of the second thoracic vertebra is taken as the level where the two curves meet, for that is the level of the upper border of the breastbone, and the upper two thoracic vertebræ lie, therefore, in a sense, in the neck. The cervical curvature is the least marked of the four curves and is undone when the neck is bent forwards. It is a *secondary* or *compensatory* curve and is due chiefly to the shape of the discs. It begins to be formed two or three months after birth, when the child begins to lift its head up from the chest; and it becomes further developed at the eighth or ninth month, when the child begins to sit upright. The **thoracic curvature** is concave forwards. It is deepest at the sixth thoracic vertebra, and extends to the twelfth, where it merges into the lumbar curve. It is a primary curve and is due to the shape of the bodies of the vertebræ. The **lumbar curvature** is convex forwards. It is more pronounced in women than in men, and in youth than in the elderly. It culminates opposite the umbilicus, between the third and fourth lumbar vertebræ or at the fourth, and it extends to the sacro-vertebral angle. It is a *secondary* or *compensatory* curve, due chiefly to the shape of the discs. It begins a year after birth, when the child, adopting the erect attitude, lifts up its trunk, straightens out its lower limbs and begins to walk; it makes its first appearance immediately above the sacro-vertebral angle, and gradually extends upwards as the lower limbs come more into use. The **sacrococcygeal curvature** is the original lower *primary curve* and is concave downwards and forwards.

Besides having those four curvatures the column of bodies is often slightly convex towards the right side in the thoracic region. That **lateral curvature** may

be due to the greater muscularity and use of the right upper limb, for it is said to be convex towards the left in left-handed people; but much more probably it is due to the pressure that the upper part of the descending aorta exerts by its pulsations on the left side of the bodies of the middle four thoracic vertebræ, and in the rare cases in which the aorta is on the other side of these vertebræ the curve is convex towards the left. When the lateral curvature is well marked there are compensatory curves, in the opposite direction, above and below it.

The curvatures of a line drawn along the tips of the spines are not repetitions of the curvatures of the bodies, owing to the varying length and obliquity of the spines; and lateral curvature of the spines may be greater or lesser in degree than that of the bodies. Occasionally one or more spines may be deflected very considerably to one side without corresponding rotation of the body towards the opposite side and without any sign of past disease or of recent accident.

Curvatures of the backbone may become accentuated and distortions may occur as a result of weakness, disease, or accident. With advancing years the column loses its flexibility and resilience and becomes more set and rigid, In many skeletons evidence of ‘ rheumatic ’ osteo-arthritis is seen in the ‘ lipping ’ of the margins of the vertebræ and rough ridges and protuberances here and there.

The following points may be noted in the vertebral column :—

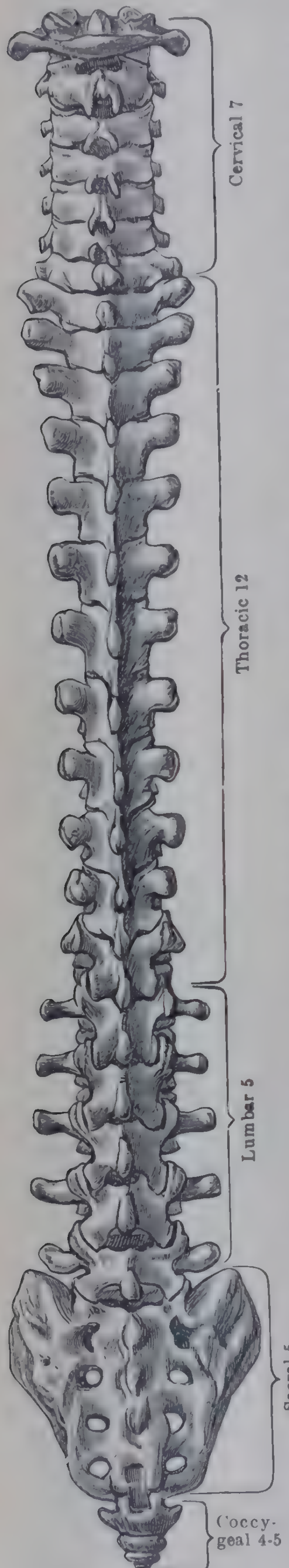


FIG. 141.—VERTEBRAL COLUMN FROM BEHIND.

When viewed from the Side.—(1) The four curvatures. (2) The antero-posterior diameters of the **bodies** increase gradually down to the *second lumbar*, and then gradually diminish. (3) The **costal facets** on the sides of the bodies, from the first thoracic downwards, gradually take up a position farther back till that on the twelfth is more on the pedicle than on the body. (4) The **intervertebral foramina** increase in size from above downwards. (5) The **transverse processes** of *cervical* and *lumbar* vertebræ are in front of the articular processes, while those of *thoracic* vertebræ, which do not incorporate a rib element, are behind and have more of a backward inclination. They are between the intervertebral foramina in the *cervical* region, and behind the foramina in the *thoracic* and *lumbar* regions; the change of characters is abrupt between cervical and thoracic regions, and more gradual between thoracic and true lumbar transverse processes. (6) Owing to the direction of the **articular surfaces** the clefts of the joints between the articular processes are visible in the cervical and thoracic regions, but not in the lumbar region. (7) The length and slope of the **spines** vary, and there is consequent lack of conformity between the curves of the spines and those of the bodies; the slope of the spines, though varying greatly, is always downwards, increasing in obliquity down to the seventh thoracic and then diminishing; in most lower animals the spines slope towards an ‘ anticlinal ’ vertebra situated in the hinder part of the thoracic region. (8) The antero-posterior diameter of the *lumbar vertebræ* is much greater than that of the others.

When viewed from the Front.—(1) The lateral curvatures, when present. (2) The column is widest at the base of the sacrum; the **bodies** increase in width from the second cervical to the first thoracic and diminish slightly from the first to the fourth; they increase gradually from the fifth thoracic to the first sacral, below which there is progressive diminution in width. (3) The side-to-side convexity of the bodies is sharper in the middle thoracic region than elsewhere. (4) In the vertical diameter the body of the second cervical vertebra is deeper than those of the lower five, which are nearly equal in depth; below that there is gradual increase in depth down to the third or fourth lumbar; the fifth lumbar is usually of less depth than the other lumbar vertebræ; in different skeletons any one of the thoracic vertebræ may be of less depth than the one above it. (5) The **transverse processes** of the *atlas* are outstanding and are wider apart than the next five pairs, the tips of which are at nearly equal distances from the median plane; those of the *seventh* are almost as long as the first thoracic; they gradually diminish from the

first thoracic to the twelfth, where they are mere tubercles; they are outstanding again in the lumbar region and vary in length, and though the third is usually the longest, its tip is not necessarily the farthest from the median plane, owing to the greater width of the fourth and fifth vertebræ as a whole. (6) The *sacrum* and *coccyx* rapidly diminish in width from above downwards, but there is little difference between the second and third pieces of the sacrum, and the third is usually the wider; the diminution is very sudden below the inferior lateral angle of the sacrum, and, again, below the transverse process of the coccyx.

When viewed from the Back.—(1) Differences in the lengths of the **transverse processes** as seen also from the front; in the cervical region they are hidden by the articular processes, so that only the posterior tubercles are visible; the transition from thoracic transverse process to lumbar mamillary and accessory processes is well seen. (2) The **articular processes** of the lower six cervical vertebræ are at equal distances apart, and are wider apart than those of the thoracic vertebræ; the distance gradually diminishes from the first thoracic to the first lumbar, below which it increases; the joint-clefts between articular processes are clearly visible in the lumbar region, less so in the cervical region, and not at all in the thoracic region. (3) The **laminæ** overlap in the thoracic region; in the lumbar region there are intervals between them; in the cervical region they overlap very slightly when the neck is straight, but there are intervals between them when the neck is bent forwards, and there is always a fairly wide interval between the atlas and the second vertebra, and also between the atlas and the skull. The widest inter-laminar gaps are between atlas and axis, fourth and fifth lumbar, and fifth lumbar and sacrum. (4) The different characters of the **spines** are seen, and their lateral curvatures or deflections, if present. (5) The **vertebral groove** is the wide furrow alongside the spines; it is shallow in the neck and the loins, where its floor is the laminæ and inferior articular processes, and deep in the thoracic region, where its floor is the laminæ, inferior articular processes and transverse processes.

OSSIFICATION OF VERTEBRÆ

A typical vertebra is ossified from three primary centres and five epiphyses. The **primary** centres are one in the *body* and one in each half of the *vertebral arch* (called also the *neural arch*); the **secondary** centres appear—one at the tip of the *spine*, one at the tip of each *transverse process*, and multiple centres (which soon coalesce) in the cartilage on the upper and lower surfaces of the *body*.

The *primary centres* for the **arch** appear gradually from above downwards, appearing first in the upper cervical region about the seventh week of intra-uterine life and reaching the sacrum about the twentieth week. They appear at the roots of the articular processes; the arch and its processes are ossified from them, and also the postero-lateral parts of the body—the parts of the body which, in thoracic vertebræ, articulate with the ribs.

The *centre* for the *centrum*, *i.e.*, the median, larger part of the **body**, appears dorsal to the notochord, first in the lower thoracic region about the tenth week; the process spreads up and down till by the twentieth week centres have appeared in all the bodies except in the last two pieces of the sacrum, where they may not appear till the thirtieth week, and in the coccyx, where they do not appear till after birth. Occasionally a body has a pair of centres which coalesce, but may fail to do so, and the body may ossify therefore as two separate halves—or one half only may ossify.

At birth the vertebra is in three pieces—the median, larger part (the *centrum*) of the body and the two parts ossified from the centres for the arch. The laminæ are not osseously united; the spine is cartilaginous. The median part (centrum) of the body is joined to each postero-lateral part by a plate of cartilage; the joint is called the *neuro-central joint*.

FIG. 142.—OSSIFICATION OF VERTEBRÆ.

The union of laminæ begins in the lumbar region soon after birth, and, spreading upwards, is completed in the cervical region early in the second year, but is deferred in the sacrum till between the seventh and tenth years. After fusion of the laminæ the ossifying process extends into the spine. The union of the body and arch, *i.e.*, the disappearance of the neuro-central joint, begins in the neck in the third year, and, spreading downwards, is completed in all regions in the sixth or seventh year.

The *secondary centres* appear at **puberty**, and the epiphyses formed from them fuse with the rest of the bone at 25. The epiphyses on the body are in the form of flat rings on the circumferential part of the upper and lower surfaces (Fig. 143 and Pl. IV, p. 105, Fig. 2); the centres for each ring appear at the edge of the cartilage; they vary in number and soon unite to form one circular centre. In the thoracic region the epiphysis on the tip of a transverse process includes part of the articular facet.

	Centres for arch.	Centre for body.	Laminæ unite.	Arch joins body.	Epiphyses appear.	Epiphyses join.
Cervical . .	7th week	15th week	Early 2nd yr.	3rd year	Puberty	25th year
Thoracic . .	10th ,,	10th ,,	1st year	4-5 years	,,	25th ,,
Lumbar . .	15th ,,	15th ,,	Early 1st yr.	6th year	,,	25th ,,
Sacral . .	20th ,,	20th ,,	7-10 years	7th year	18th year	25th ,,
Coccygeal . .	*none*	1st year to puberty	*none*	*none*	*none*	*none*

In many of the vertebræ the ossification departs from type.

In the **cervical region** the bifid tip of the **spine** has a *pair* of epiphyses.

Atlas Vertebra.—A primary centre for each half of the vertebral arch, including the lateral mass, appears at the seventh week. The two halves unite posteriorly in the third year, and their union may be preceded by a secondary centre in the cartilage between them. The anterior arch is cartilaginous at birth. One centre (or a pair) appears in it during the first year, and it fuses with the lateral masses about the seventh year. It includes the anterior part of the upper articular surface of the lateral mass. The epiphyses on the transverse processes unite about 18.

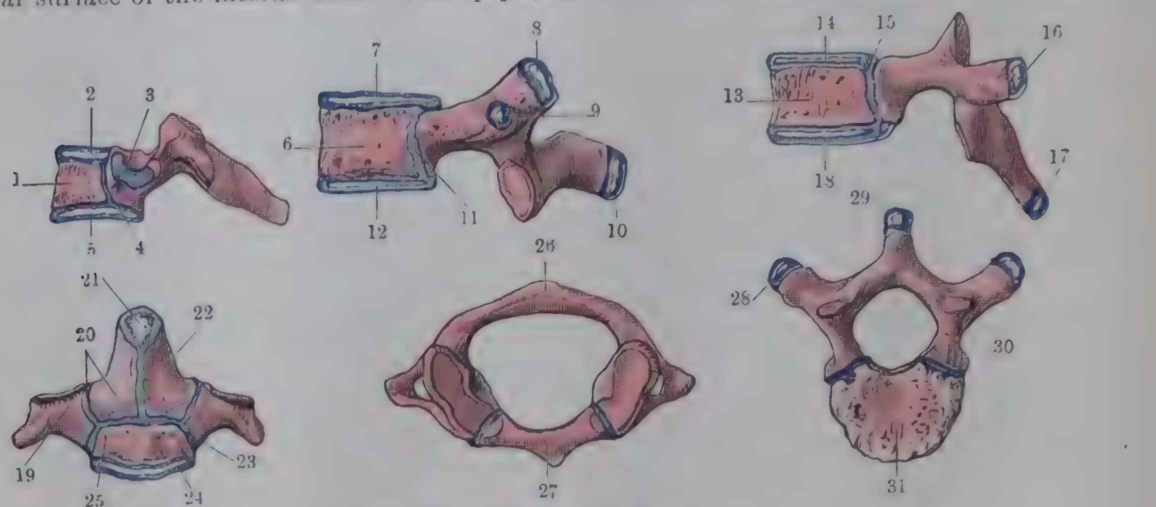


FIG. 143.—OSSIFICATION OF VERTEBRÆ.

Cervical vertebra.

1. Centre for body.
2. Superior epiphysial ring.
3. Anterior bar of transverse process ossified by lateral extension from pedicle.
4. Neuro-central joint.
5. Inferior epiphysial ring.

Lumbar vertebra.

6. Centre for body.
7. Superior epiphysial ring.
8. Centre for mamillary process.
9. Centre for transverse process.
10. Centre for spine.
11. Neuro-central joint.
12. Inferior epiphysial ring.

Thoracic vertebra.

13. Centre for body.
14. Superior epiphysial ring.
15. Neuro-central joint.
16. Centre for transverse process.
17. Centre for spine.
18. Inferior epiphysial ring.

Axis.

19. Centre for transverse process and vertebral arch.
20. Joints close about 3rd year.
21. Centre for summit of odontoid process.
22. Centre for lower part of odontoid process.
23. Neuro-central joint.
24. Inferior epiphysial ring.
25. Single or double centre for body.

Atlas.

26. Posterior arch and lateral masses ossified from a single centre on each side. In this figure the posterior arch is represented complete by the union posteriorly of its posterior elements.
27. Anterior arch and portion of superior articular surface ossified from single or double centre.

Thoracic vertebra.

28. Centre for transverse process.
29. Centre for spine.
30. Centre for vertebral arch on each side. The arch is here shown complete posteriorly.
31. Centre for body.

Axis Vertebra.—A primary centre for each half of the vertebral arch appears in the seventh week; one or two for the lower part of the body early in the fifth month; a pair appear side by side for the upper part of the body and the lower part of the odontoid process later in the fifth month, and fuse during the seventh month. *At birth* the vertebra is in four bony pieces which unite between the third and sixth years. An epiphysis for the top of the odontoid process appears between the third and sixth years and fuses before 12; another appears on the lower surface of the body at puberty and fuses about 25.

The **sixth** and **seventh cervical vertebræ** may have separate primary centres in the costal processes; these join the rest of the bone about the fifth year. Sometimes in the seventh it does not join but forms a cervical rib.

Lumbar vertebræ have additional epiphyses on the *mamillary processes*. The **first lumbar vertebra** may have a separate primary centre for its *transverse process*, and it may remain separate as a **lumbar rib**. The **fifth** may have two primary centres in each half of the arch; the two parts of each half are then united by a plate of cartilage set obliquely between the superior and inferior articular processes. Its transverse process may have two epiphyses.

Sacrum.—**Primary centres** appear between the third and eighth months. One centre for each centrum and one for each half of the vertebral arch, and one for the costal element on each side in the upper three or four vertebræ. The costal parts fuse with the arches at the fifth year. The arches fuse with the centra a little later. The halves of the arches unite posteriorly between the seventh and tenth years. The segments of the lateral mass fuse together at puberty. **Epiphysial centres** appear on the upper and lower surfaces of the bodies at puberty; the epiphyses fuse with the bodies and the bodies fuse together from below upwards between 18 and 25. Numerous epiphysial centres appear on the ends of the costal and true transverse

processes at 18 (Fawcett, 1907). From them are formed an epiphysis which covers the auricular surface, and another which completes the margin below the auricular surface.

The **coccyx** is cartilaginous at birth. Each segment has one **primary** centre. They appear, from above downwards, between the first year and puberty. Fusion between segments takes place from below upwards, but is very variable. Epiphyses on the surface of the bodies and in the cornua have been described.

VARIATIONS IN VERTEBRÆ

Variation in number is due usually to the coccygeal vertebræ being reduced to three or increased to five or even six. Variations in other regions may occur through increase or reduction or rearrangement among the regions; the formula may be altered therefore in several ways, as follows :—

Cervical	7	7	7	6	7	7	7
Thoracic	13	12	12	13	13	12	12
Lumbar	5	6	4	5	4	6	4
Sacral	5	5	5	5	5	4	6
Coccygeal	4	4	4	4	4	4	4
	34	34	32	33	33	33	33

In addition to such numerical variations as the above, it is not uncommon to find that the right or left half of a vertebra has been suppressed or intercalated (Brash, 1915), a condition which necessitates a compensatory curvature elsewhere in the column (Brailsford, 1948).

Atlas.—One or other of the arches may be incompletely ossified or may have a facet for articulation with the margin of the foramen magnum. The foramen transversarium may be incomplete owing to absence of the anterior part of the transverse process. A bar of bone may bridge across the groove for the vertebral artery. The upper articular facet may be divided. The transverse process may be bifid ; and it may articulate with an occasional projection, called the *par-occipital process*, that juts from the jugular process of the occipital bone. The atlas may be partially fused with the occipital bone or with the second cervical vertebra.

Axis.—It may be fused with the atlas or with the third vertebra. The odontoid process may articulate with the basi-occiput. It may be bifid or double, or it may be a separate bone called the **os odontoideum**. Fusion of a detached odontoid process with the anterior arch of the atlas has been recorded. Its apical part may be partially or completely detached. The foramen transversarium may be incomplete, owing to imperfect development of the posterior part of the transverse process.

Nodules representing ribs have been seen once or twice in the **fourth** and **sixth** cervical vertebræ. The **seventh** has a cervical rib fairly often (Pl. IV, p. 105, Fig. 1). One of its foramina transversaria may be absent.

The **first thoracic vertebra** may have its transverse process connected with the neck of the first rib by a bar of bone ; the posterior part of its arch may be separate. The facets on the body of the **ninth** are variable. The **tenth** may have no facets on its transverse processes ; and its spine may be shorter than that of the eleventh. The inferior articular processes of the **eleventh** may resemble those of the twelfth, and the superior processes of the **twelfth** correspondingly resemble those of a lumbar vertebra. Suppression of the right or left half of a lower thoracic vertebra (the remaining half being wedge-shaped) has been known to cause congenital lateral curvature (scoliosis) ; and so has the interpolation of a wedge-shaped half of a lumbar vertebra.

The mamillary and accessory processes of the **lumbar vertebræ** may be large and occasionally are connected by a bridge of bone which encloses a small foramen. The first transverse process may be separate, as a lumbar rib ; the fourth may spring from the side of the body, without connexion with the arch ; and the fifth may have a foramen in it. The posterior part of the arch of the fifth, comprising the spine, the laminæ, and inferior articular processes, is occasionally separate from the rest of the bone (union during life being effected by hyaline cartilage) ; the same condition has been seen in the fourth. The fifth may be fused with the sacrum partly or wholly, and may have pronounced sacral characters on one or both sides (Pl. XVII, p. 272; Figs. 1232, 1233).

The **sacrum** may have six vertebræ, owing to inclusion usually of the first coccygeal but sometimes of the fifth lumbar. More seldom there are only four vertebræ. Sometimes the first sacral is not united to the second, or only partially, and may resemble a lumbar vertebra on the un-united side. The posterior wall of the **sacral canal** may be defective in its whole length. A foramen may be present in the lateral part of the first sacral vertebra between the pedicle and the costal element. The degree of curvature varies greatly in different specimens.

The **coccyx** varies in its number of segments and the extent to which they are fused together. A curved process jutting from the front of the first piece has been recorded. The second piece may have rudimentary transverse processes and pedicles.

The standard work on vertebral variations is by Le Double (1912).

SERIAL HOMOLOGIES OF VERTEBRÆ

The **body** is the only part present in every vertebra from the first cervical to the last coccygeal. The homology of the bodies is manifest throughout the series, except that the *median part* (centrum) of the body of the atlas is detached from its own vertebra and fused with

the second, forming the odontoid process; the *lateral parts, i.e.*, the parts which in other vertebræ are ossified from the vertebral arch, form the anterior, larger parts of the lateral masses. The anterior arch of the atlas does not correspond to the front of the body of a vertebra, but is ossified from a persistent 'hypochordal bow', which disappears in other vertebræ (p. 150).

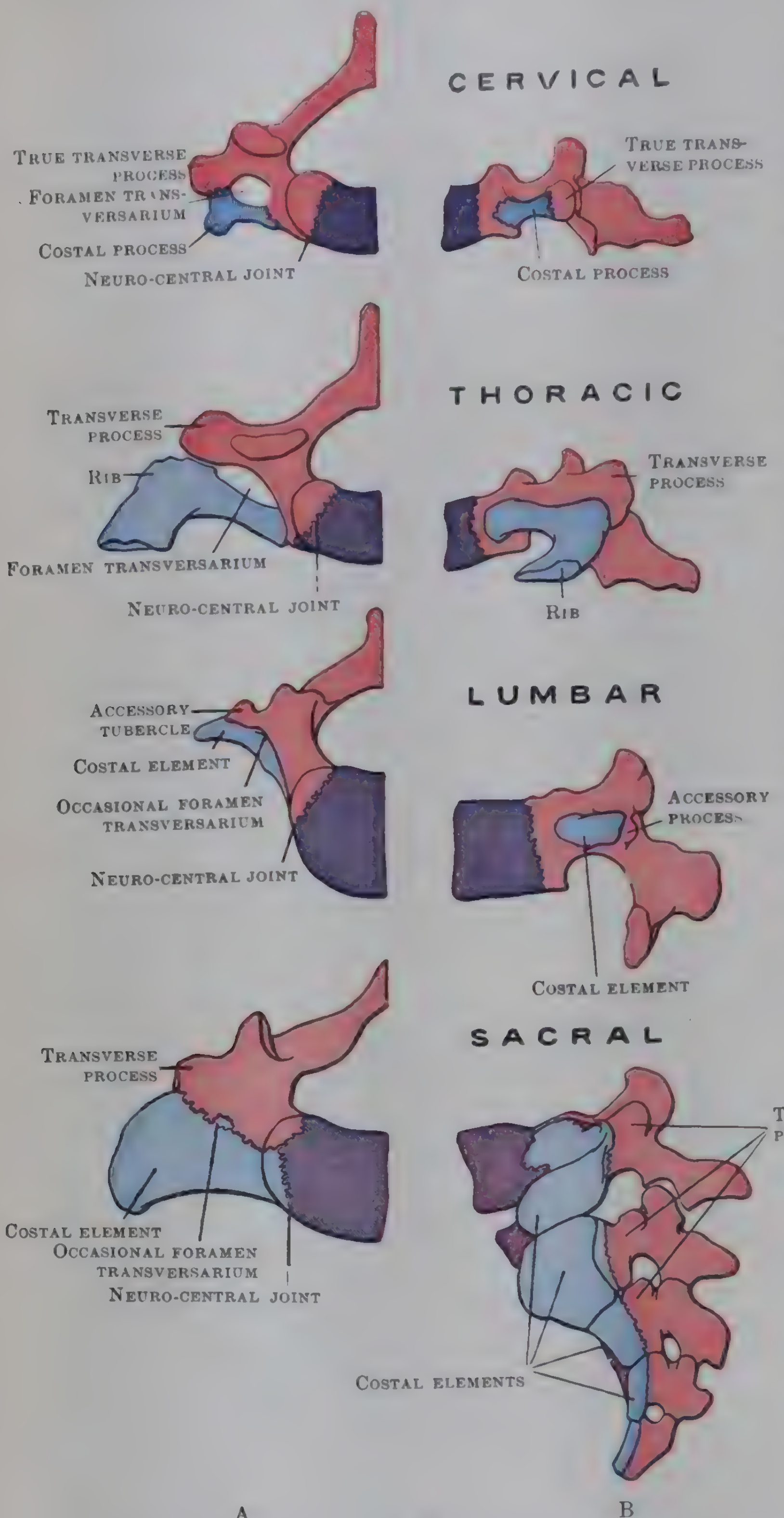


FIG. 144.—DIAGRAM TO ILLUSTRATE HOMOLOGOUS PARTS OF VERTEBRÆ.
Body, *purple*; arch and processes, *red*; costal element, *blue*.
A, from above. B, from the side.

The **vertebral arches** are incomplete below the third and fourth sacral, and wholly absent from the third and fourth coccygeal segments. Their homology is equally obvious, but the **pedicle** of the atlas is obscured in the posterior part of the lateral mass. The roots of the coccygeal cornua are pedicles. The **laminæ**, including the posterior arch of the atlas, are usually complete down to the third sacral; those of the fourth sacral may or may not be complete; those of the fifth are usually unossified; and they are quite unrepresented in the coccyx.

The **spine** of the atlas is represented by the tubercle on the posterior arch. Spines are absent below the third sacral vertebra.

The **articular processes** of the atlas and the superior articular processes of the second cervical vertebra are absent; the articular surfaces of the lateral masses of the atlas and the upper articular surfaces of the second vertebra are homologous with the very small articular areas on the lateral parts of the bodies of the other cervical vertebræ. The superior articular processes of the first sacral vertebra function as ordinary articular processes; the other sacral articular processes are fused together to form the row of articular tubercles on the back of the sacrum, except the inferior articular processes of the fifth piece, which form the sacral cornua. The upper parts of the coccygeal cornua are homologous with superior articular processes; they are absent from the other coccygeal segments.

The **transverse processes** are present in the whole series down to and including the first coccygeal vertebra; but their homologies are less obvious. The transverse processes of the **thoracic** vertebræ are taken as the type and standard. In a **cervical** vertebra the true transverse process is represented by the posterior root; the remainder of the process is the homologue of a rib; the foramen transversarium represents the interval between a transverse process and the neck of a rib. In a **lumbar** vertebra the process called the transverse process is the homologue of a rib; the true transverse process is represented by the mamillary process and the posterior part of the root of the transverse process including the accessory process. No interval is left between the costal and true transverse elements, except in the rare instance where there is a foramen in the fifth lumbar transverse process. In the **sacrum** the lateral mass is made of the true transverse processes posteriorly and the costal elements

anteriorly, the ends of the true transverse processes being the row of transverse tubercles on the back. Each transverse tubercle represents part of the ends of two true transverse processes, for the end of each process expands, growing upwards and downwards, and unites with similar expansions of the process above and below to form the tubercles lateral to the posterior sacral foramina.

STERNUM

The **sternum** or breast-bone [στέρνον (sternon) = the breast] is an elongated flat, dagger-shaped bone, six to eight inches long. It lies in the anterior wall of the thorax in the median plane, extending from the root of the neck to the pit of the stomach. It can be felt through the skin from end to end and has upper and lower ends, anterior and posterior surfaces, and right and left borders. The two clavicles articulate with its upper end, and the cartilages of the upper seven pairs of ribs articulate with it at intervals along its borders. It has three main parts, named, from above downwards, the *manubrium*, the *body*, and the *xiphoid process*. In youth, the body is in four pieces—united by cartilage.

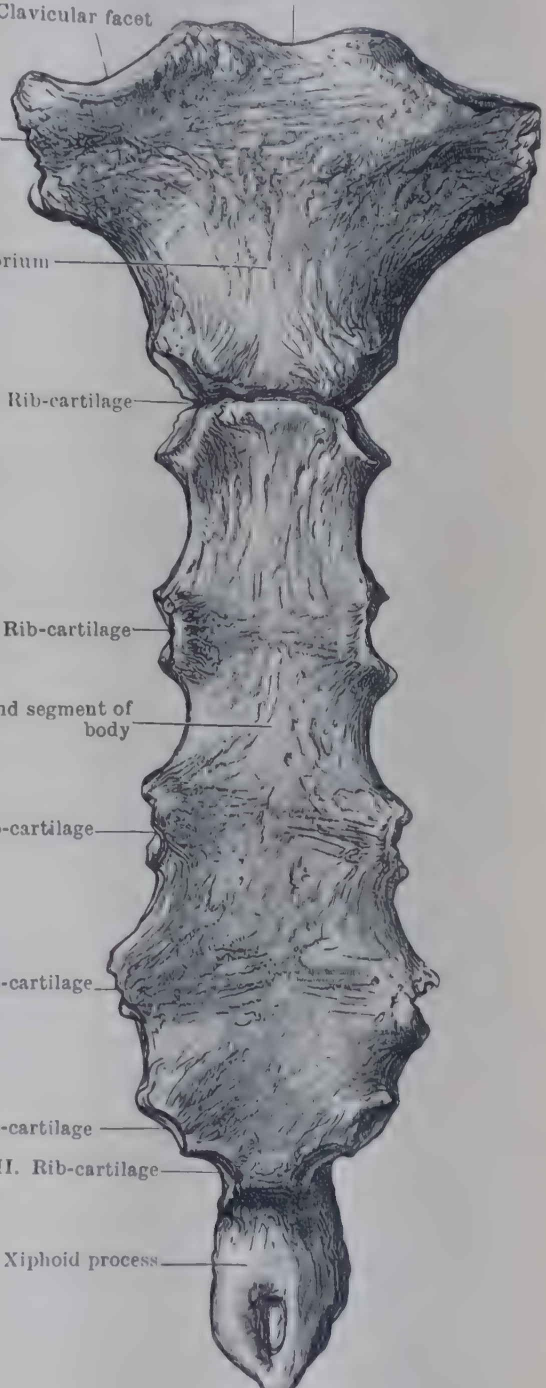


FIG. 145.—STERNUM (anterior view).

The **manubrium** [= a handle] is the widest piece of the sternum, and, unless the skeleton is that of an old person, it is a separate bone; for the manubrium and the body are united by cartilage and do not fuse together till an advanced age. It is triangular in outline, each side measuring about two inches; but the lower angle is cut off—giving it a short lower border. The *posterior surface* is slightly concave from side to side and is not so rough as the *anterior surface*. The *upper border* is the upper end of the sternum and is more than twice the width of the lower border. The middle part of the upper border is concave from side to side and can be felt in the root of the neck as the floor of the **suprasternal notch**; on each side of the suprasternal notch there is a larger notch for articulation with the medial end of the clavicle or collar-bone. On the *right* and *left margins*, immediately below the **clavicular notch**, there is a rough mark or a pit on which the cartilage of the first rib is implanted.

The lower border of the manubrium and the upper end of the body of the sternum, together, can be felt and often seen as a transverse ridge on the front of the chest about two inches below the upper end of the sternum, for the two bones are slightly thickened at their junction, and join at a very obtuse angle called the **sternal angle**. The ridge can be felt in stout people as well as in thin, and is the most serviceable of the landmarks on the front of the chest. The cartilage of the second rib joins the side of the sternum at the

junction of the manubrium and body, *i.e.*, at the sternal angle. The second rib is therefore easily identified.

The **body** consists of four segments fused together and is the longest of the three parts of the sternum. As a rule it is more than twice as long as the manubrium in men and rather less in women; it is about an inch wide at its *upper end*, increases slightly down to the fourth segment and then dwindles in breadth, and the *lower end*, at its junction with the xiphoid process, is the narrowest part. The *posterior surface* is slightly concave from above downwards and usually is smoother than the *anterior surface*. Each *margin* bears four pits for articulation with costal cartilages. The upper three pairs of pits are at the ends of indistinct **transverse lines** that indicate the junction of segments of the body. The fourth pair is on the sides of the fourth segment. In addition there are, on each side, an articular pit or notch between the body and the manubrium, and one between the body and the xiphoid process—the latter notch being on the front of their junction rather than at its side. The second rib-cartilage articulates with the notch between manubrium and body; the third, fourth, fifth, and sixth with the pits or notches on the body; and the seventh with that between the body and the xiphoid process.

The **xiphoid process** is the smallest piece of the sternum; it lies in the anterior wall of the abdomen in front of the liver and can be felt in the floor of the depression known as the *epigastric fossa* or "pit of the stomach". Its junction with the body—the *xiphi-sternal joint*—can be felt as a short transverse ridge in the upper margin of that fossa; the ridge marks the lower limit of the thorax in the median line in front, and is the landmark, in the median line, for the diaphragm, the upper surface of the liver, and the lower border of the heart.

The xiphoid process is usually flat and pointed [ξίφος (xiphos) = a sword; εἶδος (eidos) = shape], but it may be almost any shape; it may have a hole in its middle or it may be bifid. It is made of cartilage with a core of bone; the core enlarges with age at the expense of the cartilage till the process is quite ossified; it is more yielding therefore in youth than in old age. At first it is united to the body by cartilage but fuses with it after middle age.

The sternum slopes from above downwards and forwards—the manubrium slanting more than the body. The **upper end** is on a level with the *lower* border of the body of the **second** thoracic vertebra (Fig. 150); the **sternal angle** with the *upper* border of the body of the **fifth** and with the interval between the third and fourth thoracic spines; the **xiphi-sternal joint** with the **ninth** thoracic vertebra and the tip of the eighth thoracic spine.

The **manubrium** is thicker at its upper and lower parts than in the middle. The clavicular notches look upwards and sidewards, and its thickest and strongest part is below and medial to them, where it receives shocks transmitted through the clavicle. The slightly raised area on the *anterior surface*, below the medial part of the clavicular notch, gives origin to the sternal head of the sterno-mastoid; part of the pectoralis major arises from the large, concave area that accounts for most of each half of the front of the manubrium. On the *posterior surface* of the manubrium, part of the sterno-hyoid arises medial to the clavicular notch, and part of the sterno-thyroid about half-way down. The capsule of the sterno-clavicular joint is attached to the margins of the **clavicular notch**; the articular disc of that joint to the junction of the manubrium and first costal cartilage; the interclavicular ligament, slightly, to the floor of the **suprasternal notch**.

The chief structures *behind the manubrium* are: (1) the edges of the pleuræ and lungs, (2) the remains of the thymus, (3) the left innominate vein, (4) the arch of the aorta and its three branches, and (5) the trachea, which ends opposite the sternal angle.

The **body** is thinner along its middle than along the margins. Its *anterior surface* gives origin to part of the pectoralis major; the lower part of its *posterior surface* gives origin to part of the sterno-costalis and the sterno-pericardial ligaments are attached to its upper and lower ends.

The chief structures *behind the body* are—the edges of the pleuræ and lungs, the pericardium and heart; and the ascending aorta and right pulmonary artery behind the first segment.

The **xiphoid process** is thicker in the middle than at the sides. It is thinner than the body, but their posterior surfaces are flush—hence the depression called the epigastric fossa. It varies in length, so that its lower end, though palpable, is of no use as a landmark.

The linea alba (p. 456) is attached to its *lower end*. Fibres of the rectus abdominis and of the external and internal oblique aponeuroses are inserted into its *anterior surface*; of the internal oblique and transversus aponeuroses into its *margin*; part of the sterno-costalis and a slip of the diaphragm arise from its *posterior surface*, to which the fascia transversalis and the falciform ligament of the liver also are attached.

The sterno-chondral ligaments are attached to the front and back of the sternum at the notches for the rib-cartilages, and the intra-articular ligaments, when present, to their floors.

Ossification. — The following table gives the approximate dates of the appearance of centres and of fusion of segments, but there is a certain amount of variation, and centres for adjoining segments may appear almost simultaneously :—

	Manubrium.	Body, 1st Seg.	2nd Seg.	3rd Seg.	4th Seg.	Xiph. proc.
Centres (one or two) appear	5th month of intra-uterine life	6th m.	7th m.	8th m.	9th m.	3rd year
Parts unite	Old age	21st yr.	Puberty	Child	Middle age	

The fourth segment does not always have a separate centre. Epiphyses have been found at the clavicular notches in an adult.

Structure and Variations.—The sternum is composed of highly vascular spongy bone enclosed in thin compact bone. The *vascular foramina* are best marked on the back of the manubrium. Occasionally there is a hole in the lower part of the body, and more rarely the sternum is fissured longitudinally to a greater or lesser degree, the gap being wider above; the cleft is sometimes associated with *ectopia cordis*—a condition incompatible with life. Deformities, such as a bending back of the lower part of the sternum, arise from disease and in certain occupations. The two halves of the sternum are often asymmetrical, the clavicular notch being higher and the costal notches more crowded together on one side, with the junction of manubrium and body oblique; occupational use of the right upper limb may account for the asymmetry in some cases. Occasionally the manubrium includes the first segment of the body and carries three pairs of ribs, as in the gibbon; the *sternal angle* is then between the third pair of costal cartilages, and is felt about 3 inches below the suprasternal notch. The eighth costal cartilage in about ten per cent. of bodies reaches the sternum, more often on the right side than on the left; and in rare cases the seventh cartilage fails to reach the sternum. Small ossicles called *suprasternal bones* are sometimes found in the ligaments of the sterno-clavicular joint. (See Cobb, 1937.)

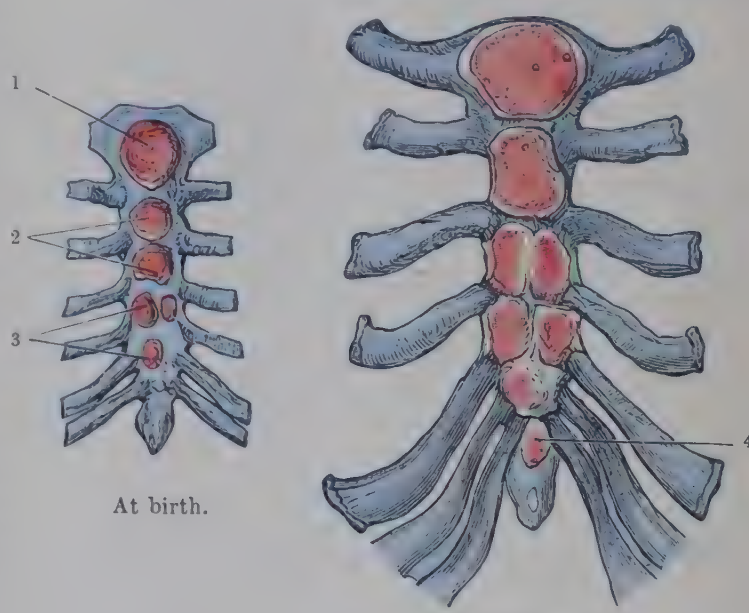


FIG. 146.—OSSIFICATION OF STERNUM.

1. Appears at 5th intra-uterine Month. 2. At 6th and 7th M. 3. At 8th and 9th M. 4. At 3rd Year.

In women the manubrium is at a rather lower level and is narrower and longer than in men, but the body of the sternum is wider and shorter (Paterson, 1904).

RIBS (COSTÆ)

There are twelve **ribs** on each side in both sexes. They are thin, narrow, curved strips of bone, and, though elongated, they are classed among the "flat" bones. They are attached posteriorly to the thoracic vertebræ and curve round the sides of the chest, slanting downwards and forwards; anteriorly they end by joining a **costal cartilage**. The ribs lie at the back, at the sides, and at the front of the thorax; and they provide protection for the sides and back of the upper part of the abdomen also. The upper seven ribs increase in length from above downwards and are called *true* ribs because their cartilages are attached to the side of

the sternum. The lower five are called *false* ribs; they diminish in length from above downwards and their cartilages fail, by increasing distances, to reach the sternum; but the ends of the eighth, ninth, and tenth each join the one above, edge to edge. The cartilages of the eleventh and twelfth are free, and are called *floating ribs.*

A rib has anterior and posterior ends, external and internal surfaces, and superior and inferior borders. The *posterior end* is called the **head**, and is articular; the *anterior end* is hollowed out to form a pit into which the costal cartilage fits. The *upper border* is smooth and rounded; the *lower* is thin and sharp. The *outer surface* is convex; the *inner* is concave lengthwise.

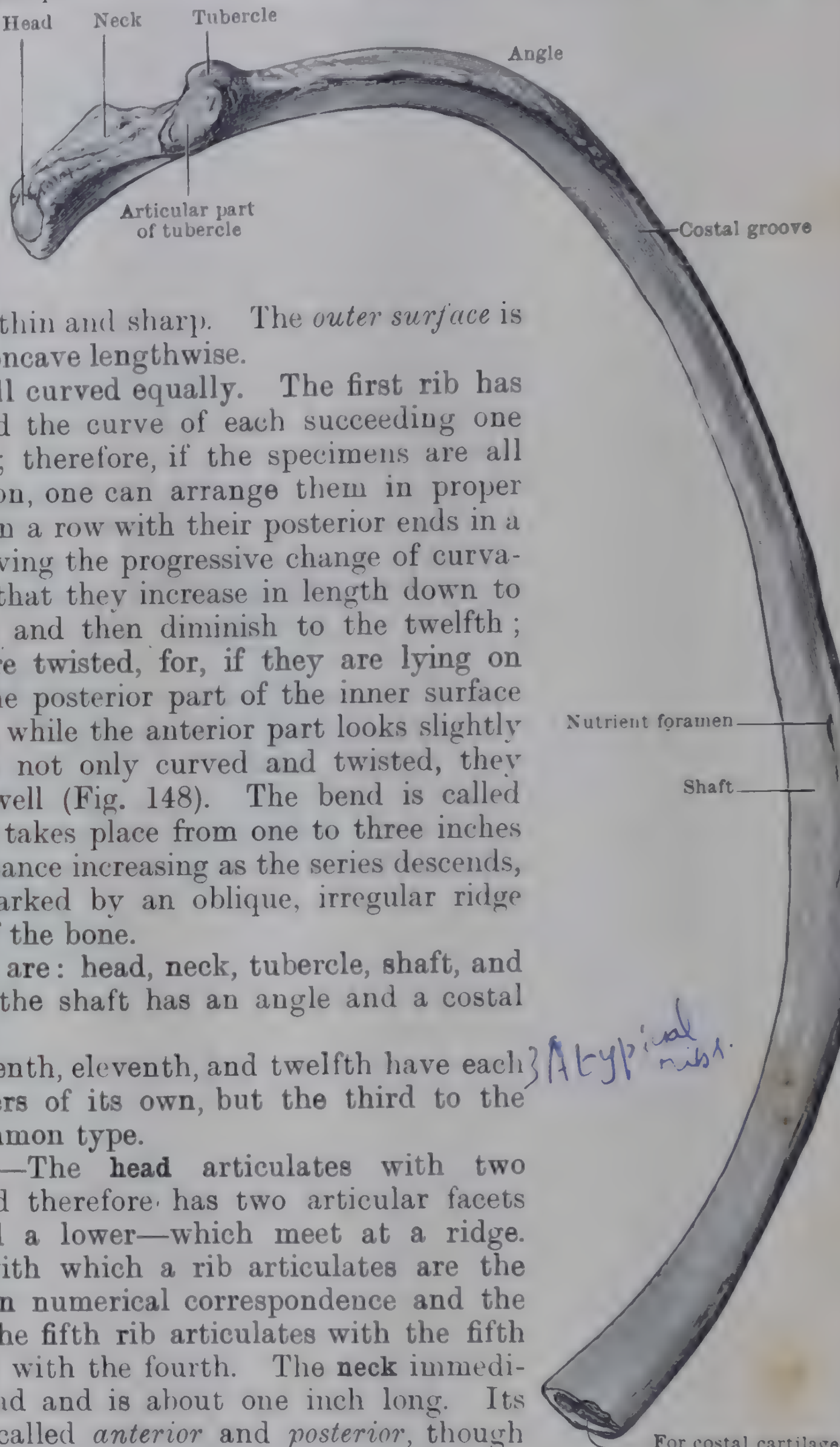


FIG. 147.—FIFTH RIGHT RIB FROM BELOW.

The ribs are not all curved equally. The first rib has the sharpest curve, and the curve of each succeeding one is wider or more open; therefore, if the specimens are all from the same skeleton, one can arrange them in proper order by laying them in a row with their posterior ends in a straight line and observing the progressive change of curvature. It will be seen that they increase in length down to the seventh or eighth and then diminish to the twelfth; and also that they are twisted, for, if they are lying on their lower borders, the posterior part of the inner surface looks largely upwards, while the anterior part looks slightly downwards. Ribs are not only curved and twisted, they are slightly bent as well (Fig. 148). The bend is called the *angle* of a rib; it takes place from one to three inches from the head, the distance increasing as the series descends, and its position is marked by an oblique, irregular ridge on the outer surface of the bone.

The **parts** of a rib are: **head, neck, tubercle, shaft,** and **costal cartilage**; and the shaft has an angle and a costal groove.

The first, second, tenth, eleventh, and twelfth have each some special characters of its own, but the third to the ninth belong to a common type. 3 Atypical ribs.

3rd – 9th – Typical ribs

A Typical Rib.—The **head** articulates with two thoracic vertebræ and therefore has two articular facets on it—an upper and a lower—which meet at a ridge. The two vertebræ with which a rib articulates are the one with which it is in numerical correspondence and the one above that, *e.g.*, the fifth rib articulates with the fifth thoracic vertebra and with the fourth. The **neck** immediately succeeds the head and is about one inch long. Its surfaces are usually called *anterior* and *posterior*, though they are continuous respectively with the inner and outer surfaces of the shaft. The **tubercle** is situated on the outer surface where the neck and shaft join; it articulates with the front of the tip of the transverse process of the vertebra with which the rib corresponds numerically. The **shaft** is all the rest of the bone. The ridge on the outer surface that marks the position of the **angle** is placed near the posterior end. In the first rib the angle is at the junction of neck and shaft and the ridge coincides with the tubercle; in the second rib the ridge is close to the tubercle; as the ribs are followed down, the ridge gradually recedes from the tubercle, down to the eighth or ninth; and below that the ridge becomes indistinct. The curve of a rib is sharpest at the

angle and a curved bone is most likely to be broken where the curve is sharpest; the rib is therefore thickest there. The **costal groove** is the long, shallow groove on the inner surface of the shaft immediately above the lower border.

The articular surface of the **head** of a rib is surrounded by a joint-capsule; the thick, anterior part of the capsular ligament—radiate ligament—is attached to the front of the head. Of the two facets the lower is the larger; the blunt ridge between them gives attachment to the intra-articular ligament which lies within the joint and binds the rib to the intervertebral disc.

The **neck** lies in front of the transverse process. The posterior surface is rough and is bound to the transverse process by the inferior costo-transverse ligament; the upper border is rough and raised as the **crest**, from which the superior costo-transverse ligament stretches up to the transverse process next above. The lower part of the anterior surface is smooth and covered with pleura. It is separated from the upper part by a faint ridge that gives attachment to the posterior intercostal membrane. The **tubercle** bulges backwards and downwards and has a *facet* on its lower and medial part for articulation with the transverse process. An articular capsule surrounds the facet, and the lateral costo-transverse ligament connects the rough part of the tubercle with the tip of the transverse process.

The *upper border* of the **shaft** gives insertion in all its length to an external intercostal muscle, and, internal to that, a posterior intercostal membrane is attached between the neck and the angle, while an internal intercostal muscle is inserted into the rest of the length of the border. The **costal groove** is broad and well-marked posteriorly, but indistinct in the anterior part of the rib; the intercostal vessels and nerve run along the groove. The groove has an upper and a lower lip, the lower lip being the sharp *lower border* of the bone; the external intercostal muscle arises from the whole length of its lower lip; the posterior intercostal membrane is attached to the floor of the groove between the tubercle and the angle; an internal intercostal muscle arises from the upper lip from the angle forwards. The rest of the *inner surface* of the rib is smooth and is covered with pleura.

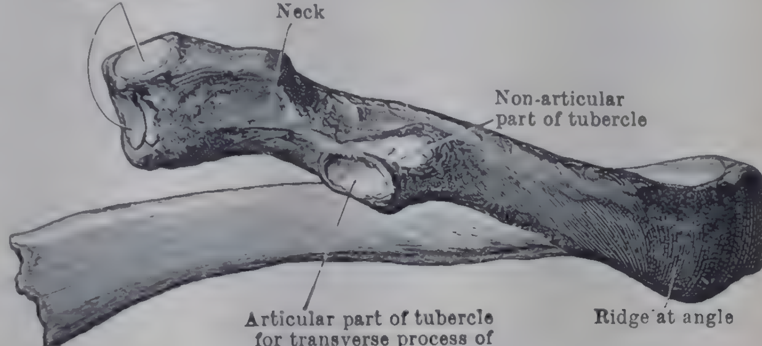


Fig. 148.—Fifth Right Rib from behind.

Many muscles are attached to the *outer surface* of the ribs. The *angle* is very obtuse, and is open upwards; the ridge that marks it is for the attachment of the ilio-costo-cervicalis—*i.e.*, the lateral division of the large composite mass of muscle, called sacro-spinalis, that lies alongside the spines of the vertebræ. On the longer ribs there is often a slight bend called the *anterior angle*, marked by an indistinct ridge on the outer surface two inches or more from the anterior end; the ridge is for the origin of slips of the serratus anterior and obliquus externus abdominis.

In each of the upper ten ribs the anterior end is the widest part of the rib.

The **first rib** is the shortest rib, except the twelfth; it is the most sharply curved, and it is broad in comparison with its length. It lies at the boundary between neck and thorax, largely under cover of the clavicle; its posterior end is above the level of the clavicle, and its anterior end is immediately below the clavicle (Fig. 150). Unlike the other ribs, it lies nearly all in one oblique plane, and its **surfaces** are *upper* and *lower*, its **borders** *inner* and *outer*. The inner border is concave; the outer border is convex. The surfaces are not always easily distinguished at first glance, but if the rib is laid on the table and its head touches the table, then its lower surface is looking downwards; if it is turned upside down the head stands away from the table.

The **head** is small and articulates with one vertebra, the first thoracic. It has therefore only one facet. The **neck** is relatively long, and is compressed from above downwards; the top of the pleura and lung lie immediately in front of it. The **tubercle** is on the outer border and is relatively large.

The outer part of the *lower surface* of the **shaft** is roughened by the attachment of the internal intercostal muscle. The inner part is covered with pleura and is crossed obliquely by the first intercostal nerve which may groove it. The subclavian artery and vein lie across the *upper surface*, producing broad, shallow grooves. The groove for the artery is about the middle of the shaft; the groove for the vein is nearer the anterior end. The scalenus anterior muscle is inserted into the **scalene tubercle** and a small rough triangular area that separates the two grooves; the tubercle is a small projection on the *inner border* of the rib. The surface behind the groove for the artery between that groove and the

tubercle of the rib—gives insertion to the scalenus medius muscle, while the first digitation of the serratus anterior arises from it near the outer border immediately behind the groove for the artery. The greater part of the anterior primary ramus of the first thoracic nerve, on its way to join the brachial plexus, runs upwards and laterally in front of the neck and then lies in the posterior part of the groove for the artery, between the artery and the scalenus medius. On many specimens the grooves and tubercles are faintly marked; while in others there is a special groove for the lodgment of the first thoracic nerve, or the lowest trunk of the brachial plexus, immediately behind the groove for the artery. The subclavius muscle and the costo-clavicular ligament are attached to the upper surface of the rib at its junction with the cartilage.

The external and internal intercostal muscles of the first space arise from the *outer border.* A fibrous sheet, called the suprapleural membrane, stretches fanwise from the transverse process of the seventh cervical vertebra to be attached to the *inner border.*

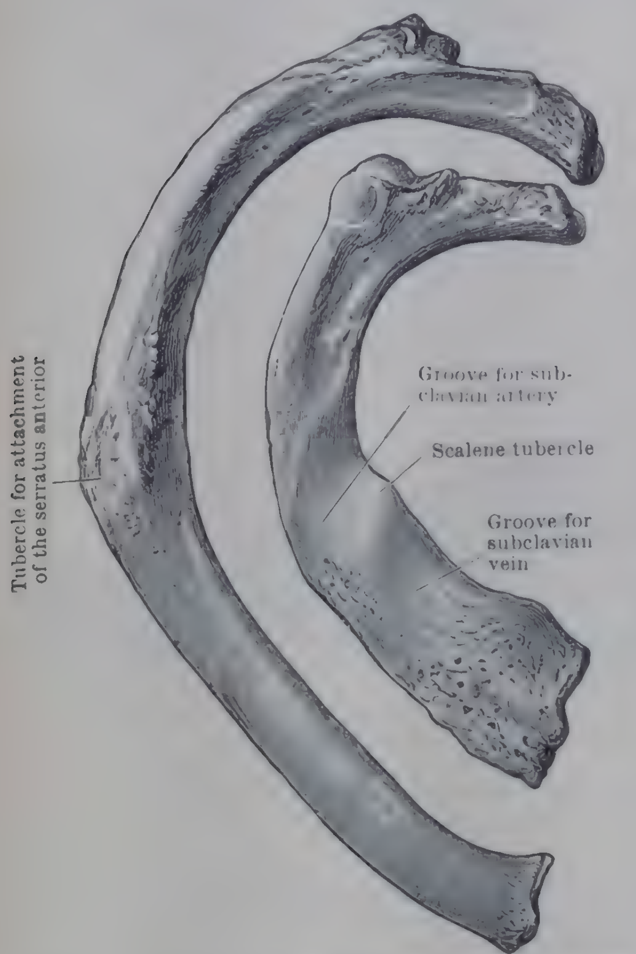


Fig. 149.—First and Second Right Ribs as seen from above.

The **second rib** is about twice as long as the first, and the sharpness of its curve distinguishes it from one of the lower ribs of similar length; it is not twisted; its surfaces are, in direction, intermediate between those of a first rib and those of a typical rib, and its costal groove is poorly marked. But the *special character* of the second rib is that on its outer surface, about its middle, there is a broad rough **tubercle** for the origin of part of the **serratus anterior** muscle. No other rib has a similar tubercle.

The **tenth, eleventh,** and **twelfth** ribs have each only one facet on the head, for each articulates with only one vertebra and that is the thoracic vertebra of corresponding number. The tenth, however, may be a typical rib. The eleventh differs from the tenth mainly in that its tubercle is small and has no articular facet, and the angle is ill-defined; but the tubercle and angle of the tenth also may be ill-defined, so that it is sometimes difficult to say whether a given rib is tenth or eleventh if the other ribs of the same skeleton are not at hand.

The **twelfth rib** is small and slender. It may be as short as the first, or even shorter. *Tubercle, angle,* and *costal groove* are absent or are poorly marked. The **body** tapers off at the free end, while other ribs are nearly always slightly swollen at their anterior ends.

Costal Cartilages

The **costal cartilages** are bars of hyaline cartilage fitted into the pits at the anterior ends of the ribs and held in place because the perichondrium of each is continuous with the periosteum of its rib. They greatly increase the resilience of the framework of the thorax and the perichondrium is so strong that there is little or no displacement of the fragments when a costal cartilage is fractured. The **upper seven** pairs join the sternum and can be felt at its sides; they increase in length from above downwards, from one inch to four or five inches. The *first* cartilage is fitted on to a rough mark on the margin of the manubrium and is held in place by the continuity of its perichondrium with the periosteum

of the sternum; the *other six* are joined to the sternum by synovial joints. The first and second slope downwards slightly from the bony rib to the sternum; the third is horizontal; the fourth incli s upwards; the fifth, sixth, and seventh continue the direction of the rib for about an inch, and then turn upwards, with increasing degrees of obliquity, to reach the sternum. The cartilages of the **lower five** ribs diminish in length from above downwards; they can be felt in the costal margin between the thorax and abdomen. The eighth, ninth, and tenth continue in the direction of their ribs for about an inch and then turn upwards; they fail, by increasing distances, to reach the sternum, and each tapers off to a point. They are each united edge to edge with the one above, forming synovial joints at the points of contact, except the tenth, which is separated from the ninth by the fibrous tissue that unites them. The eleventh and twelfth are mere pointed cartilaginous tips on the ends of the ribs.

THORAX

The **thorax** lodges the lungs, the heart and many other structures. It gives them protection and its skeleton provides attachment for many muscles besides those that belong to the thorax itself; but the chief use of the thorax in mammals is to act as a bellows by which air, for oxygenating the blood, can be drawn into the lungs. Its framework is a bony and cartilaginous cage the bars of which are arranged so that they not only resist atmospheric pressure as the bellows is opened, but also, by their mobility, share in the expanding movement.

The skeleton or cage is made of the thoracic vertebræ and intervertebral discs, the sternum, the ribs, and their cartilages. It is barrel-shaped, but is narrower above than below. It is also longer behind than in front, and is compressed from before backwards, so that it is wider from side to side, the greatest width being at the level of the eighth or the ninth rib. The antero-posterior diameter of its interior is greatly diminished by the bodies of the vertebræ. It communicates with the front of the neck by an inlet, and with the abdomen by an outlet.

The **inlet** is small and is kidney-shaped in outline; it slopes from above downwards and forwards; it measures about 2 inches or 50 mm. from before backwards and 100 mm. across. It is bounded by the first thoracic vertebra behind, the manubrium in front and the first pair of ribs and their cartilages at the sides. It is occupied by the apices of the lungs and pleuræ, the windpipe, the gullet, and numerous vessels and nerves that pass between neck and thorax (Fig. 597, p. 707).

The **outlet** is large and is uneven in outline. It is bounded by the xiphi-sternal joint, the lower six pairs of costal cartilages, the shafts of the twelfth pair of ribs, and the last thoracic vertebra. It is closed by the diaphragm, which forms a highly vaulted and movable floor for the thorax and roof for the abdomen, separating the two cavities (Fig. 385). The *infrasternal angle* is situated at the anterior part of the inferior aperture; its sides are the seventh pair of costal cartilages; its apex is the xiphi-sternal joint; and the xiphoid process juts down into the angle.

The **posterior wall** of the thorax is made up of the thoracic vertebræ and intervertebral discs and the posterior part of the ribs. The ribs have a backward sweep as far as their angles which makes their angles nearly flush with the tips of the spines of the vertebræ, so that Man, unlike most animals, can lie on his back with stability and ease. The forward projection of the vertebral bodies and the backward curve of the ribs create a large hollow, on each side, in the posterior part of the interior of the thorax for the lodgment of the thickest part of the lung.

In the **sides** of the thorax there are the shafts of the ribs which are not all the same distance apart, nor are they parallel. The upper intercostal spaces are wider than the lower; and the ribs slope downwards and forwards with an obliquity which increases from the first down to the ninth or tenth, and the intercostal spaces are wider therefore in front than behind. The obliquity is more marked in women than in men, and in the old than in the young. The sides slope

outwards down to the level of the eighth or ninth rib, and usually slope inwards slightly below that.

The **anterior wall** is made of the manubrium and body of the sternum, the anterior ends of the upper ten pairs of ribs and their cartilages. It is shorter than the posterior wall or the sides, especially in the median plane, for the upper border of the manubrium is opposite the lower border of the second thoracic vertebra and the xiphi-sternal joint is opposite the ninth.

In the fœtus the thorax is compressed from side to side. At birth its form alters with the expansion of the lungs, but full transverse expansion takes place only after the child begins to

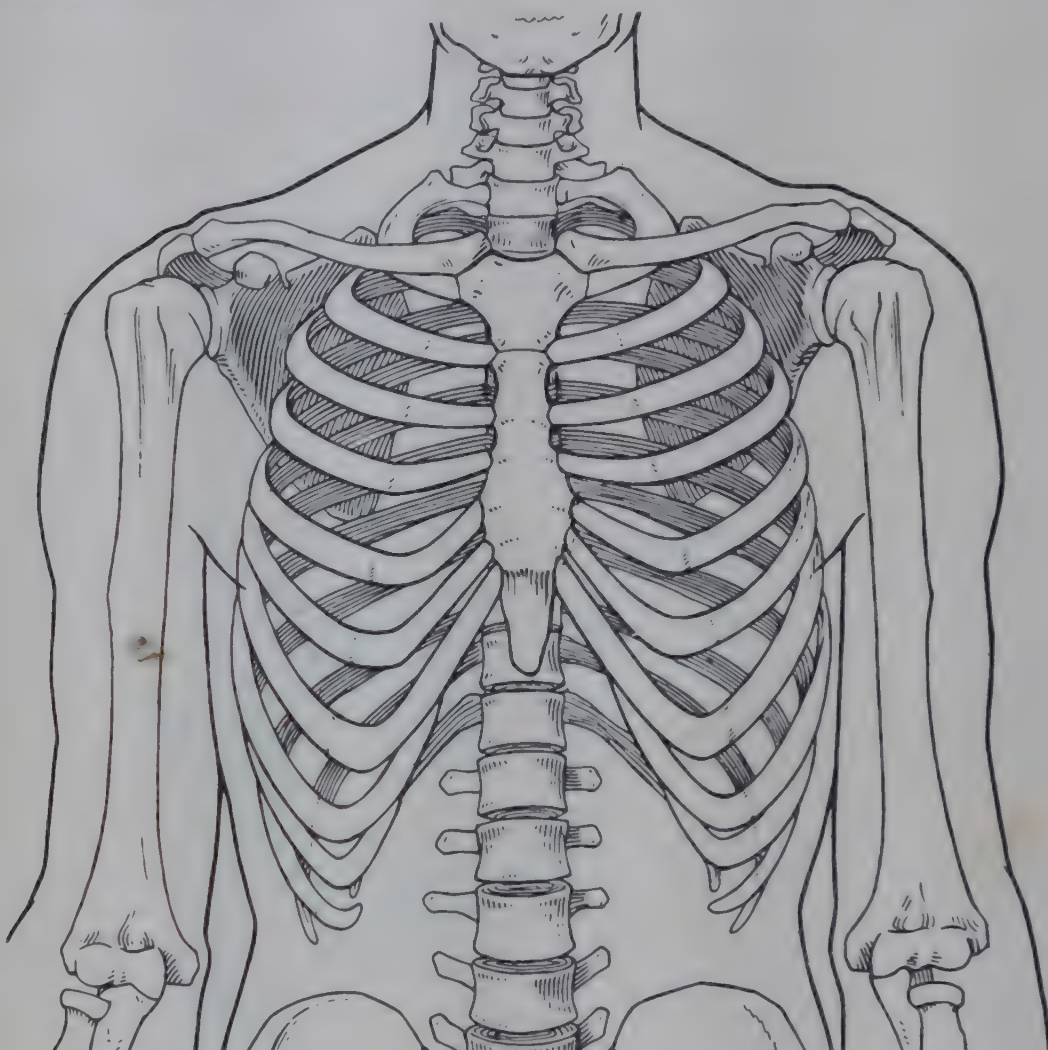


FIG. 150.—FRONT OF PORTION OF SKELETON SHOWING THORAX.

walk and to use its upper limbs more exclusively for prehensile purposes. *In a woman* the thorax is shorter and rounder than in a man, and the upper ribs are more movable.

Surface Relations.—The thorax is well covered externally with muscles that belong to the upper limb, the abdomen, the back, and the neck. There are only three parts that have no muscular covering. These are (1) a finger's-breadth down the middle of the sternum, (2) the median line of the back, (3) a portion of the seventh rib just medial to the lower part of shoulder-blade, especially when the shoulder is drawn forwards.

The **first rib** provides the bony resistance felt in the neck above the middle of the clavicle; its cartilage is immediately below the sternal end of the clavicle.

The **second rib** is the most easily identified of all on the front of the chest. Its cartilage joins the sternum at the **sternal angle**, which is always easily felt; both angle and second cartilage are often easily seen as well as felt. When ribs have to be counted, or when a particular rib has to be found in the living person, the best method is to find the second and count downwards from it. There are

rough and ready, though uncertain, guides to some of the other ribs and cartilages. The *nipple* is usually opposite the **fourth intercostal space** between the anterior ends of the bony parts of the fourth and fifth ribs. The cartilage felt on the costal margin next the sternum is nearly always the **seventh.** The cartilage felt where the groove marking the lateral margin of the rectus abdominis reaches the costal margin is usually the **ninth.** The **tenth** cartilage is the lowest one felt when the costal margin is examined from the front, and it is at the level of the body of the *third lumbar vertebra.* A line drawn from the medial end of the clavicle to the point a thumb's-breadth behind the lowest point of the tenth cartilage will

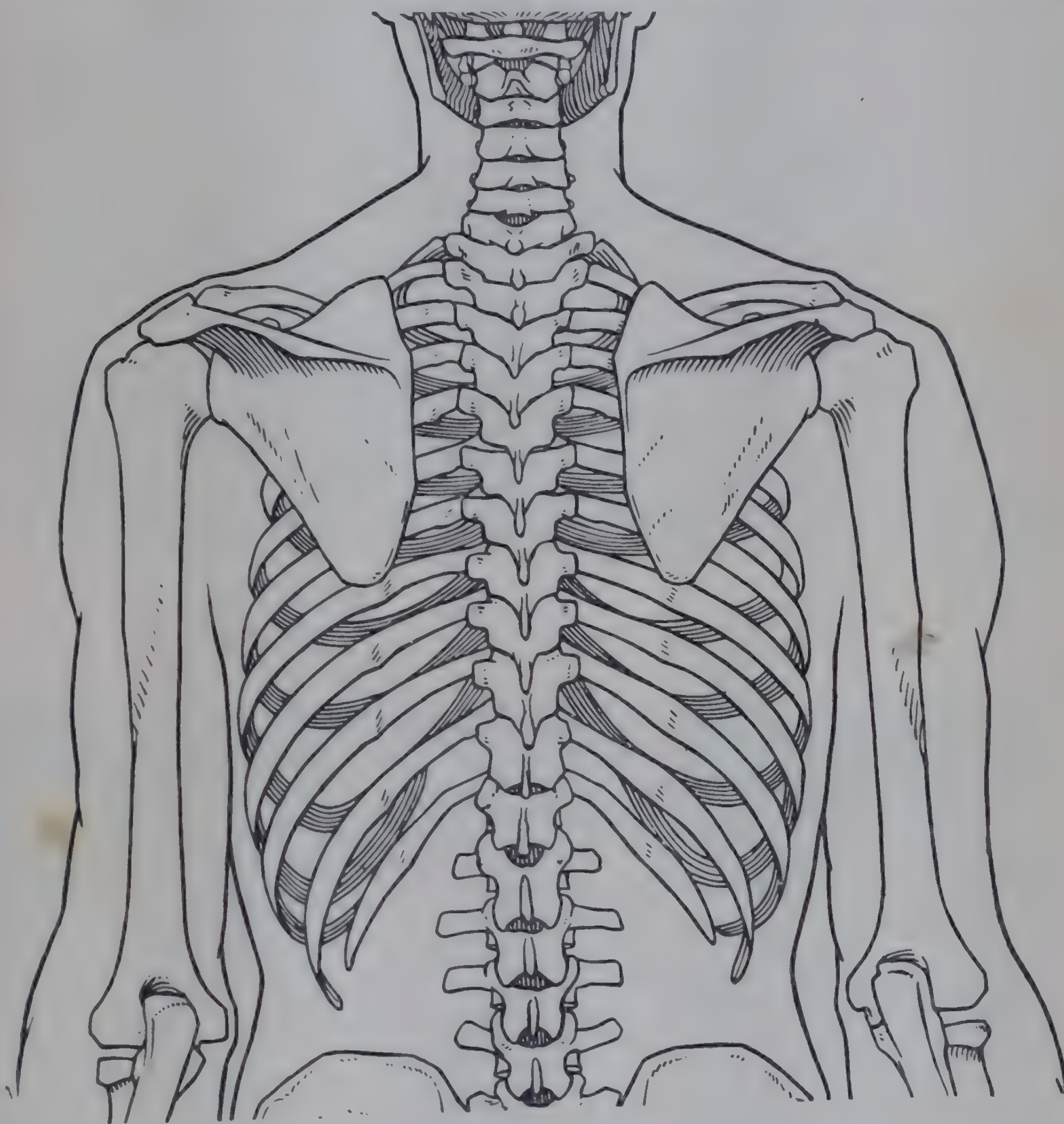


FIG. 151.—BACK OF PORTION OF SKELETON SHOWING THORAX.

pass through or near the junction of ribs and cartilages from the second to the tenth. If the *posterior axillary line* is followed downwards, the lowest rib it crosses is the **eleventh.** The **twelfth** rib may be felt, but sometimes it is so short that it is hidden by the sacro-spinalis. **On the back** the point where the *spine of the scapula* meets the medial border overlies the **fourth** rib; and the *inferior angle* of the scapula overlies either the **seventh** intercostal space or the eighth rib.

Ossification, Structure, and Variations of Ribs

Ossification.—A rib is ossified from one primary centre and one or two or three secondary centres. The **primary centre** appears near the angle (first in the sixth rib) in the sixth week of intra-uterine life, and ossification spreads rapidly through the rib. **Secondary centres** appear at *puberty* and the epiphyses fuse with the rest of the bone at 25. The **first rib** has *one* epiphysis for the **head** and *one* for the **tubercle.** The **second to the sixth,** inclusive, have *one* epiphysis for the **head,** *one* for the *articular* part of the **tubercle,** and *one* for the *non-articular* part. The **seventh to the tenth,** inclusive, have *one* for the **head** and *one* for the **tubercle.** The **eleventh and twelfth** have *one* for the **head.**

Structure and Variations.—A rib is composed of highly vascular spongy bone enclosed in a flattened tube of compact bone. The compact bone is thicker in the two surfaces than at the borders. The inner table is much thicker than the outer, and both tables are thickest at the angle. The *vascular foramina* are best marked at the back of the neck; the *nutrient canal* is in the costal groove and is directed towards the vertebral end.

The most important variation is a **cervical rib**. It may unite with the sternum or with the first costal cartilage, or with the vertebral end of the first rib, making a bicipital rib. Part of the cervical rib may be represented by fibrous tissue, and in some cases the only part present is the sternal end. Occasionally increase of number is due to a lumbar rib. Diminution in number is rare, but sometimes the twelfth rib is absent, or the first rib is rudimentary and may fuse with the second, making a bicipital rib. Sometimes two ribs are partly fused together. Occasionally the posterior parts of two ribs are united by a projection from each articulating with an intervening nodule of bone. The anterior end of a rib is sometimes very wide and may have a hole or a cleft in it. *Costal cartilages* also may be broad and perforated. The seventh cartilage sometimes throws out a projection which articulates with a similar projection from the sixth; the sixth may unite similarly with the fifth. The seventh sometimes fails to reach the sternum, but a commoner anomaly is that the eighth articulates with the sternum, more often on the right than on the left side. In old age the cartilages may undergo partial ossification; this condition may be regarded as normal in the first costal cartilage in elderly people. Costal cartilages are seldom exactly alike on the two sides.

Development of Vertebræ, Ribs, and Sternum

Vertebræ.—In the Section on Embryology it is explained that the *paraxial mesoderm* is divided by transverse clefts into a number of segments called *mesodermal somites*, and that the cells of the ventro-medial or *scleratogenous* parts of the somites proliferate and form a continuous mesodermal sheath around the notochord and neural tube [σκληρός (sclēros) = hard; γεννάω (gennaō) = produce]. The sheath is called the **membranous vertebral column**: in it the vertebræ are formed, and pass through a pro-cartilage stage and a cartilage stage before ossification. A *pro-cartilage vertebra* has only a body enclosed in a horseshoe-shaped vertebral bow. The **body** surrounds the notochord, and its position is such that it corresponds to the contiguous halves of two adjacent somites, its middle being opposite an *intersegmental septum*, *i.e.*, the interval

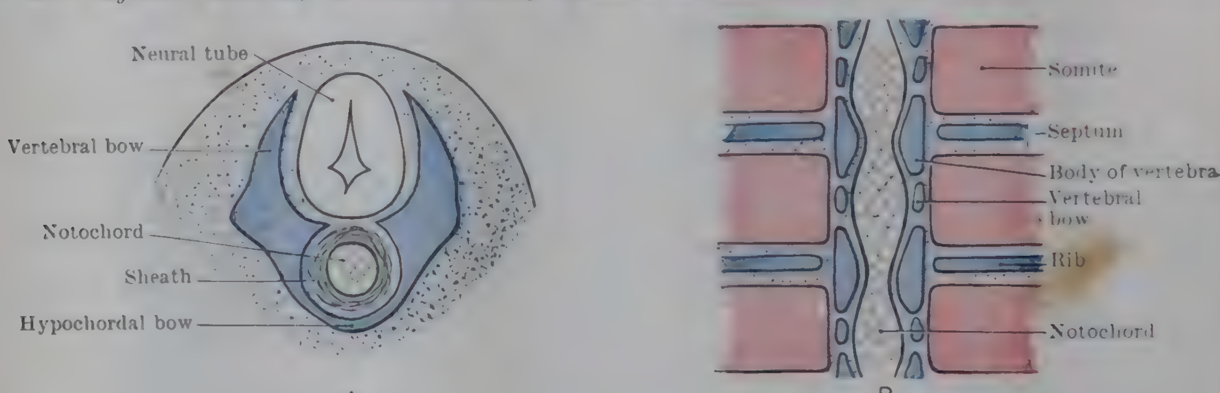


Fig. 152.—Development of the Membranous Basis of a Vertebra. (After Keith, 1948.)
A, in transverse section. B, in longitudinal section, showing the relation of the vertebræ to the primitive segments.

between two somites (see Wyburn, 1944). The middle part of the **vertebral bow** is sometimes called the *hypochordal bow* [ὑπό (hypo) = below]; it is ventral to the headward part of the vertebral body to which it belongs; the two limbs of the bow slant backwards to enclose the neural tube dorsal to the tailward part of the vertebral body; in time they meet each other dorsal to the neural tube and thus form a *vertebral ring*.

About the fourth *week* of intra-uterine life, the scleratogenous tissue between two bodies, opposite the middle of a somite, begins to undergo fibrous and chondrifying changes and becomes an *intervertebral disc*. About that time *chondrification* begins also in the **vertebral body** and in the **limbs of the bow**; the body and the bow rapidly unite, and chondrification of the bow is completed dorsally during the fourth *month* of intra-uterine life. The body forms the median part (*centrum*) of a body of a vertebra. The limbs of the bow form the postero-lateral parts of a body and the vertebral arch and its processes; the transverse processes and the spine grow out from it into the intersegmental septum that lies between the two somites to which the vertebra corresponds. The scleratogenous tissue between the arches of two vertebræ becomes the ligamenta flava and the capsules that unite articular processes. *Ossification* begins at the seventh week of intra-uterine life in the arches and at the tenth week in the bodies.

The ventral or hypochordal part of the vertebral bow disappears, except in the **atlas** vertebra, where it chondrifies and ossifies to form the anterior arch. The atlas is therefore a complete vertebral ring; its centrum becomes the odontoid process, and its lateral masses correspond to the parts of the body of a typical vertebra that are formed from the vertebral bow. The ligaments that connect the odontoid process with the margins of the foramen magnum represent the disc between the atlas and the last occipital segment.

PLATE V

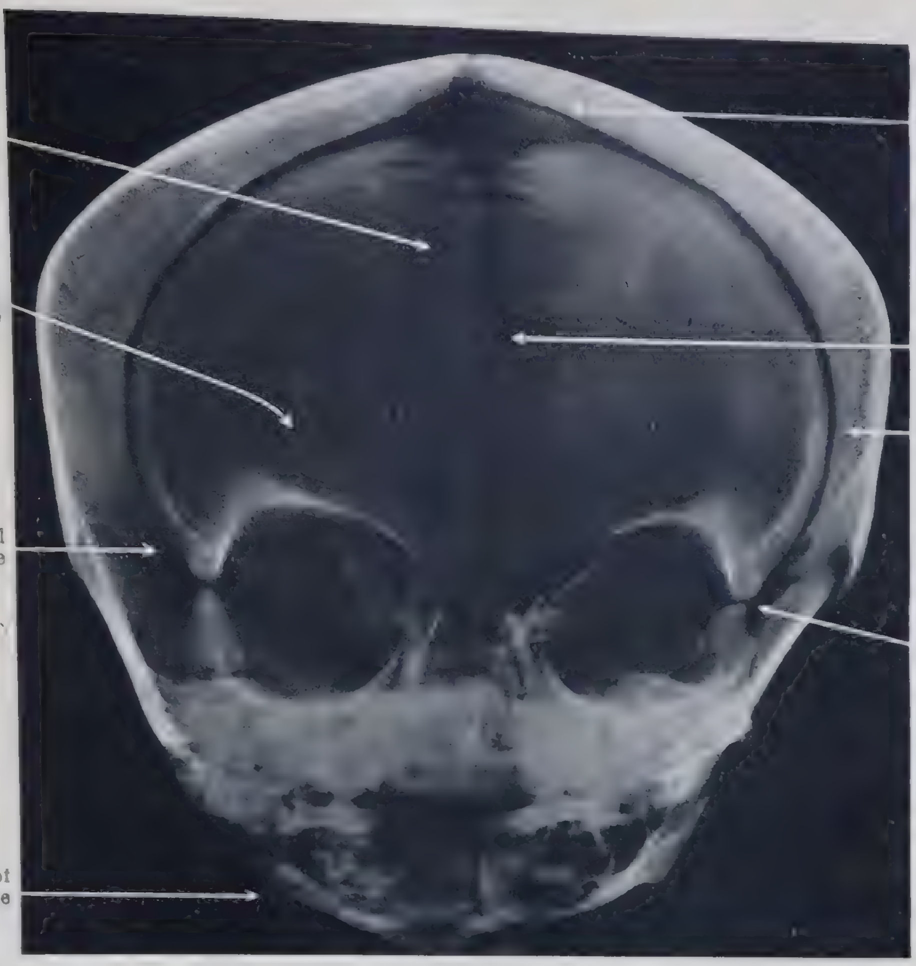


Fig. 1.—Anterior Radiograph of Skull of Full-Time Fœtus.
Compare with Fig. 174, p. 208.

Fig. 2.—Lateral Radiograph of the same Skull of a Full-Time Fœtus.
Compare with Fig. 175, p. 209.

PLATE VI

PLATE VI.—LATERAL RADIOGRAPH OF THE SAME MALE SKULL AS IN PLATE VIII.

Compare with Fig. 155, p. 162; Fig. 164, p. 193; with Plate VII (radiograph of one-half of the same skull in which confusion due to doubling of outlines is absent) and with radiographs of the living head (Plates LXXIV, p. 945, LXXV, p. 969, and LXXX

The rudimentary condition of a **coccygeal** vertebra is due to the failure of the limbs of the vertebral bow to develop. The incomplete condition of the laminæ of the last two **sacral** vertebræ is due to imperfect chondrification and ossification of vertebral bows. Imperfections in the formation of vertebral bows in regions farther up in the vertebral column give rise to the condition known as *spina bifida*, commonest in the lumbar region because fusion spreads downwards from the cervical region.

The part of the *notochord* enclosed in the bodies of the vertebræ is first constricted, and finally disappears after ossification begins. The part enclosed in the discs persists in them as their pulpy centres. For the evolutionary history of the notochord and the vertebral column, consult Gadow (1933).

Ribs.—The ribs are developed in the intersegmental septa and pass through pro-cartilage and cartilage stages before ossification. Each articulates at first with only one vertebra—*i.e.*, the vertebra opposite the septum in which the rib is developed. Later, the vertebral ends of the ribs, except the first, tenth, eleventh, and twelfth, are shifted headwards, so that each articulates not only with its own vertebra but also with the disc and the vertebra above.

Sternum.—The sternum is formed from mesodermal tissue in front of the pericardium. The **manubrium** probably arises in association with the ventral part of the shoulder-girdle, and the **body** and **xiphoid process** from a pair of *sternal bars* that grow from the mesodermal rudiment of the manubrium and fuse together in the median plane. After chondrification the sternum becomes connected with the costal cartilages by synovial joints. For the morphology of the sternum, consult Paterson (1904).

SKULL

The **skull** is the skeleton of the head and face. It is made of 22 bones, including the mandible, which is the skeleton of the lower part of the face and is a movable bone. The other 21 bones are so firmly knit together that they are taken apart with difficulty; they are built together in such a way that they enclose one large cavity and three smaller ones. The large cavity is the *cranial cavity*, and contains the brain and its membranes; the smaller cavities are the *cavity of the nose*, and the two *orbits*, which hold the eyeballs. There are lesser cavities contained within certain of the skull-bones; these are the *middle ear*, the *internal ear*, and the *air-sinuses*. The skull-bones consist of two plates or **tables** of compact substance that enclose a layer of spongy substance between them—in this case called **diploë**. In some of them the diploë is absorbed, leaving cavities or air-sinuses between the tables of compact bone; the sinuses communicate with the cavity of the nose and have a mucous lining continuous with that of the nose.

The *hyoid bone*, which lies in the neck below the mandible, is described along with the skull-bones, but is not part of the skull. The *auditory ossicles*, which lie in the middle ear, are described in the Section on the Sensory Organs.

Some of the united bones of the skull are paired and some are unpaired. The *paired* bones are bracketed (2), the *unpaired* (1), in the following list.

Frontal (1)	Nasal (2)	The first six in the list—eight bones in all—are those that share in the formation of the walls of the cranial cavity.
Ethmoid (1)	Lacrimal (2)	
Sphenoid (1)	Inferior nasal conchæ (2)	
Occipital (1)	Vomer (1)	
Parietal (2)	Maxillæ (2)	
Temporal (2)	Zygomatic (2)	
	Palatine (2)	

In a young person, these bones are separable. The joints by which they are held together are either *sutures* (p. 334), in which the articulating parts are connected by a ribbon of fibrous tissue, or *primary cartilaginous joints* (p. 334), in which they are connected by hyaline cartilage. With advancing years the joints disappear and neighbouring bones fuse together gradually.

There is some confusion in regard to the meaning of the terms *skull, cranium,* and *calvaria.* In ordinary English, 'skull' denotes the skeleton of the head with or without the mandible, and the word 'cranium' may be used in the same general sense. Its use in technical works is better restricted, however, to mean 'skull without mandible', although κρανιον (kranion) originally had the still more restricted meaning of the part of the head covered with hair. Even the word 'calvaria' has been employed in the general sense of *brain-pan* or *skull* but it usually means the top part of the skull or skull cap [*calvus* = bald, *calva* = the scalp].

In catalogues of craniological collections the following meanings are attached to the terms :—*Skull* = entire skeleton of head and face including mandible ; *Cranium* = skull without mandible ; *Calvaria* = skull after bones of the face have been removed or destroyed. In this text the word 'skull', being the more generalized term, is frequently employed instead of 'cranium' as a matter of convenience and common usage.

It is much more important that the student should acquire a knowledge of the skull as a whole than of the separate bones. The detailed description of the separate bones is put at the end of the Section for reference, and the skull as a whole is dealt with earlier. It is advisable to identify at the outset the following parts, for they will be referred to as landmarks.

(1) The **orbits** are the pair of large pyramidal cavities in the front of the skull (Fig. 154). They are so named because the eyes rotate in them. [*Orbita* = a wheel rut, a circuit.]

(2) The **anterior bony aperture of the nose** is the large, egg-shaped hole between and below the two orbits ; through it one can see into the cavities of the nose.

(3) The **external auditory meatus** or ear-hole (Fig. 155) is the small, round or oval hole or passage seen in the lower part of the side of the skull about midway between the front and the back. [*Meatus* = a passage.]

A standard position is used to facilitate description or measurement of the skull. When it is in its **proper position** the lower margin of the orbit and the upper margin of the orifice of the meatus are in the same horizontal plane. This plane is known as the " Frankfurt plane " (Fig. 176).

(4) The **zygomatic arch** is the bridge of bone on the side of the skull that spans the interval between the lower part of the orbit and the front of the meatus [ζύγωμα (zygōma) = a bar, from ζυγόν = anything that connects two bodies].

(5) The **foramen magnum** is the large, round hole on the lower surface of the skull a little behind its centre (Fig. 156).

(6) The **posterior bony apertures of the nose** are a pair of large openings about two inches in front of the foramen magnum ; they are oval and oblique, and are close together ; through them one can see into the cavities of the nose from behind.

(7) The **bony palate** is the platform of bone that forms the median part of the front of the lower surface of the skull ; its posterior edge is the *lower* margin of the posterior apertures of the nose (when the skull is held right way up).

(8) Examine the interior of the skull (Fig. 157). The cranial cavity has a very uneven floor, and is divisible into three main regions which are at different levels. Those regions are called the **anterior, middle**, and **posterior cranial fossæ** ; each of them has a median part and a right and a left lateral part.

SKULL AS A WHOLE

The skull as a whole is slightly flattened from side to side. Looked at from above, it is smooth, but from below it is very uneven. It is never quite bilaterally symmetrical, but usually is nearly so.

The **exterior of the skull** is examined from five points of view : from the front, the back, above, below, and from the side. Each of those aspects is called a 'norma' [= a square]. They are named norma frontalis, occipitalis, verticalis, basalis, and lateralis. There are no boundary lines between the aspects, for they overlap one another to a large extent, but the area visible is fixed by proper orientation of the skull with the coronal, or sagittal plane or the Frankfurt plane (Fig. 176) set at right angles to the line of vision.

Norma Verticalis

The **top of the skull** has convex contours, so that any impact received at a particular point is distributed over a considerable area, and the danger of fracture is thereby lessened. The horizontal outline varies considerably in different

specimens, but in most European skulls the outline is ovoid, the wider part being nearer the back than the front (Fig. 153).

The top of the skull shows portions of four bones—the **frontal** bone is the large

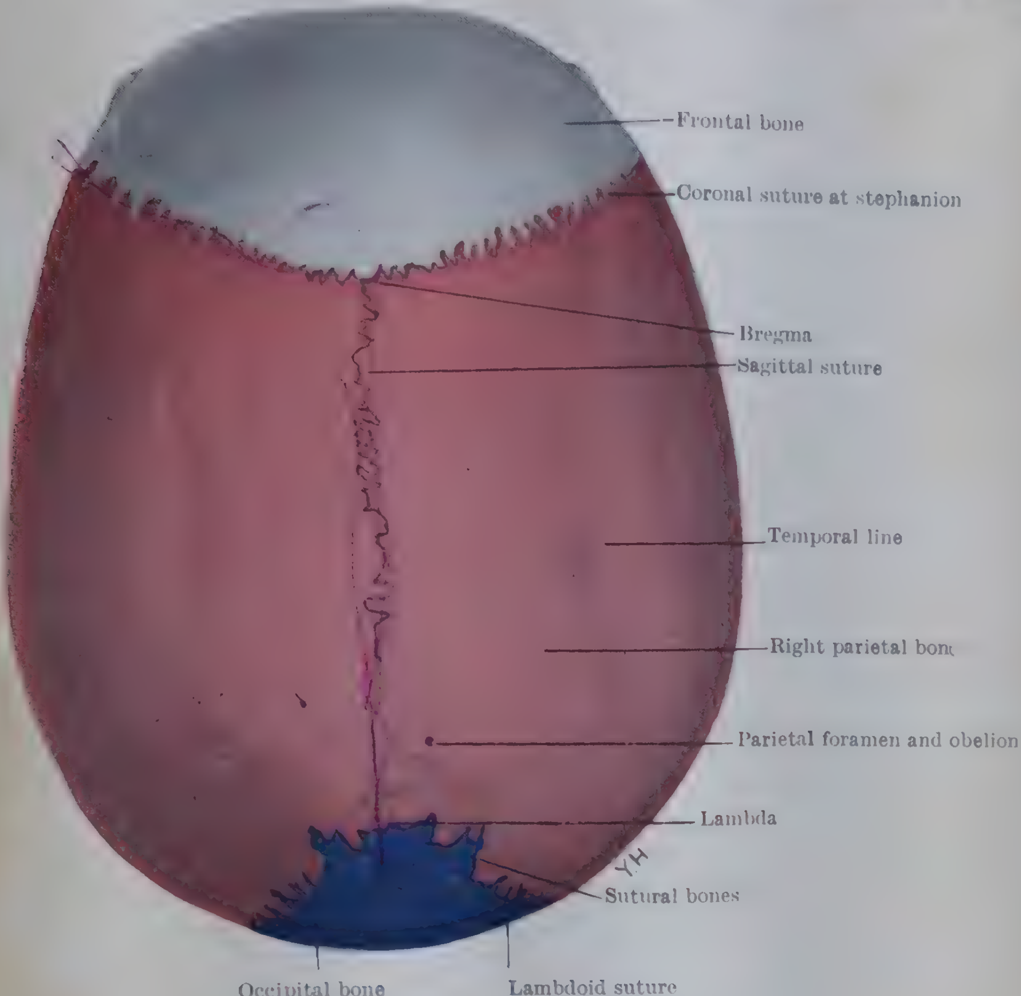


FIG. 153.—TOP OF THE SKULL (Norma Verticalis).

shell-like bone, seen in Fig. 155, forming the forehead and the anterior part of the top of the skull [*frons* = the brow]. The **occipital** bone forms the back of the skull and only a small part of it is seen from above [*occiput* (*ob caput*) = the back of the head up to the crown ; *sinciput* (*semi caput*) = the front part of the head from the crown to the forehead]. Between the frontal and occipital bones lie the right and left **parietal** bones which form a large part of the top and side of the skull [*paries* = a wall]. They are convex, with a rather square outline, and meet in the median plane above.

The bones are united by serrated *sutures*—the jagged, saw-like edges of the bones interlocking with one another [*sutura* = a seam]. If the skull is that of a young adult the sutures are seen distinctly as irregular lines between the bones. If the skull is that of an old person they are more or less obliterated and the bones are fused, but the positions of the sutures are usually indicated by narrow, irregular linear depressions. In many skulls small circumscribed pieces of bone are seen in the sutures in certain places, and are called **sutural bones** (Fig. 153).

The suture that unites the frontal bone to the two parietal bones and arches across the skull from side to side, is the **coronal suture** [*corona* = a curved line, circle, crown]. The suture that unites the occipital bone to the two parietal bones is called the **lambdoid suture**, because it is shaped like the Greek capital letter *Lambda* [Λ = L]. The suture between the two parietal bones is called the **sagittal suture**; that name is given because in an infant's skull the sagittal suture, the lambdoid suture, and an unossified region, called the anterior fontanelle, together resemble a heraldic arrow [*sagitta* = an arrow].

The point where the sagittal suture meets the coronal suture is called the **bregma** [βρέγμα = the front part of the head]. At birth the parts of the frontal

and parietal bones around the bregma are not fully ossified, and leave a large, lozenge-shaped membranous area which is yielding to the touch and is called the *anterior fontanelle*, because it rises and falls with every beat of the heart; in a healthy child the bones approach each other and close the fontanelle by the end of the second year. The coronal suture slopes downwards and forwards from the top of the skull; the bregma is therefore the farthest back point on the suture; it is immediately in front of the mid point of a line drawn from one external auditory meatus to the other in the vertical transverse plane, and is occasionally felt as a depression in the living head. The *post-coronal depression* is the name given to a slight flattening or even hollowing seen in some skulls on the surface of each parietal bone behind and parallel to the coronal suture. Occasionally there is a broad, low ridge along the line of the sagittal suture.

The **lambda** is the point at which the sagittal and lambdoid sutures meet.

The **vertex**, or highest point of a skull held in proper position, is on the sagittal suture near its middle, but varies slightly in different skulls. The **parietal foramen** is a small hole present in many skulls in the parietal bone near the sagittal suture about 35 mm. from the lambda. It is usually only big enough to admit a pin; a small artery and vein pass through it; the vein connects the veins of the scalp with the superior sagittal venous sinus which lies along the middle line on the inside of the skull-cap, and infection can travel along the vein from the scalp and so reach the sinus. The sagittal suture is less serrated between the two parietal foramina than it is elsewhere.

The *sagittal fontanelle* is an unossified space in the region of the parietal foramina; it is usually closed at birth. If it is not closed at birth, the parietal foramen in the adult skull will probably be large enough to admit a match. The point on the sagittal suture between the two parietal foramina is called the **obelion** [ὀβελός (obelos) = ÷ (a mark used by literary commentators)].

The **parietal eminence** is the most convex part of the parietal bone, and is the region where the top of the skull and the side and the back merge into one another. Its position varies with the shape of the skull, but none the less it is used as a landmark, for it is fairly easily identified in the living head. It is best felt with the palm of the hand and overlies the most convex part of the surface of the brain.

The frontal eminences anteriorly and the temporal lines at the sides are visible, but will be dealt with later. In some specimens the zygomatic arches can be seen when the skull is looked at from above.

Norma Frontalis

The **front of the skull** (Fig. 154) is uneven in contour and outline. Almost more than any other aspect of the skull it varies with age, race, and sex, besides displaying individual variations in the details of its configuration.

The front of the skull is made up of: (1) the frontal region or forehead; (2) the two orbits; (3) the bony external nose, between and in front of the orbits; (4) the anterior bony aperture of the nose; (5) the two maxillæ, forming the upper jaw; (6) the zygomatic bone or cheek-bone, below the lateral part of the orbit; and (7) the mandible, when it is in place.

Frontal Region.—The forehead is formed by the frontal bone and is convex. Superiorly it merges into the top of the skull; inferiorly it is limited by the orbits, where wide thin shelves of bone project backwards to form most of the roofs of the two orbits, and by the root of the nose. The **nasion** is the point in the median plane at the root of the nose where the two nasal bones articulate with the frontal bone: it is opposite the anterior extremity of the brain. The **glabella** is the small region immediately above the nasion, between the two eyebrows [*glabellus* = without hair]. The **superciliary arch** is the smooth elevation that arches upwards and in a lateral direction from the glabella a little above the margin of the orbit. Behind it, in the interior of the frontal bone, there is usually a large air-space, called the **frontal sinus** (Figs. 163, 166), from which a short channel leads down into the cavity of the nose. The **frontal eminence** is the most convex part of

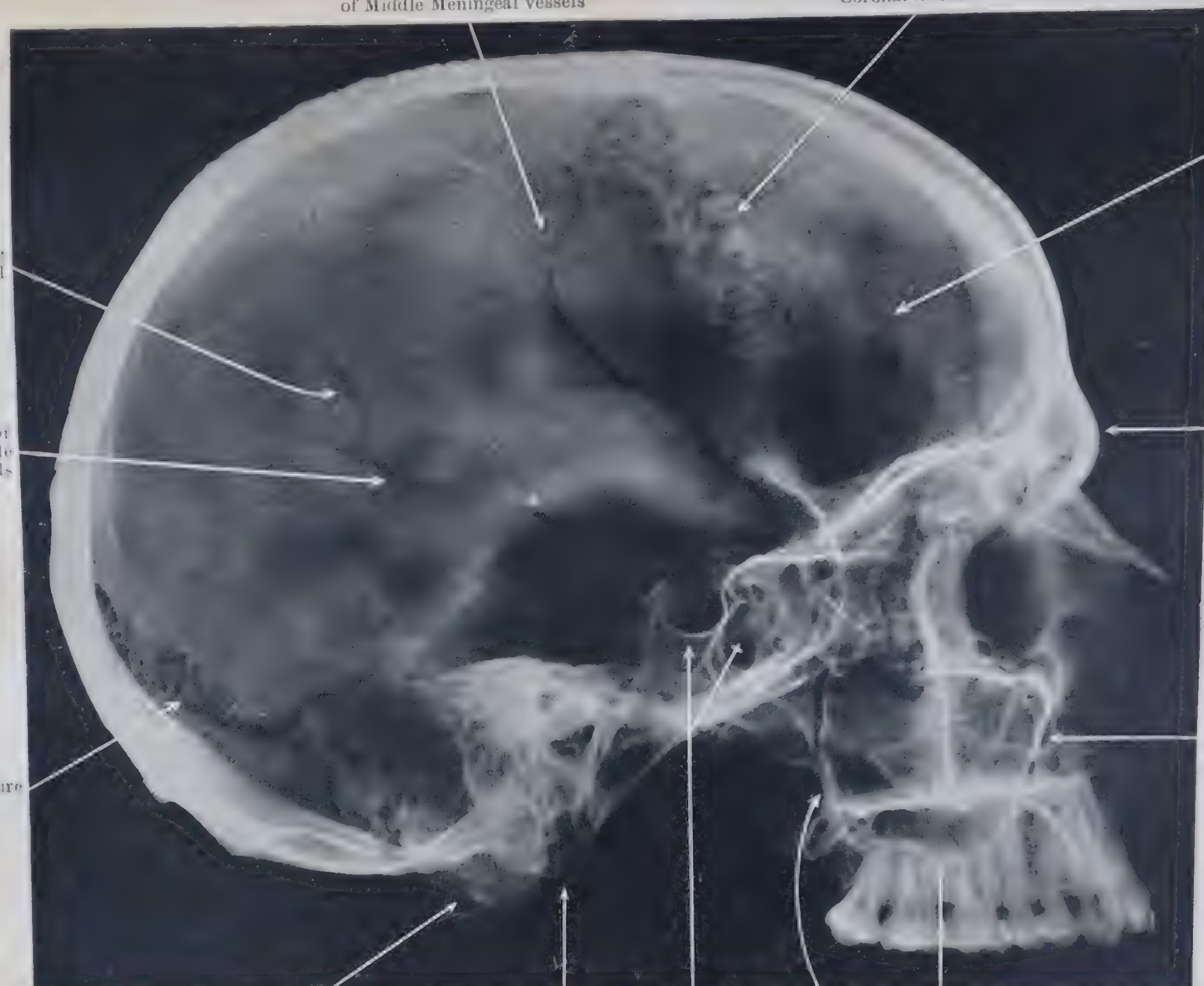


PLATE VII.—LATERAL RADIOGRAPH OF RIGHT HALF OF MALE SKULL.

Compare with Fig. 155, p. 162; Fig. 164, p. 193; with Plate VI. p. 151 (radiograph of the same skull complete), and with radiographs of the living head (Plates LXXIV, p. 945, LXXV, p. 960, and LXXX, p. 1217).

[Facing p. 154

PLATE VIII

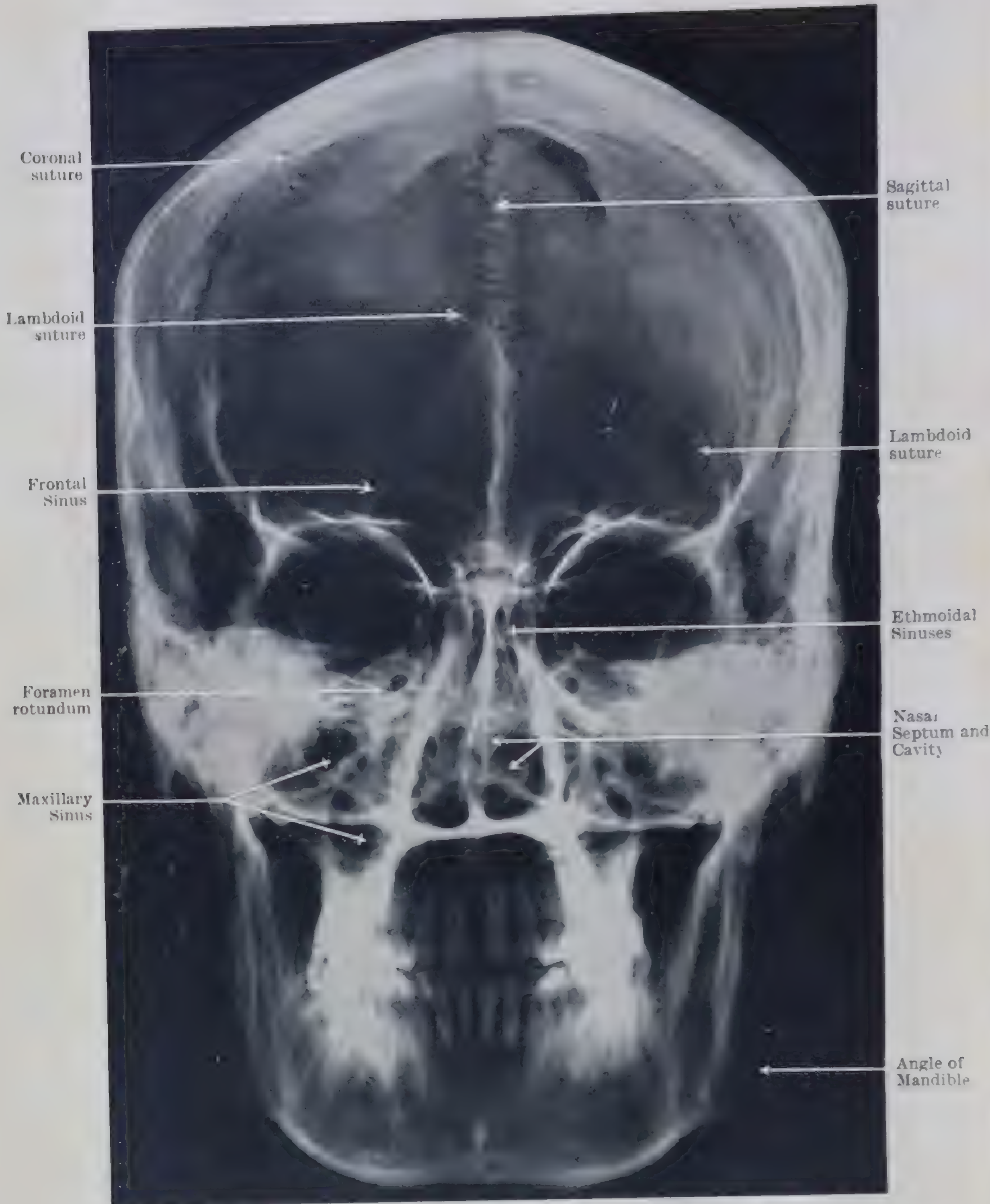


PLATE VIII.—ANTERIOR RADIOGRAPH OF THE SAME MALE SKULL AS IN PLATE VI, p. 151.

Compare with Fig. 154, Fig. 165, p. 195; and, for variations in the extent of the frontal sinuses, with Plate LXXVII, p. 1200. Note that in this skull the septum between the two frontal sinuses is broad, which accounts for the fact that their cavities are not well seen in Plate VI.

each half of the frontal bone; it is situated about two finger-breadths above the lateral end of the superciliary arch.

The **supra-orbital margin** or upper margin of the orbital opening is a curved

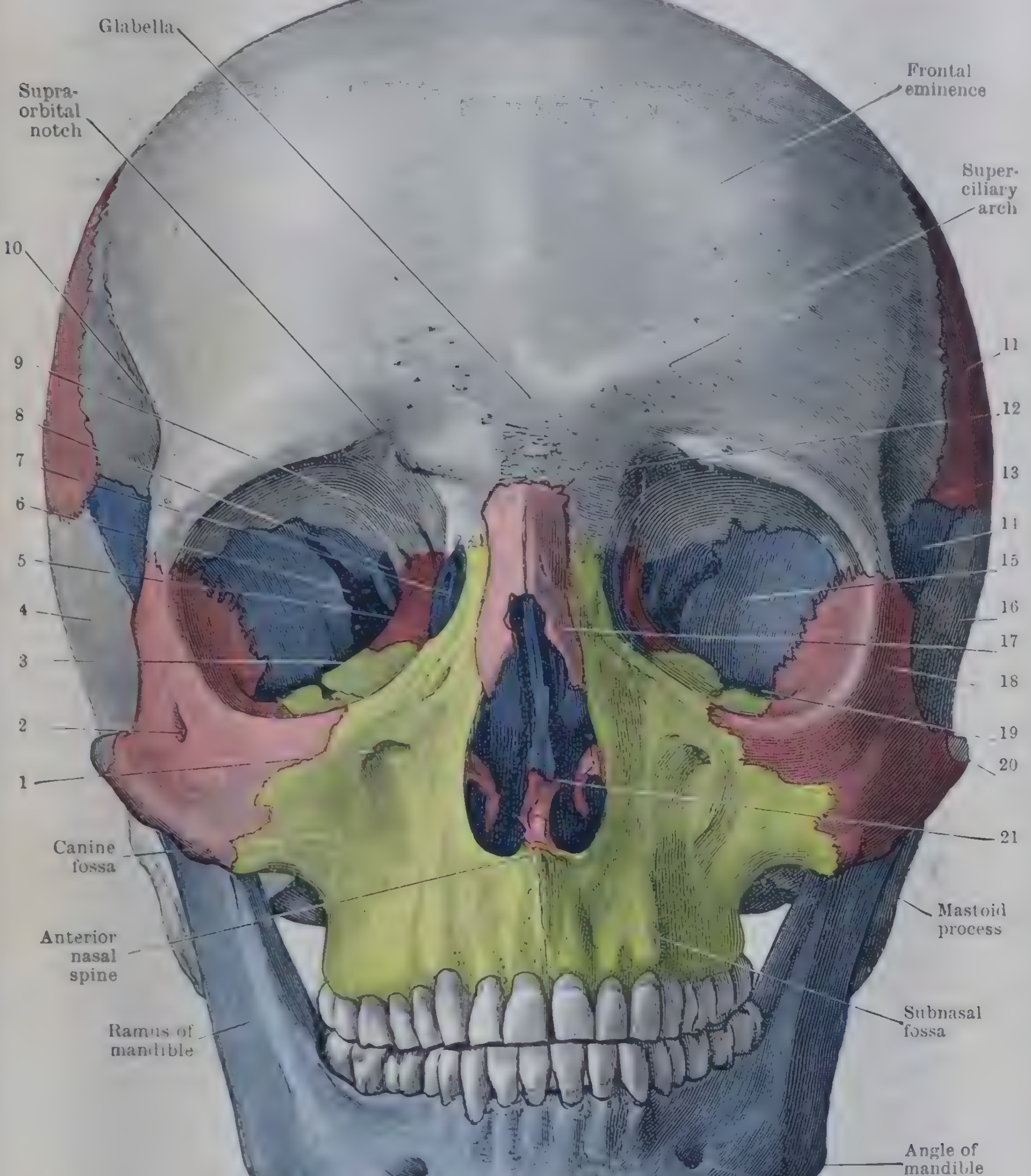


FIG. 154.—FRONT OF THE SKULL (Norma Frontalis).

Red: parietal; zygomatic; orbital plate of ethmoid; nasal; vomer; inferior concha.
Blue: sphenoid; lacrimal; perpendicular plate of the ethmoid and middle concha; mandible.
Yellow: maxilla. **Uncoloured**: frontal; temporal.

1. Infra-orbital foramen.
2. Zygomatico-facial foramen.
3. Orbital surface of maxilla.
4. Squamous temporal.
5. Orbital plate of ethmoid.
6. Superior orbital fissure.
7. Lacrimal bone and groove.
8. Optic foramen.
9. Ethmoidal foramina.
10. Temporal line.
11. Parietal bone.
12. Naso-frontal suture.
13. Pterion.
14. Greater wing of sphenoid.
15. Orbital surface of greater wing.
16. Squamous part of temporal.
17. Left nasal bone.
18. Zygomatic bone.
19. Inferior orbital fissure.
20. Zygomatic arch.
21. Anterior aperture of nose.

border. At the highest point of the curve, about two finger-breadths from the median plane, there is usually a small **supra-orbital notch**; the notch can be felt in the living head by the thumb-nail pressed on the margin *from below*. Laterally, the

supra-orbital margin ends in a prominent projection which is named the **zygomatic process** of the frontal bone because it curves downwards and articulates with the frontal process of the zygomatic bone. The zygomatic process is easily felt at the lateral end of the eyebrow hairs and is one of the most serviceable landmarks in the head. The ridge that curves upwards and backwards from it is the anterior part of the **temporal line**, and can be both felt and seen in thin people between the brow and the temple.

The two halves of the **frontal bone** are separable at birth and are not fused together completely till some period between the sixth and the tenth year. The suture between the halves is called the *frontal suture.* Remains of the suture can often be seen in the adult skull at and above the glabella, and in some skulls, especially in the more civilized races, the whole suture persists till late in life (p. 215); it is sometimes called the *metopic suture* [μετόπη (metopē) = the interstice between two beam ends (in Doric architecture)]. The point in the middle of the forehead, on the shortest diameter between the two temporal lines, is usually a little above the glabella and is called the **ophryon** [ὀφρύς (ophrys) = the brow].

The **superciliary arch** is more prominent in men than in boys and women; the lower part of the forehead therefore protrudes more in a man, and the forehead is less vertical. Though the arch overlies the frontal sinus it is not produced by the sinus, for in a skull in which the sinus is small or absent the arch may be prominent. The upper part (corrugator supercilii) of the orbicularis oculi arises from the medial end of the arch. The **frontal eminence** is the region where the views of the skull from the front, from above, and from the side overlap; it is more conspicuous in boys and women than in men, as their foreheads are more vertical; it overlies the part of the brain called the middle frontal gyrus. Like the parietal eminence it is best felt with the palm of the hand.

The **supra-orbital margin** is the lower limit of the forehead. Its lateral two-thirds is thin and sharp and bends down to the zygomatic process. The medial third is rounded; it bends down into the medial margin of the orbit to articulate with the frontal process of the maxilla, and its end is sometimes called the *maxillary process.* The **supra-orbital notch** is situated at the junction of the medial third and lateral two-thirds of the margin; the supra-orbital vessels and nerves lie in it as they pass out of the orbit and turn upwards into the scalp. In the bottom of the notch there is a minute foramen through which the frontal diploic vein passes to join the supra-orbital vein. In some skulls there are two shallow notches instead of one; in others the notch is converted into a **supra-orbital foramen** by a bridge of bone.

External Nose.—The bony part of the external nose is formed by the two *nasal bones* lying side by side in the bridge of the nose, and, on each side of these, by the *frontal process of the maxilla*, which lies behind the nasal bone in the side of the nose, extends up to reach the frontal bone, and forms also the medial margin of the orbital opening.

Anterior Bony Aperture of Nose.—This opening is bounded above by the lower margins of the two nasal bones, and at the sides and below by the sharp, anterior margins of the frontal processes and bodies of the two maxillæ. It is the anterior opening into the **cavity of the nose**, and one can look through it into the cavity and out through the posterior apertures. The cavity is divided by a thin, median partition or **septum** into a right and a left half. Each half is called a cavity of the nose or nasal cavity, and the term may mean, according to the context, either the whole cavity or one of the halves. Most of the anterior part of the septum is a plate of cartilage; the septum is therefore always incomplete in a macerated and dried skull, and considerable parts of the bony septum may have been broken away. If the bony septum has not been broken the principal part seen through the anterior aperture is the *perpendicular plate of the ethmoid* bone, which forms the upper part of the septum; it is usually slightly bent to one or other side.

The side-wall of the nasal cavity is very uneven, because the three rough curled plates of bone called the *conchæ* project from the side-wall and hang down into the cavity like curtains. The portions of the cavity which lie below the conchæ and lateral to them are called the *meatuses* of the nose—superior, middle, and inferior. The superior concha is too far back to be seen through the anterior aperture, but the inferior and middle conchæ and meatuses can be seen if the conchæ have not been broken away. The middle concha is on a level with the medial wall of the orbit, and is rather less liable to be broken off. The inferior concha is situated about half an inch above the floor of the nose, and even should it have been broken away the ridge on the side-wall of the cavity to which it was attached can be seen.

Maxillary Region.—The lower parts of the two maxillæ meet in the mid-line and a sharp, median spur of bone, called the **anterior nasal spine**, projects forwards from them at the lower margin of the anterior aperture of the nose; it is embedded in the lower, mobile part of the septum of the nose immediately above the upper lip. In a much-handled skull it is usually broken off.

A thick curved ridge projects downwards on each side to form, with its neighbour, the horseshoe-shaped **alveolar process** which carries the upper teeth. These are embedded in a row of sockets on the inferior surface [*alveolus* = a small cavity]. If the walls of the sockets for the teeth have not been absorbed, smooth vertical ridges, produced by the roots or fangs of the teeth, are seen above the alveolar margin. The largest of those ridges corresponds to the root of the canine tooth and is called the **canine eminence**. (The *canine* tooth is the third tooth, counting from the middle in front; and the first two teeth are *incisors*.) The **canine fossa** is the wide, shallow depression above and lateral to the canine eminence, reaching up almost to the lower margin of the orbit. The *infra-orbital foramen* is the opening immediately above the canine fossa, about 5 mm. below the lower margin of the orbit; in the living person it is about a finger's-breadth lateral to the side of the nose, and it may be felt indistinctly if pressure is made there with the finger-tip. It transmits the infra-orbital vessels and nerve.

Between the medial ends of the two supra-orbital margins there is a horseshoe-shaped suture which unites the frontal bone to the upper ends of the two nasal bones and frontal processes of the maxillæ. The middle of the suture is the **nasion**, from which a suture runs down the middle of the bridge of the nose between the two nasal bones; the lower end of the suture is called the **rhinion** [ῥίς (rhis) = the nose]. On each side of the bony external nose there is a linear suture between the nasal bone and the frontal process of the maxilla. On the nasal bone, at a varying point, there is often a minute foramen through which a vein passes from the skin to the interior of the nose. Occasionally that vein continues upwards to join the commencement of the superior sagittal sinus in the cranial cavity, and then infection can pass along the vein to the sinus. At the lower end of the nasal bone there is very often a narrow notch that marks the point where the external nasal nerve escapes from the interior of the nose. Some fibres of the procerus muscle are attached to the nasal bone. The levator labii superioris alæque nasi arises from the upper part of the frontal process of the maxilla; the compressor naris arises from the bone near the lower boundary of the anterior aperture of the nose.

The pliable, lower part of the external nose has a framework of cartilage united to the sharp margins of the anterior bony aperture by fibrous tissue. The **anterior bony aperture** is oblique, and is ovoid in outline with the narrow end above and in front. It measures about 30-35 mm. in height, and about 25 mm. across its widest part; it is shorter, wider, and more vertical in flat-nosed races. Parts of the septum and side-walls of the **nasal cavity** can be seen through it, and also the floor and part of the roof when the skull is tilted.

If the bony **septum** is complete, its anterior edge forms an angle into which the septal cartilage fits (Fig. 163). The upper limb of the angle is the perpendicular plate of the ethmoid. The lower limb is formed *posteriorly* by the lower and anterior part of the vomer and *anteriorly* by the prominent, anterior part of the *nasal crest* of the maxillæ (*i.e.*, a rough ridge that stands up from the junction of the palatine processes of the two maxillæ and is continuous with the anterior nasal spine). On the **side-wall** note again the inferior and middle conchæ. The inferior concha reaches the anterior aperture. The middle concha is shorter than the inferior and does not reach so far forwards; the interval between it and the septum is very narrow, and also the part of the middle meatus that lies lateral to it is very narrow, because a part of the labyrinth of the ethmoid, called the *bulla ethmoidalis*, bulges into the meatus; the lower part of the middle meatus is roomier, and in its side-wall the opening of the maxillary sinus can be found. Identify the floor of the fossa for the lacrimal sac in the orbit and then in the side-wall of the nasal cavity immediately in front of the middle meatus. The part of the **roof** visible is the anterior sloping part, formed by the nasal bone and the nasal part of the frontal bone and its nasal spine —a projection which is hidden from the exterior by the nasal bone. The whole **floor** can be seen. Though the upper part of the nasal cavity is very narrow, the floor is half an inch in width; it is made of the palatine process of the maxilla and the horizontal part of the palatine bone, which, at the same time, constitute the bony palate and are seen better on the lower surface of the skull.

The **anterior nasal spine** consists of a spicule from each maxilla; its apex is called the **akanthion** [ἄκανθα (akantha) = a thorn]. Running downwards from it there is the *intermaxillary suture*, the lower end of which, in the front of the alveolar margin, is called the **prosthion** [πρόσθιος = foremost]. On each side of the suture, immediately below the anterior aperture of the nose there is a shallow **subnasal fossa**. The **canine fossa** is below the infra-orbital foramen on the anterior wall of the maxillary sinus; the levator anguli oris arises from its floor. The levator labii superioris arises from the infra-orbital margin above the infra-orbital foramen; the incisive slips of the orbicularis oris arise from the floor of the subnasal fossa and the canine eminence.

Lateral to the canine fossa, the suture between the maxilla and the zygomatic bone can be seen. It begins at the middle of the lower margin of the orbit and ends at the lower border of

the zygomatic arch in line with the lateral margin of the orbit. The **zygomatico-facial foramen** is a small hole on the zygomatic bone about 5 mm. below the lateral part of the lower margin of the orbit; it is only big enough to admit a pin; it transmits the zygomatico-facial branch of the zygomatic nerve and a small branch of the lacrimal artery; sometimes it is represented by two openings instead of one. Below the foramen, a smooth low eminence gives origin to the zygomaticus major; the eminence is conspicuous in some thin people.

The **zygomatic bone** (Figs. 154, 155, 206) makes the hard, prominent part of the cheek; it forms the anterior part of the zygomatic arch and has a considerable share in forming the lower and lateral parts of the rim of the orbit. The part of the zygomatic bone that projects backwards to articulate with the zygoma of the temporal bone is called its **temporal process.** The part that projects upwards along the side of the orbit to articulate with the frontal bone is called its **frontal process**; posteriorly, it articulates with the greater wing of the sphenoid.

Orbit (Figs. 154, 165).—The orbit is a cavity of a shape not unlike a four-sided pyramid laid on one side. The sides are called the *roof*, the *floor*, the *medial wall* and the *lateral wall*. The *base* of the pyramid is the opening on to the face, and the boundaries of the base are the **margins of the orbit.** At the *apex* there is a large aperture; it is the medial and lower part of a cleft called the **superior orbital fissure** (Fig. 154); the rest of the fissure extends forwards, upwards, and in a lateral direction *between the roof and the lateral wall* of the orbit, becoming narrower as it does so. The fissure leads back into the middle cranial fossa, and its size varies in different skulls.

Between the roof and the medial wall there are three foramina—the optic and two ethmoidal. The **optic foramen** is the round aperture immediately above and medial to the apex of the orbit; it leads back into the middle cranial fossa. The **anterior** and **posterior ethmoidal foramina** are farther forward; they are about half an inch apart and the anterior is the larger. They lead into canals that open into the median part of the anterior cranial fossa, but their openings there are rather hidden under lips of bone.

The **fossa for the lacrimal gland** [*lacrima* = a tear] is a broad, smooth depression, of varying depth, in the anterior and lateral part of the roof of the orbit, under shelter of the zygomatic process of the frontal bone. The **fossa for the lacrimal sac** (Fig. 155) is on the medial wall close to the orbital margin. If the lacrimal bone is broken away, only part of the fossa will be seen, for it is a fairly broad, vertical groove, partly on the anterior part of the lacrimal bone and partly on the frontal process of the maxilla. The **lacrimal bone** is the thin, uneven scale of bone, about the size of a finger nail, placed behind the frontal process of the maxilla and in front of the orbital plate of the ethmoid. The fossa becomes continuous with the **naso-lacrimal canal**, the upper opening of which is seen at the *junction of the medial wall and floor* of the orbit; the canal is a short tunnel that leads down into the inferior meatus of the nose under cover of the anterior part of the inferior concha—a fact which one can demonstrate by pushing a match down through the canal from the orbit (Fig. 166). The lacrimal sac is a wide tube, blind at its upper end, and its lower end is continuous with the naso-lacrimal duct, which goes down through the canal into the nose. The lacrimal gland produces the lacrimal fluid; most of the fluid evaporates, and the remainder passes into the sac and thence into the nose—any excess of fluid overflowing the eyelids as tears. The gland is at the upper, lateral part of the orbit, and the sac is at the lower, medial part; that arrangement ensures that the front of the eye shall be well washed.

Between the floor and the lateral wall of the orbit there is a long cleft, called the **inferior orbital fissure,** which opens into a space behind the maxilla called the infratemporal fossa. The **infra-orbital groove** is in the floor of the orbit. It begins about the middle of the inferior orbital fissure and runs nearly straight forwards in the roof of the maxillary sinus which occupies the interior of the maxilla. The anterior part of it has a thin roof of bone and is called the **infra-orbital canal**; and the canal opens on the face as the infra-orbital foramen. In one or both orbits the groove may be roofed over in all its length; one can then find it by passing a pointer back through the infra-orbital foramen.

The chief **relations** of the orbit are :—*Superiorly*—The frontal sinus to a varying extent ; the anteror cranial fossa, containing the frontal lobe of the brain. *Inferiorly*—The maxillary sinus in the body of the maxilla (Fig. 165). *Medially*—Near the apex, the sphenoidal sinus in the body of the sphenoid (Fig. 164) ; farther forward, the ethmoidal sinuses, which separate the orbit from the cavity of the nose (Fig. 166) ; within the orbital margin, the floor of the fossa for the lacrimal sac intervenes between the orbit and the nasal cavity, and is so thin that an operator can reach the lacrimal sac by passing from the nose through the floor of the fossa, if he wants to avoid a scar at the medial corner of the eye. *Laterally*—The posterior part of the orbit is related to the middle cranial fossa, which lodges the temporal lobe of the brain ; the anterior part is related to the anterior part of the temporal fossa (p. 161).

The two **orbits** are placed so that their medial walls are almost parallel, while their lateral walls are nearly at right angles to each other ; the axis of each orbit is directed therefore in a forward and lateral direction ; none the less, the axes of the two eyeballs are antero-posterior and parallel. Each orbit is about 50 mm. long.

The **orbital opening** or base of the orbit is more or less four-square, measuring about 40 mm. each way ; it is directed forwards and slightly in a lateral direction, and it is tilted so that the upper and lower margins slope slightly downwards from medial to lateral side. The *lower margin* of the opening is formed by the maxilla and the zygomatic bone. *The lateral margin* is formed by the frontal process of the zygomatic bone and the zygomatic process of the frontal bone ; the suture between the processes, near the upper angle of the opening, can usually be felt in the living person ; within the middle of the margin, about 10 mm. below the suture, there is a slight eminence (felt by the finger-tip rather than seen) for the attachment of the lateral palpebral ligament and the check and suspensory ligaments of the eye. The *upper margin* is the supra-orbital margin of the frontal bone ; its lateral two-thirds is sharp, and the medial third is smooth and rounded ; the supra-orbital notch or foramen is at their junction ; the supratrochlear nerve and vessels, passing out of the orbit on to the forehead, cross the margin about 5 mm. medial to the supra-orbital notch and may produce a shallow groove. The *medial* margin is formed by the maxillary process of the frontal bone and the frontal process of the maxilla ; the medial palpebral ligament and the orbicularis oculi are attached to the margin immediately in front of the groove for the lacrimal sac.

The orbit being pyramidal, its walls are more or less triangular in outline. The lateral wall is strong and fairly thick. The other walls are made of thin bone—especially the medial wall, where the bone is almost like paper.

The *roof* is concave ; it is formed by the orbital plate of the frontal bone, supplemented posteriorly by the lesser wing of the sphenoid. The frontal sinus extends for a variable distance backwards *in* the roof of the orbit between the two tables of the orbital plate. At the lateral angle of the roof there is the wide **fossa for the lacrimal gland** (*i.e.*, the greater part of the gland ; the smaller part protrudes beyond the fossa into the upper eyelid). At the medial angle the trochlea is attached ; the attachment may be marked by a very small pit or by a spicule of bone, or by both (the **trochlear fossa** and **spine**) ; the trochlea is a small fibro-cartilaginous ring through which the tendon of the superior oblique muscle of the eyeball passes.

The greater part of the *lateral wall* is formed by the greater wing of the sphenoid, but the anterior part is formed by the frontal process of the zygomatic bone. On the anterior part there is a small aperture, called the **zygomatic foramen**, through which the zygomatic nerve leaves the orbit, accompanied by a small branch of the lacrimal artery ; sometimes there are two apertures instead of one. A great part of the lateral wall is separated posteriorly from the roof by the **superior orbital fissure**, which is bounded medially by the body of the sphenoid, above by the lesser wing, below and laterally by the greater wing. The two heads of the lateral rectus muscle of the eyeball lie across the wide, lower and medial part of the fissure. Some of the structures transmitted by the fissure pass between the two heads ; the others pass above both heads. They are :—

(*a*) *Between the Heads.*—The ophthalmic vein or veins, passing backwards to join the cavernous sinus [ὀφθαλμός (ophthalmos) = *oculus* = the eye] ; the abducent nerve, the naso-ciliary nerve, and the two divisions of the oculomotor nerve—all passing forwards.

(*b*) *Above the Heads.*—The trochlear nerve, the frontal nerve, and the lacrimal nerve, all passing forwards, in that order from medial to lateral side ; a small branch of the lacrimal artery passing backwards to the dura mater ; occasionally a small branch of the middle meningeal artery passing into the orbit ; and sympathetic twigs from the carotid plexus. [Μῆνιγξ (mēninx) = any membrane, but especially a membrane around the brain.]

The *floor* is formed chiefly by the orbital surface of the body of the maxilla, which is, at the same time, the roof of the maxillary sinus. But the antero-lateral corner of the floor is formed by the zygomatic bone ; and the posterior corner is formed by the orbital process of the palatine bone—that is, the anterior of the two projections on the upper end of its perpendicular plate.

A great part of the floor is separated from the lateral wall posteriorly by the **inferior orbital fissure.** The fissure is bounded *above* by the greater wing of the sphenoid, *below* by the orbital surface of the maxilla and the orbital process of the palatine bone ; its *anterior* end is closed either by

the zygomatic bone or by an articulation between the greater wing and the maxilla. The posterior end of the inferior orbital fissure meets the medial end of the superior orbital fissure at the apex of the orbit. The greater part of the inferior fissure leads into the infratemporal fossa behind the maxilla; but its posterior part leads down into the pterygo-palatine fossa, which also is behind the maxilla and is below the most posterior part of the orbit. The inferior orbital fissure *transmits*: the maxillary nerve, as it changes its name to infra-orbital nerve; the infra-orbital vessels; the zygomatic nerve; small twigs from the spheno-palatine ganglion to the lacrimal gland and the periosteum of the orbit; a vein which connects the ophthalmic veins with the pterygoid venous plexus in the infratemporal fossa.

The **infra-orbital groove** and **canal** run forwards in the floor of the orbit and the roof of the maxillary sinus. The infra-orbital nerve, accompanied by the infra-orbital vessels, traverses the groove and canal, sends down branches through the facial wall of the sinus to the incisor and canine teeth, and enters the face through the infra-orbital foramen.

The upper end of the **naso-lacrimal canal** separates the anterior part of the floor from the medial wall; and at the medial corner of the floor, immediately lateral to the canal, there is a shallow depression for the origin of the inferior oblique muscle of the eyeball.

The *medial wall* of the orbit is formed, from behind forwards, by: the anterior part of the side of the body of the sphenoid; the orbital plate of the ethmoid; the lacrimal bone; and the posterior part of the frontal process of the maxilla. The optic foramen and the ethmoidal foramina lie between the medial wall and the roof. The **optic foramen** is bounded by the body of the sphenoid and the roots of the lesser wing; it transmits the optic nerve and the ophthalmic artery; note that the ophthalmic vein and artery pass through different apertures. The **anterior** and **posterior ethmoidal foramina** are the orbital ends of the anterior and posterior ethmoidal canals, which transmit vessels and nerves of the same name.

The **fossa for the lacrimal sac** grooves the anterior part of the lacrimal bone and the posterior part of the frontal process of the maxilla; its margins are called the **lacrimal crests**; the anterior crest is part of the medial margin of the orbit; the posterior crest gives attachment to the pars lacrimalis of the orbicularis oculi muscle. The upper end of the suture between the two bones is called the **dacryon** [*δάκρυον* (dakryon) = *lacrima* = a tear].

Norma Occipitalis

The **back of the skull** is markedly convex and has the outline of a wide arch; the arch is widest usually at the level of the parietal eminences. The bones seen are portions of the two parietal bones, a portion of the occipital, which lies between the two parietal bones and is continued into the base of the skull below (Fig. 155), and the mastoid portion of the temporal bone and its mastoid process, which are visible at the lower corner on each side. The parts already seen on the top of the skull but seen again in the back are the parietal eminences, the posterior part of the sagittal suture, the parietal foramina, the lambda, and the lambdoid suture, which is now seen in the whole of its extent.

From the lower end of the lambdoid suture, on each side, the *occipito-mastoid suture* descends between the occipital bone and the mastoid temporal. The **mastoid foramen** is the aperture seen in the suture or on the mastoid temporal near the suture, and it varies in size from a pin-point to a match; it passes through the skull-wall and opens internally in the posterior cranial fossa into the groove for the sigmoid venous sinus; it transmits a small branch of the occipital artery and an emissary vein that connects the sinus with the veins on the outside of the head; it is at the level of the external auditory meatus and about three finger-breadths behind it.

The **external occipital protuberance** is the projection—usually well marked—in the median plane, at the lower part of the back of the skull, about midway between the lambda and the foramen magnum. It is easily felt in the living person immediately above the nape of the neck, and it is a useful landmark. If two protuberances are felt there, one below the other, the lower one is the normal protuberance. The central point of the protuberance is called the **inion**. The **superior nuchal line** is the blunt, curved ridge that arches laterally from the protuberance. The protuberance and the right and left superior nuchal lines mark the boundary between the back of the head and the back of the neck [*ἰνίον* (inion) = back of head or nape of neck; *nucha* = nape of neck]. The part of the skull seen in perspective below the protuberance and the superior nuchal lines belongs to the lower surface of the skull.

In some skulls a curved ridge is seen immediately above the superior nuchal

line; it is called the *highest nuchal line*, and gives attachment to the epicranial aponeurosis, a tendinous sheet in the scalp.

In most skulls the most bulging part of the back of the head is not at the protuberance but is a little above it. The degree of bulging of the occipital bone above the nuchal lines varies with the size and shape of the occipital lobes of the brain, and is frequently unequal on the two sides.

The **lambda** is situated between two and three inches above the protuberance. In many heads it can be felt by the finger-tip as an apparent depression, owing to the prominence of the apical part of the occipital bone; it overlies the interval between the two halves of the brain a little behind the parieto-occipital sulcus in the brain.

Norma Lateralis

The **side of the skull** is divisible into two parts: a smaller part below and in front belongs to the face and is very uneven; a larger ovoid part above and behind belongs to the brain-case. Each **parietal bone** occupies a wide area between the frontal and occipital bones; below it and extending into the base of the skull is the **temporal bone.** The part, shaped like a large scale, which lies below the parietal bone is the *squama* or **squamous temporal** (*squama* = a scale); the prominent, narrow process which arches forward from it is the zygomatic process or **zygoma** which reaches the zygomatic bone to form the zygomatic arch. The **mastoid temporal** lies behind and is so named because of the rounded **mastoid process** which projects down from it [μαστός (mastos) = the breast]. In front of the mastoid process lies the round or oval opening of the bony external auditory meatus, the tunnel leading into the middle ear in a dried skull. Most of the **sphenoid bone** lies in the base of the skull but a portion of its greater wing can be seen wedged between the frontal bone and the squamous temporal and reaching a corner of the parietal bone.

Many of the parts seen already when the posterior and the upper and the anterior aspects of the skull were examined, are seen again in the lateral aspect. Identify again the superior nuchal line, the lambdoid suture, the occipito-mastoid suture, the mastoid foramen, the parietal eminence, the coronal suture, the frontal eminence, the superciliary arch, the bony external nose, the maxilla, the zygomatic bone, the margins of the orbit, and the zygomatic process of the frontal bone. The following parts are now to be looked for.

The **temporal line** is a long, curved ridge that begins at the zygomatic process of the frontal bone. From there it curves upwards and slightly medially and then arches backwards across the frontal bone along the lateral margin of the forehead; then backwards over the parietal bone, passing through the parietal eminence or immediately below it; having passed the parietal eminence it bends downwards and slightly forwards, and it ends by joining a blunt, prominent ridge called the **supramastoid crest**; that crest is situated on the squamous temporal near its junction with the mastoid temporal. The anterior part of the temporal line is easily felt in the living head above the zygomatic process of the frontal bone between the forehead and the temple. Its middle part is usually represented by two lines—an upper and a lower—about half an inch apart; the bone between those lines is often more polished than that above and below, and if the lines are indistinct they can often be identified as the margins of a smooth strip along the upper part of the side of the skull. The posterior part of the line is frequently very indistinct. [*Tempora* = the temples, from *tempus* = time: grey hairs appear first in the temples.]

The **temporal fossa** is the wide space outlined by the temporal line and the zygomatic arch. Parts of four bones are seen in the **floor** of the fossa: (1) the lower part of the *parietal* bone; (2) the *squamous* part of the *temporal* bone below the parietal bone and united to it by a curved suture called the *squamous suture*; (3) a small part of the *frontal* bone in the upper and anterior part of the fossa; (4) a part of the *greater wing of the sphenoid* below the frontal and in front of the squamous temporal. In the anterior part of the fossa the

four bones are so close together that a small circle, the size of a sixpence or a shilling, would include portions of them all; the region enclosed by such a circle is called the **pterion**, because one of the pairs of Hermes' wings was attached to the corresponding part of his head-piece. [πτέρυξ (pteryx) = a wing].

In a man's skull, the centre of the pterion is 3 cm. behind the lower end of the zygomatic process of the frontal bone and about 1 cm. higher *i.e.*, about 4 cm. above the zygomatic arch. It is a region made much use of as a guiding point when the

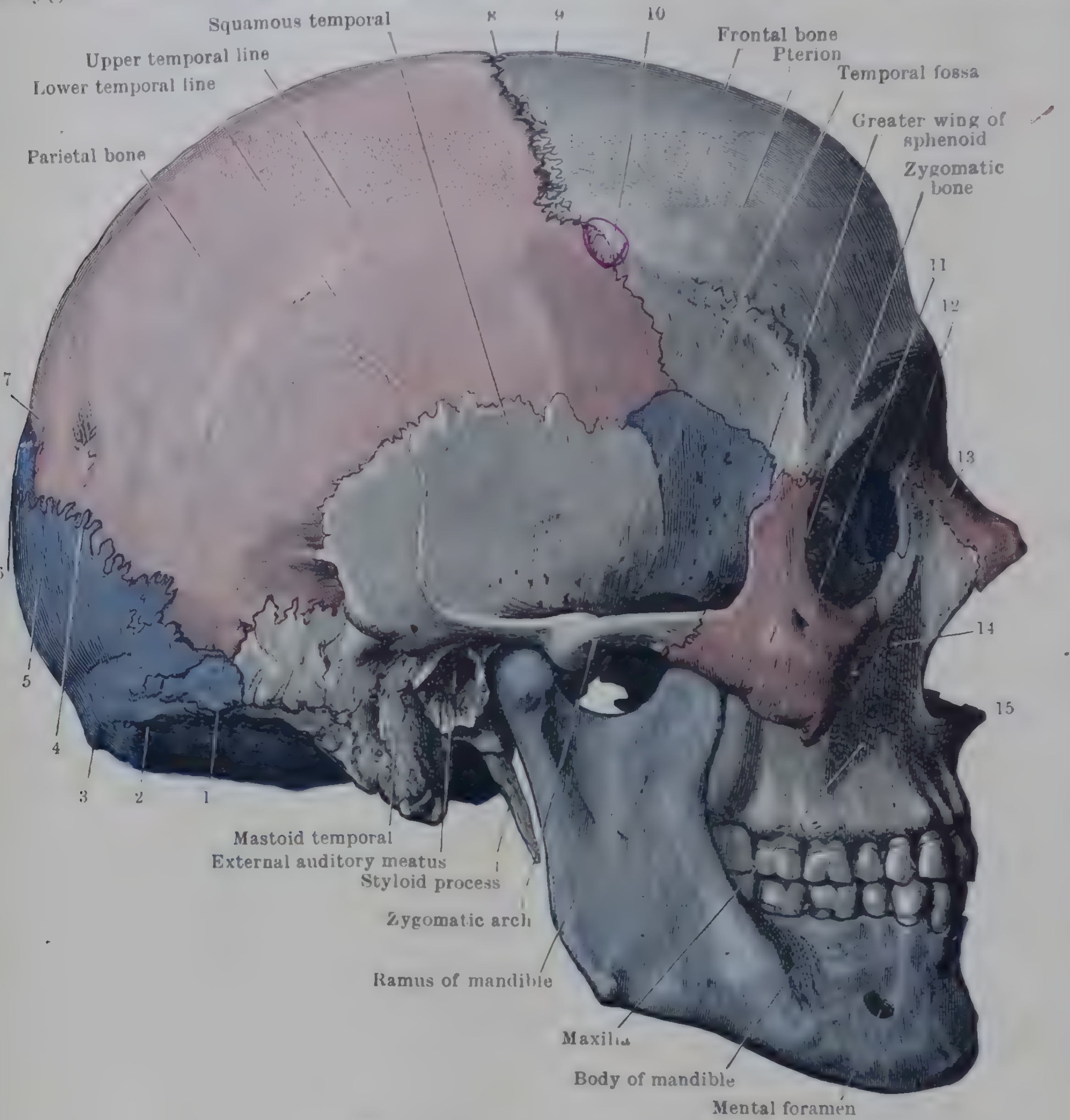


FIG. 155.—SIDE OF THE SKULL.

Red : parietal ; zygomatic ; nasal. **Blue** : occipital ; sphenoid ; lacrimal ; mandible. **Uncoloured** : temporal ; frontal ; ethmoid ; maxilla.

1. Asterion.
2. Superior nuchal line.
3. External occipital protuberance.
4. Lambdoid suture.
5. Occipital bone.
6. Lambda.
7. United sutural bone.
8. Bregma.
9. Coronal suture.
10. Stephanion.
11. Zygomatico-facial foramen.
12. Fossa for lacrimal sac.
13. Nasal bone.
14. Infra-orbital foramen.
15. Anterior nasal spine.

position of deeper structures and their relations to the surface of the head are being explained. In many skulls sutural bones are present in the region of the pterion.

The part of the greater wing of the sphenoid which is seen in the temporal fossa is its *temporal surface*. The surface is limited below by a horizontal, antero-posterior ridge called the **infratemporal crest**. The crest may be smooth and blunt or rough and prominent; it separates the temporal surface of the greater wing from the infratemporal surface, which is seen on the lower surface of the skull.

The **zygomatic arch** is formed by the zygomatic bone and its temporal process and the zygoma of the temporal bone; it can be felt from end to end, and

in thin people it stands out prominently between the temple and the side of the face. About an inch in front of the auditory meatus the arch divides into two parts, the **anterior** and **posterior roots** of the zygoma, which diverge from each other. The posterior root extends backwards, the anterior root turns medially towards the side of the skull.

The **anterior root** is easily found if one traces the lower border of the arch backwards; it is broad and its two surfaces look upwards and downwards; its lower surface is convex and is continuous, at the side of the skull, with a smooth, convex elevation, called the **articular eminence**, which is seen on the lower surface of the skull in the front of a smooth concavity called the **articular fossa** (Fig. 156). The lateral end of the lower surface of the root is called the **tubercle of the root of the zygoma** and is made use of as a landmark; it is felt immediately in front of the head of the mandible when the mouth is shut, immediately above it when the mouth is opened.

The **posterior root** is continuous with the upper border of the zygomatic arch. It joins the side of the skull and is continued backwards as a ridge immediately above the external auditory meatus, where it can be felt through the skin of the ear; it ends by joining the supramastoid crest immediately behind the level of the meatus. The posterior root and the upper border of the arch are opposite the lower border of the brain.

From the lower surface of the posterior root a smooth triangular prominence, called the **post-glenoid tubercle**, juts downwards immediately in front of the auditory meatus and extends medially for some distance, forming the posterior boundary of the lateral part of the articular fossa.

The **temporal line** gives attachment to the epicranial aponeurosis, to the temporal fascia, and to the uppermost fibres of the temporalis muscle; where the line is divided, the fascia is attached to the upper line and to the space between the lines, but the muscle fibres reach only the lower line. The point where the lower temporal line crosses the coronal suture is called the **stephanion** [*στέφανος* (stephanos) = a circle or crown].

The **temporal fossa** contains the temporalis muscle, the middle and deep temporal vessels, the deep temporal nerves, the zygomatico-temporal branch of the zygomatic nerve, and a quantity of fat—all under cover of the temporal fascia; and the chief structures on the surface of the fascia are the superficial temporal vessels, the auriculo-temporal nerve, and the temporal branches of the facial nerve.

The depth and width of the fossa depend, in a measure, on the size of the temporal muscle, which is proportional to the size and weight of the mandible. The anterior and lower part of the fossa is much the deepest part and has an *anterior wall*, which separates it from the orbit; the anterior wall is formed by the zygomatic process of the frontal, the frontal process of the zygomatic, and sometimes by the greater wing of the sphenoid where it articulates with that process of the zygomatic bone. On the part of the wall formed by the zygomatic bone there is a small aperture, called the **zygomatico-temporal foramen**, which transmits the zygomatico-temporal nerve, accompanied by a small branch of the lacrimal artery. The posterior border of the frontal process of the zygomatic bone gives attachment to the temporal fascia, and it shows a slight fullness or tubercle called the *marginal tubercle*; the point where the posterior border of the frontal process joins the upper border of the zygomatic arch is the **jugal point**.

The *floor* of the fossa gives origin to the temporalis muscle. It is limited below by the infratemporal crest of the sphenoid, by the roots of the zygoma, and by a short, horizontal ridge on the squamous temporal between the anterior root and the infratemporal crest; that ridge separates the temporal surface of the squamous temporal from a small triangular area—its infratemporal surface—which forms part of the roof of the infratemporal fossa. The part of the floor formed by the greater wing sometimes shows grooves for the deep temporal arteries; and the part of the floor above the auditory meatus shows a long and narrow vertical groove for the middle temporal artery.

The **pterion** (p. 162) is opposite the point where the anterior branch of the middle meningeal artery is deeply embedded in a groove on the inner side of the skull-wall and is most liable to injury, and it is opposite the point on the brain where the stem of the lateral sulcus breaks up into its three rami.

The suture between the two constituent bones of the **zygomatic arch** runs obliquely from above downwards and backwards.

The *upper* border of the zygomatic arch—thin, sharp, and nearly horizontal—is formed chiefly by the zygoma, and gives attachment to the temporal fascia. The *lower* border, formed chiefly by the zygomatic bone, is thicker and rougher and extends much farther forwards, but not so far back; it slopes downwards as it is traced forwards, for the arch is much deeper in front than behind; the lower border gives origin to the masseter muscle, which arises also from the *deep* surface of the arch, while the *superficial* surface is subcutaneous. The **tubercle of the root of the zygoma** gives attachment to the temporo-mandibular ligament. The anterior root is not only

continuous with the articular eminence but also forms part of it. The **posterior root** and the **supramastoid crest** give attachment to the temporal fascia.

A small portion of the squamous temporal lies below and behind the supramastoid crest. The anterior part of that portion sends downwards a pointed extension, called the **post-auditory process** (Fig. 185), which forms the upper part of the posterior wall of the external auditory meatus.

The *post-glenoid tubercle* corresponds to a prominent process developed in some mammals to prevent backward displacement of the mandible.

The **suprameatal triangle** is a small (and often inconspicuous) depression below the posterior root of the zygoma, immediately behind the upper margin of the external auditory meatus. Although small, it is very important, for the tympanic antrum lies about half an inch directly medial to it. The tympanic antrum is a cavity in the temporal bone, and it often has to be opened into when diseased; the road to it is through the suprameatal triangle, the position of which, therefore, has to be accurately known. If the depression of the triangle is fairly well marked, one may be able to feel it in the living head by pulling the ear vigorously forwards and downwards, and pressing with the finger-tip immediately above and behind the meatus.

The entire **external auditory meatus**, leading from the exterior to the drum of the ear, is about 25 mm. long, but only the medial, bony part of it is left in a dried skull; the lateral part is made of cartilage and has been removed during maceration. The bony part is a tunnel about 15 mm. long. Its *inferior wall* and the greater part of the *anterior* and *posterior walls* are formed by the lateral half of the *tympanic plate*, a small plate of bone which is curled to form these boundaries (see p. 176). The *upper wall* and small adjoining parts of the anterior and posterior walls are formed by the squamous temporal. The *medial end* of the meatus is closed up during life with a tense, vibratile membrane, the **tympanic membrane**, which separates the meatus from the tympanic cavity or **middle ear** and forms the greater part of the lateral wall of the middle ear. The tympanic cavity or middle ear or drum of the ear [τύμπανον (tympanon) = a kettledrum] is a cavity in the temporal bone, and is narrow from side to side. The membrane is the drum-head, and it, along with the contents of the middle ear, has been removed during maceration, and therefore, when one looks into the meatus, the bony surface seen at the far end is the medial wall of the middle ear (Figs. 158, 160).

The **styloid process**—a slender process about an inch long—projects downwards, forwards, and slightly medially from behind the lower edge of the tympanic plate [στῦλος (stylos) = a pillar, a stake, a pen]. It is situated deeply in the interval between the mastoid process and the mandible. It is dealt with more fully when the lower surface of the skull is examined.

The **mastoid part** of the temporal bone lies behind the external meatus, wedged in between the parietal bone, the occipital bone, and the squamous temporal; it is united with the parietal and occipital by sutures, but is continuous with the squamous temporal; the line of fusion is a little below and behind the supramastoid crest (Fig. 185), but the crest approximately indicates the position of the junction of the two parts. The lower part of the mastoid temporal juts downwards as a thick, prominent process—the *mastoid process*, which is easily felt behind the ear in the living head.

There may be no triangular depression to mark the **suprameatal triangle** in the skull the student is using, and even a well-marked triangle measures only a few millimetres. The triangle is above and behind the opening of the meatus, close to the meatus, at the meeting of tangents drawn to the upper and posterior margins of the meatus. The *suprameatal spine*, described as a spicule of bone on the antero-inferior side of the triangle, is seldom present.

The **external auditory meatus** is barely wide enough to admit an ordinary pencil. It passes in a medial direction and slightly forwards; its opening into the middle ear is very oblique, so that the tympanic membrane, which closes the opening, looks downwards and forwards as well as in a lateral direction. The outer orifice also is oblique—the upper margin overhanging the lower—and it is at a slightly higher level than the outer orifice of the cartilaginous part. The parts of the outer orifice formed by the lateral margin of the tympanic plate are rough for the attachment of the cartilage of the auricle; the auricularis posterior muscle arises from the bone behind the meatus.

In the child the meatus is very short, for the tympanic plate, which forms so much of the meatus, is at birth not a curved *plate* but an incomplete, slender *ring*; in a child, therefore, the tympanic membrane is quite near the surface of the head. In an infant's skull there is a

foramen in the floor of the meatus; for, as the ring becomes a plate, ossification is incomplete in its lower part till the fifth year. Occasionally the foramen persists in the adult.

The meatus as a whole is described in the Section on the Sensory Organs; the student is liable to get misleading ideas about the meatus if he studies the osseous portion apart from the cartilaginous portion.

The **medial wall of the tympanic cavity**, seen when one looks into the meatus, is uneven, and has about its middle a white bulging called the **promontory**. If the meatus is fairly wide, and the skull is tilted this way and that, a little hole may be seen above the posterior part of the promontory; it is called the **fenestra vestibuli**, because it leads into the *vestibule* of the internal ear. During life the footpiece of the auditory ossicle called the *stapes* or stirrup fits into it. [*Fenestra* = a window.]

The **tympano-mastoid fissure**, which transmits the auricular branch of the vagus nerve, is a narrow slit between the posterior part of the lateral margin of the tympanic plate and the front of the mastoid temporal. In many skulls the tympanic plate is so closely applied to the mastoid that the fissure is represented by a minute foramen just large enough to emit the nerve.

The mastoid portion of the temporal bone or **mastoid temporal** is more or less triangular in outline, the apical part being the mastoid process. Anteriorly it fuses with the squamous temporal a little behind and below the *supramastoid crest*, and, below that, it is closely related to the tympanic plate. Posteriorly it articulates with the occipital bone. Its upper border or base articulates with the postero-inferior angle of the parietal bone. The point, at the lateral angle of the occipital bone, where the lambdoid, parieto-mastoid, and occipito-mastoid sutures meet together, is called the **asterion** [ἀστήρ (astēr) = a star]; the superior nuchal line of the occipital bone, when well marked, reaches the asterion. In skulls in which the supramastoid crest is not a mere curved ridge but is a broad, blunt, prominent elevation, there is a depression behind the crest in the angle between the squamous temporal and the base of the mastoid temporal. Note that, in the living head, the depression is immediately behind the top of the root of the auricle—a full inch away from the meatus—and is not to be mistaken for the suprameatal triangle; it is directly opposite the sigmoid venous sinus immediately below its commencement.

The **mastoid process** juts down from the mastoid temporal and is felt as a prominence behind the lower part of the auricle. It is opposite the foramen magnum, and a line drawn from one mastoid process to the other passes immediately below the foramen. It is absent at birth; it is small in a child, for it does not begin to appear till the second year and is not fully developed till after puberty; it is variable in size in the adult, and is usually larger in men than in women.

In the adult, the mastoid temporal (including the mastoid process) is permeated with small air-spaces called the **mastoid air-cells**. The cells are diverticula from the tympanic antrum that replace the marrow and diploë in the mastoid temporal, and they may extend into adjoining parts of the petrous and squamous. They begin to develop at or shortly before birth. They increase in number and size slowly, and do not extend into the mastoid process till shortly before puberty; but at puberty they begin to enlarge rapidly and reach their full size in a year or two. They remain in communication with the tympanic antrum, and, like it, they are lined with a thin muco-endosteum which is continuous with the mucous lining of the tympanum and is covered with simple, flat epithelium. Occasionally in the adult the cells are few in number or are absent, the bone being diploëtic or even quite dense; on the other hand, the cells may extend to the mastoid process during childhood.

The sterno-mastoid muscle is inserted into a strip that extends from the tip of the mastoid process to the asterion and then includes the lateral third of the superior nuchal line; the splenius capitis into a strip immediately below that for the sterno-mastoid; the longissimus capitis into the back of the root of the mastoid process; and the posterior belly of the digastric arises from the floor of the well-marked groove, called the **mastoid notch**, at the medial side of the root of the mastoid process.

The **infratemporal fossa** (Fig. 156) is the open space behind the maxilla; it communicates with the temporal fossa through a wide opening under cover of the zygomatic arch. Its *anterior wall*—full and rounded—is the posterior surface of the maxilla. The lowest part of that surface, behind the last molar tooth, is the **tuberosity of the maxilla**. (The *molar* teeth or grinders are the hindermost three teeth in a full set of eight a side.) Above the posterior surface of the maxilla, between it and the greater wing of the sphenoid, there is the horizontal cleft, called the **inferior orbital fissure**, by which the infratemporal fossa communicates with the orbit, where the fissure has been seen already (pp. 158 and 159).

The greater part of the *roof* of the fossa is a large, fairly flat surface of bone already pointed out as the *infratemporal surface* of the greater wing of the sphenoid; the lateral margin of the surface is the **infratemporal crest**, which also has been referred to already (p. 162).

The *medial wall* of the fossa is the *lateral pterygoid plate*. This plate is thin and wide, and is set nearly perpendicularly behind the maxilla. Between its upper part and the upper part of the maxilla there is a narrow V-shaped

cleft, called the **pterygo-maxillary fissure**, whose upper end joins the inferior orbital fissure at almost a right angle. The maxillary artery passes out of the infratemporal fossa through the pterygo-maxillary fissure into the *pterygo-palatine fossa.*

The **pterygo-palatine fossa** is the small, confined space one sees immediately beyond the pterygo-maxillary fissure. If a pin or a match is passed through the upper part of the fissure into the fossa, and onwards through the fossa, it appears in the nasal cavity. The hole in the medial wall of the fossa through which the pin enters the nose is the **spheno-palatine foramen.**

The **infratemporal fossa** is a roomy space that contains the two pterygoid muscles, the spheno-mandibular ligament, the pterygoid venous plexus, the maxillary artery (first and second parts) and its branches, the mandibular nerve and its branches, and the chorda tympani nerve —all embedded in a quantity of fat and lying under cover of the tendon of the temporalis, the coronoid process, and the ramus of the mandible and the masseter muscle. The coronoid process and the ramus constitute a *lateral wall* of the fossa; the temporalis tendon is inserted into the process; the masseter lies on the lateral surface of the process and the ramus, being inserted into the lateral surface of the ramus. [Μασητήρ (masētēr) = a chewer.]

The *anterior wall* of the fossa (*i.e.*, the posterior surface of the maxilla, ending inferiorly in the maxillary tuberosity) presents, about its middle, two or three small holes which are the upper ends of the **dental canals** through which vessels and nerves descend to the molar and premolar teeth of the upper jaw.

The *roof* of the fossa is chiefly the infratemporal surface of the greater wing of the sphenoid, and partly also the infratemporal surface of the squamous temporal, *i.e.* a small triangular area that lies in front of the medial part of the articular eminence. In the infratemporal surface of the sphenoid, close to its posterior border, there are two holes, called the **foramen ovale** and **foramen spinosum**, which will be considered with the lower surface of the skull (p. 171).

The *medial wall* is the lateral pterygoid plate and a narrow strip of bone which belongs to the tubercle of the palatine bone and is wedged in between the lower part of the plate and the maxilla; very often, however, the strip is so closely united to the bones between which it lies that it cannot be distinguished, and the lower part of the plate appears to be fused with the maxilla.

The **pterygo-palatine fossa** is a small space situated *below* the apex of the orbit, bounded *anteriorly* by the maxilla, *posteriorly* by the common root of the pterygoid process and greater wing of the sphenoid bone, and *medially* by the perpendicular plate of the palatine bone, which separates it from the cavity of the nose. The fossa is filled with fat, in which there lie the third part of the maxillary artery and its branches, corresponding veins, the maxillary nerve, and the spheno-palatine ganglion and its branches.

The fossa communicates with the infratemporal fossa by the **pterygo-maxillary fissure**, through which the maxillary artery enters it and the maxillary nerve leaves it. It is on a level with the zygomatic arch immediately below the jugal point, about two inches distant from the side of the head. In intractable neuralgia of the branches of the maxillary nerve a needle conveying analgesic fluid may be passed through the contents of the infratemporal fossa into the pterygo-palatine fossa to reach the maxillary nerve.

The following apertures (several of which will be referred to more fully later), open into or out of the pterygo-palatine fossa: (1) the pterygo-maxillary fissure; (2) the inferior orbital fissure, through the posterior end of which the fossa communicates with the apical part of the orbit; (3) the greater palatine canal, which descends to the posterior corner of the bony palate; (4) the foramen rotundum, which opens out of the middle cranial fossa; (5) the pterygoid canal, which passes backwards through the root of the pterygoid process; (6) the palatino-vaginal canal, which passes backwards and medially in the roof of the nose; (7) the spheno-palatine foramen.

The **spheno-palatine foramen** is in the medial wall of the fossa and is bounded by the spheno-palatine notch and the lower surface of the body of the sphenoid. It opens into the superior meatus of the cavity of the nose immediately above the posterior end of the middle concha, but during life it is closed up by the mucous membrane. It transmits the spheno-palatine vessels and the long and short spheno-palatine nerves from the spheno-palatine ganglion. The foramen can be identified in the dried skull if a match is pushed onwards through the pterygo-palatine fossa into the nose, where one can see it by looking through the posterior aperture of that side; the foramen is large and round, but by frequent examination the thin bone around it may have been broken down, so that it may be a large opening with jagged margins.

Norma Basalis

When the skull is turned upside down for the examination of the **lower surface** of its base, many of the parts already seen from the other aspects are seen again. These and the main features of the region should be identified (Fig. 156).

The **medial pterygoid plate** is the most posterior bone in the side-wall of the nasal cavity; inferiorly a portion of it stands also in the side-wall of the nasal part of the pharynx (naso-pharynx), *i.e.*, the uppermost division of the interior of the pharynx; its medial surface is therefore clothed with mucous membrane. The posterior border is thin and sharp, and rather more than half-way up a sharp spur of bone sometimes juts backwards from it; above that spur, the border divides into two ridges which bound the **scaphoid fossa**, the medial margin of which is looked on as the upper part of the border. The end of the pharyngo-tympanic tube, as it opens on the side-wall of the naso-pharynx, is closely related to the medial margin of the scaphoid fossa and is supported inferiorly by the spur of bone. The lower or palatine end of the posterior border is continued into the hooklet or **hamulus**, the concavity of which is directed backwards and upwards towards the base of the skull; the *lower* surface of the root of the hamulus is crossed by a groove. The anterior part of the tensor palati muscle arises from the floor of the scaphoid fossa, descends along the lateral surface of the medial pterygoid plate, and the slender tendon of the muscle turns at a right angle in a medial direction and forwards, in the groove on the lower surface of the hamulus, and spreads out as it enters the soft palate. The posterior border of the medial plate, in its whole length, gives attachment to the pharyngo-basilar fascia; its lower half or third, together with the hamulus, gives origin to the upper part of the superior **constrictor of the pharynx**; **the tip of the hamulus** gives attachment to a fibrous band, the pterygo-mandibular ligament, which extends to the posterior end of the mylo-hyoid ridge of the mandible and gives origin to most of the remaining fibres of the superior constrictor.

The **lateral pterygoid plate** is wider than the medial plate, and its lower part is slightly bent in a lateral direction. Its posterior border is sharp and very uneven; its surfaces give origin to the pterygoid muscles. The lateral pterygoid muscle has two heads—an upper and a lower. The lower head arises from the lateral surface of the lateral pterygoid plate; the upper head arises from the infratemporal surface and infratemporal crest of the sphenoid. The two heads pass backwards, join together, and are inserted chiefly into the front of the neck of the mandible (the mandible should now be placed in position). The medial pterygoid muscle also has two heads—a superficial and a deep. The superficial head is very small and arises from the tuberosity of the maxilla and the strip of the tubercle of the palatine bone that appears between the maxilla and the lateral pterygoid plate. The deep head forms nearly the whole muscle; it arises from the medial surface of the lateral pterygoid plate and the surface of the tubercle that appears in the pterygoid fossa. The two heads join and pass downwards and backwards to be inserted into the medial surface of the mandible above and in front of the angle.

The **infratemporal surface** of the greater wing of the sphenoid is limited in front by the inferior orbital fissure, laterally by the infratemporal crest, while posteriorly it extends backwards and ends as the spine of the sphenoid at the medial side of the articular fossa of the temporal bone. The **spine of the sphenoid** is grooved on its medial side by the chorda tympani nerve, and it gives attachment to (1) the posterior part of the tensor palati muscle, (2) the spheno-mandibular ligament, which stretches to the margin of the mandibular foramen, and (3) the pterygo-spinous ligament—a weak fibrous band that stretches to the posterior border of the lateral pterygoid plate, but may, however, be transformed into a bar of bone.

The **foramen spinosum** is antero-medial to the spine of the sphenoid. It transmits the middle meningeal vessels and sympathetic plexus, a nerve-filament called the nervus spinosus, and lymph-vessels from the meninges.

The **foramen ovale** is antero-medial to the foramen spinosum. The only large structure that it transmits is the mandibular nerve, including the motor root of the trigeminal nerve; but there pass through it also the accessory meningeal artery, small veins which connect the cavernous venous sinus with the pterygoid venous plexus, lymph-vessels from the meninges, and, sometimes, the lesser superficial petrosal nerve. The foramina ovale and spinosum began as notches on the posterior edge of the greater wing, and were gradually enclosed in bone.

Very frequently there is a small aperture, called the **sphenoidal emissary foramen** (*Vesalii*), situated antero-medial to the foramen ovale and close to the scaphoid fossa. It opens directly into the middle cranial fossa and transmits a small emissary vein that connects the cavernous sinus with the pterygoid plexus. In the same neighbourhood there are one or more minute foramina that transmit either emissary or diploic veins. And occasionally there is a very small unnamed hole behind the foramen ovale for the transmission of the lesser superficial petrosal nerve.

Posterior Region of Lower Surface of Skull

There are only three bones in the posterior part of the base of the skull—the occipital bone, and the right and left temporal bones. The **occipital** bone occupies a large part of the region in the middle and posteriorly; the **temporal** bone is wedged in at the side between the occipital bone and the greater wing of the sphenoid.

The **occipital bone** is divided into four parts which surround the foramen magnum—the *basilar part* (*basi-occiput*) in front, a *condylar part* at each side, and a large, expanded *squamous part* behind. The four parts are separable at birth, but usually are fused together by the sixth year.

The **foramen magnum** is the large opening in which the medulla oblongata, or lowest division of the brain, becomes continuous with the spinal cord. It is on a level with the mastoid process at the side of the head, and is opposite a point on the back of the neck midway between the external occipital protuberance and the spine of the second cervical vertebra.

The **foramen magnum** is usually ovoid in outline with the narrower part in front, and its antero-posterior diameter varies from 30 to 40 mm. It *contains* the upper end of the spinal cord with its membranes and blood-vessels, the spinal roots of the accessory nerves, the vertebral arteries surrounded by plexuses of sympathetic nerves derived from the inferior cervical ganglia, lymph-vessels from the meninges of the brain; the lowest part of the cerebellum lies in it; and the membrana tectoria and upper band of the cruciate ligament pass upwards through it to be attached to the upper surface of the basi-occiput in front of the foramen magnum. The posterior atlanto-occipital membrane is attached to the posterior margin of the foramen magnum; the anterior atlanto-occipital membrane and the apical ligament of the odontoid process to the anterior margin; the alar ligament to the low tubercle on the medial surface of the occipital condyle on the side of the foramen magnum. The vertebral artery enters the foramen immediately behind the condyle, and sometimes grooves the margin of the foramen. The posterior margin of the foramen is in the same horizontal plane as the bony palate; and its middle point is called the **opisthion** [ὀπίσθιος (opisthios) = posterior]. The anterior margin is usually a little higher, for the foramen is slightly oblique in white races; the middle point of the margin is called the **basion**.

The **basilar part** of the occipital bone, or **basi-occiput**, is a wide bar of bone, thin at the margin of the foramen magnum, but thick at its anterior end, where it joins the body of the sphenoid. In youth it is united to the sphenoid by a plate of cartilage. It is fused with the sphenoid after the twenty-fifth year, but the position of their fusion may be indicated by an interrupted transverse depression. The **pharyngeal tubercle** is a small elevation which lies at the centre of the basi-occiput. It is about half an inch in front of the foramen magnum and on a line passing through the upper part of the neck of the mandible on each side. The surface of bone in front of the tubercle is clothed with the muco-periosteum of the roof of the pharynx.

The hole with jagged edges, seen alongside the anterior part of the basi-occiput, is the **foramen lacerum**; it leads directly up into the middle cranial fossa but is filled in the living state by cartilage and the structures which pierce it. Look for the pterygoid tubercle and the pterygoid canal on its anterior margin, as seen from below. The *pterygoid tubercle* is a small rounded elevation at the extreme upper end of the medial pterygoid plate. The posterior end of the **pterygoid canal is** on the anterior margin of the foramen—immediately above the tubercle and rather hidden by it—and is only large enough to admit a thick pin; in some skulls it is so hidden that it cannot be seen, but a hook or a bent pin enables one to find it. The canal runs forwards through the root of the pterygoid process, and its anterior end opens into the pterygo-palatine fossa. (See also pp. 183 and 186.)

The **pharyngeal tubercle**, in an articulated skeleton, lies directly above the tubercle on the anterior arch of the atlas. The pharyngeal tubercle gives insertion to the uppermost bundle of fibres of the superior constrictor of the pharynx and attachment to a median, fibrous longitudinal band, called the *pharyngeal raphe*, that lies in the posterior wall of the pharynx. The rectus capitis anterior is inserted into an impression on the basi-occiput in front of the occipital condyle, and the longus capitis into an impression lateral to the pharyngeal tubercle and in front of it; the back of the uppermost part of the pharynx is therefore recessed in between the right and left longus capitis muscles, and the prevertebral fascia is attached to a line which curves forwards from behind the pharyngeal tubercle to the front and lateral margins of the impression for the longus capitis.

The basi-occiput, the body of the sphenoid and the ethmoid form what is called the **basi-cranial axis**; a line drawn between the tips of the pterygoid tubercles marks the spheno-occipital junction. Posteriorly, the basicranial axis is wedge-shaped and solid; anteriorly it is thick but is hollow—owing to the sphenoidal and ethmoidal sinuses.

The **condylar parts** of the occipital bone lie at the sides of the anterior half of the foramen magnum, and are so named because they bear the occipital condyles.

The **occipital condyles** are the large, smooth, oblong protuberances that lie at the margins of the foramen magnum. They articulate with the lateral masses of the atlas vertebra, and through them the weight of the head is transmitted to

the vertebral column. The nodding movements of the head take place at the joints between the condyles and the atlas. The condyle and the joint are at the level of the mastoid process and are almost directly opposite it. The articular surface of each condyle is often notched at the sides, and in some skulls the notches meet and divide the articular surface into two parts.

The **condylar fossa** is the depression behind the condyle. In many skulls there is a canal that begins in the fossa and passes obliquely forwards and upwards into the cranial cavity; it is named the *posterior condylar canal*. The bony wall of the fossa is thin and may have an artificial perforation in it that can be mistaken for the canal, but the artificial opening leads directly up into the cranial cavity—not obliquely.

The **occipital condyles** lie alongside the anterior part of the foramen magnum. They are placed obliquely, their anterior ends being nearer each other than the posterior ends. The articular surface of each is convex from before backwards and slopes downwards from lateral to medial side. The articular capsule is attached to the margins of the articular surface, and the alar ligament is attached to the medial surface of the condyle.

The **condylar fossa** accommodates the upper part of the back of the lateral mass of the atlas when the head is bent backwards.

The **posterior condylar canal**, when present, passes above the posterior part of the condyle and opens, in the posterior cranial fossa, into (or near) the groove on the upper surface of the jugular process that lodges the lower end of the sigmoid venous sinus. The canal transmits a vein that connects the sinus with the suboccipital venous plexus.

The external opening of the **anterior condylar canal** is above the lateral margin of the anterior part of the condyle; it is usually largely hidden by the condyle, and the skull has therefore to be tilted before the opening is seen. The beginner should not mistake the jugular foramen for it because the foramen chances to catch his eye first. The jugular foramen is a large irregular opening nearly half an inch away from the condyle, and through it one can see into the cranial cavity. The anterior condylar canal is only wide enough to admit a match; it is medial to the jugular foramen and quite close to the condyle; internally, it opens into the cranial cavity a little above the margin of the foramen magnum (p. 187).

The **jugular process** is the part of the occipital bone—about half an inch square—that lies lateral to the posterior half of the condyle. Its anterior border is the posterior margin of the jugular foramen; this border is concave from side to side and the concavity is called the **jugular notch.**

The **anterior condylar canal** passes in a medial direction and backwards above the anterior part of the condyle. The important structure that passes through it is the hypoglossal nerve; but it transmits also a meningeal branch of the ascending pharyngeal artery, veins which connect the meningeal veins and the veins of the medulla oblongata with the pharyngeal venous plexus, and lymph-vessels from the meninges.

The **jugular process** is the homologue of the transverse process of a vertebra. It blends medially and posteriorly with the rest of the occipital bone; its anterior margin is free and bounds the **jugular notch**; its lateral margin is united to the petrous temporal by a plate of cartilage which may ossify after the twenty-fifth year; its lower surface is rough and gives insertion to the rectus capitis lateralis, and the prevertebral fascia is attached to the anterior margin in front of the rectus; its upper surface, in the floor of the posterior cranial fossa, has a broad shallow groove which lodges the lower part of the sigmoid venous sinus.

In some skulls a curved process, called the *intrajugular process*, projects from the floor of the jugular notch and partially or completely divides the jugular foramen. Occasionally a projection, called the *paramastoid process*, juts downwards from the lateral part of the jugular process, and it may be long enough to articulate with the transverse process of the atlas.

The **squamous part** is by far the largest division of the occipital bone It lies partly in the base and partly in the back of the skull. The *external occipital protuberance* and the *superior nuchal lines*, already examined (p. 160), are the boundary between the base and the back. The part in the base may be comparatively flat or may be full and rounded—the contour varying with the size and shape of the cerebellum, which lies on the upper surface of this part of the bone.

The **external occipital crest** is a median ridge that extends from the protuberance to the posterior margin of the foramen magnum; in some skulls it is very poorly marked.

The **inferior nuchal lines** are a pair of faint curved ridges, situated about

midway between the foramen magnum and the superior nuchal lines. Each begins about the middle of the external occipital crest and arches in a lateral direction and forwards and downwards towards the side of the occipital bone.

The upper end or border of the ligamentum nuchæ is attached to the **external occipital crest** and **external occipital protuberance**; the protuberance and the medial part of the **superior nuchal line** give attachment to the epicranial aponeurosis and origin to the uppermost fibres of the trapezius; the lateral part of the line gives origin to the occipital belly of the occipito-frontalis and insertion to part of the sterno-mastoid and of the splenius capitis. The semispinalis capitis is inserted into the medial half of the area between the **superior** and **inferior nuchal lines**; the obliquus capitis superior into the lateral half; the rectus capitis posterior minor into the medial part of the area below or in front of the inferior nuchal line; the rectus posterior major into the lateral part. Though the oblique muscle and the two recti are small, their insertions are wide and in many skulls are mapped out by ridges. Place the atlas and the skull together properly and note the position and the direction taken by the obliquus superior as it passes from the transverse process of the atlas to its insertion into the occipital bone.

All the divisions of the **temporal bone** appear in the lower surface of the skull:—the lower end of the *mastoid temporal*; the *tympanic plate*; the lower surface of the *petrous temporal* medial to the tympanic plate; the *styloid process* emerging from behind the lower part of the tympanic plate; and the portion of the *squamous temporal* that bears the articular eminence and articular fossa is in front of the tympanic plate.

The petrous part of the temporal bone is more easily identified in the interior of the skull (p. 179). In the base of the skull it can be seen extending medially from the region of the mastoid process and external auditory meatus to lie between the occipital bone behind and medially and the sphenoid bone in front. Its apex lies behind the root of the pterygoid process (see Fig. 156). Certain parts that belong to the temporal bone (or are placed close alongside it) are easily identified. (1) The **articular eminence** medial to the posterior part of the zygomatic arch and continuous with its anterior root; (2) the **articular fossa** behind the articular eminence; the head of the mandible is in relation with the fossa when the mouth is shut, and is pulled forwards and downwards into relation with the eminence as the mouth is opened; (3) the **spine of the sphenoid** medial to the eminence or medial to the fossa; (4) the **post-glenoid tubercle** in the posterior boundary of the fossa immediately in front of the opening of the external auditory meatus; (5) the **tympanic plate** behind and below the fossa; (6) the **mastoid process** behind and below the external auditory meatus; (7) the **mastoid notch** at the medial side of the root of the mastoid process; (8) the **foramen lacerum** alongside the anterior part of the basi-occiput, between it and the petrous temporal.

The floor of the **mastoid notch** gives origin to the posterior belly of the digastric muscle. Close to the medial side of the notch and parallel with it, the occipital artery runs backwards and in a lateral direction in contact with the mastoid temporal or with the suture between it and the occipital bone, and usually produces a groove on the bone. The entire absence of a groove indicates that the artery was lower than usual.

The **styloid process** lies deeply in the interval between the mastoid process and the mandible and intervenes between the parotid gland and the internal jugular vein. It projects downwards, forwards, and medially from the petrous temporal, behind the lower part of the tympanic plate, which partly ensheaths its basal portion. Two ligaments and three muscles are attached to it. The stylo-hyoid ligament stretches from its tip to the hyoid bone; the stylo-mandibular ligament (which is a thickened part of the fascia that covers the antero-medial surface of the parotid gland) extends from the front of it to the posterior border of the mandible. The stylo-glossus arises from the front of it near the tip; the stylo-hyoid from the postero-lateral surface of the middle third; the stylo-pharyngeus from the medial side near the root. The styloid process is ossified in cartilage from two centres—an upper and a lower. The lower part of the process does not fuse with the upper till after puberty and may remain a separate bone throughout life.

The following parts are now to be looked for:—

The **stylo-mastoid foramen** is the aperture immediately behind the root of the styloid process, between it and the mastoid process, in front of the mastoid notch. It is the lower end of a canal, in the substance of the temporal bone, through which the facial nerve travels on its way from the brain to the exterior of the skull; besides the facial nerve, it transmits the stylo-mastoid branches of the posterior auricular vessels, which pass upwards through it into the temporal bone.

The **jugular foramen** is a large opening with uneven margins situated a little to the medial side of the root of the styloid process, and it leads into the posterior cranial fossa. It is bounded anteriorly by the petrous temporal and posteriorly by the jugular process of the occipital bone.

The largest structure in the jugular foramen is the internal jugular vein, which begins in it as a continuation of the sigmoid venous sinus. The vein is dilated at its commencement and the dilatation is called the *superior bulb* of the internal jugular vein. To accommodate the bulb there is a concavity, called the **jugular fossa**, on the petrous temporal where it forms the antero-lateral wall of the jugular foramen.

The jugular foramen is opposite the external auditory meatus and is almost at the level of its lower margin. A part of the bone that bounds the jugular fossa forms also the floor of the tympanic cavity or middle ear. That relationship can be verified if one looks at the medial wall of the tympanic cavity through the external meatus and gauges the position of the floor of the cavity. In middle-ear disease, infection may damage the bone and attack the internal jugular vein.

The **jugular foramen** leads upwards and backwards into the cranial cavity, and the structures it transmits will be enumerated more intelligibly when it is examined from inside the skull (p. 189). Sometimes spicules of bone project across the foramen from its margins, and they may divide it into compartments.

The right internal jugular vein is usually larger than the left, and the right jugular foramen and fossa are therefore larger than the left. When the fossa is large there may be very little bony substance between it and the tympanic cavity and antrum, which lie above it.

On the lateral wall of the foramen, in the floor of the jugular fossa, there is a small 'pin-point' aperture: it is the medial end of a narrow, horizontal canal, called the **mastoid canaliculus**, which passes through the temporal bone and opens laterally in the tympano-mastoid fissure. The canal is traversed by a slender nerve-filament called the auricular branch of the vagus. The canal is not present at birth, but is formed as the growing tympanic plate and mastoid temporal enclose the nerve—which is outside the skull in an infant.

The **carotid canal** is a tunnel in the petrous temporal through which the internal carotid artery travels to reach the cranial cavity. The lower end of the canal is immediately in front of the jugular foramen and fossa in the lower surface of the petrous temporal; it is a circular or an oval opening, wide enough to admit a thin pencil. From this opening the canal leads upwards for a short distance; it then bends to become horizontal and runs in a medial direction and forwards to open into the side of the foramen lacerum. Since the lower end of the canal is anterior to the jugular foramen, the internal carotid artery, as it enters the bone, is in front of the internal jugular vein.

The lower end of the canal is opposite the anterior margin of the orifice of the external auditory meatus, and the ascending part of the canal lies below and in front of the middle ear and the internal ear; the thudding sound that one hears in the head during moments of excitement or after a spurt of violent exertion is due to the beating of the carotid artery against the bone which separates it from the internal ear.

The anterior margin of the jugular foramen and fossa is separated from the lower opening of the carotid canal by a ridge of bone on which there may be more than one small hole for small vessels that enter the bone. But one of these foramina is the lower end of the **tympanic canaliculus**, through which a small nerve, called the tympanic branch of the glosso-pharyngeal nerve, passes up to enter the tympanic cavity and form the tympanic plexus on its medial wall.

The **carotid canal** transmits the internal carotid artery, the internal carotid plexus of sympathetic nerves derived from the superior cervical ganglion, small veins that connect the cavernous venous sinus with the pharyngeal venous plexus, and lymph-vessels from the meninges. On the postero-lateral wall of the canal, immediately above its lower aperture, there are the openings of two very narrow tunnels; they are the **carotico-tympanic canaliculi**, which transmit the tympanic branches of the carotid artery and of the carotid sympathetic plexus.

The **quadrate area** of the petrous temporal is the rough, nearly four-square area medial to and in front of the lower opening of the carotid canal, between that opening and the foramen lacerum. The *antero-lateral border* of the area lies against the posterior border of the greater wing of the sphenoid, *i.e.*, the border immediately behind the foramen ovale and foramen spinosum; the two borders may touch each other or there may be a narrow fissure between them.

The *cartilaginous part* of the *pharyngo-tympanic tube* lies along the fissure, or the line of contact, in a shallow groove shared by both the bones. The postero-lateral end of the groove is at the medial side of the spine of the sphenoid, and it is continuous there with two canals in the interior of the temporal bone. These canals are one above the other and are separated by a thin, bony septum. The lower and wider is the **canal of the pharyngo-tympanic tube**—*i.e.*, the osseous part of the tube—and it passes obliquely into the middle ear or tympanic cavity. If a pin or a hook is run along the groove to its postero-lateral end and pushed onwards, it will pass, usually without difficulty, into the canal; and, if one looks through the external auditory meatus, the point will be seen in the tympanic cavity. The upper canal is the **canal for the tensor tympani.** That tiny muscle springs chiefly from the cartilage of the tube, runs in the canal above the bony part of the tube, enters the tympanic cavity and is inserted into one of the auditory ossicles, namely, the *malleus*.

Squamo-tympanic fissure is the name given to the narrow slit between the articular fossa of the squamous temporal and the upper edge of the tympanic plate. The lateral end of the slit is directly in front of the opening of the external auditory meatus; the medial end is directly behind the spine of the sphenoid. See also pp. 221, 223.

The **foramen lacerum** can be seen between the petrous temporal and the basi-occiput, and the posterior end of the **pterygoid canal** is situated on the anterior margin of the foramen above and lateral to the **pterygoid tubercle**; they will be dealt with more fully when the floor of the cranial cavity is examined (p. 185).

The **quadrate area** gives origin to the levator palati muscle. Cartilage, or dense fibrous tissue, unites the *postero-medial border* of the area to the basi-occiput, and its *antero-medial border* to the posterior border of the greater wing of the sphenoid; the cartilaginous part of the pharyngo-tympanic tube lies along its line of union with the greater wing. The levator palati at its origin is therefore postero-medial to the tube. The tensor palati is a thin muscle with a triangular outline; the apex of the triangle is the tendon as it turns round the lower surface of the pterygoid hamulus, and the base is the origin of the muscle from the skull. It arises from the spine of the sphenoid and from the floor of the scaphoid fossa, and, between those points, from the cartilage of the tube; the upper part of the muscle therefore lies on the antero-lateral side of the tube and separates it from the mandibular nerve descending from the foramen ovale and the middle meningeal artery ascending to the foramen spinosum.

The **bony part of the pharyngo-tympanic tube** is about 10 mm. long. It is in the temporal bone, between the tympanic plate and the petrous temporal; and a thin bony septum separates it from the canal for the tensor tympani, which is above it. One end opens into the anterior part of the tympanic cavity; from there the tube passes medially, forwards and slightly downwards, and opens on the lateral end of the groove for the cartilaginous part, at the medial side of the spine of the sphenoid, where the opening is easily found. Push a pin through the opening and along the tube to the tympanic cavity, and note that the tube has the ascending part of the carotid canal on its postero-medial side, and the mandibular joint on the antero-lateral side.

The **tympanic plate** has three surfaces. The medial part of the **posterior surface** is fused with the petrous temporal and helps to form the anterior wall of the first part of the carotid canal; the lateral part is fused with the mastoid temporal and the post-auditory process of the squamous temporal, but is partly separated from the mastoid by the tympano-mastoid fissure. The **upper surface** is curved, for it belongs to the curled, lateral part of the plate; it forms the lower wall of the **external auditory meatus**, nearly the whole of its anterior wall, and the greater part of its posterior wall; the rough, curved *lateral margin* of the plate gives attachment to the cartilage of the auricle. The **anterior surface** is free and concave and is related to the upper part of the parotid gland, which separates it from the back of the head and neck of the mandible. Its *lower border* is uneven and sharp, and gives attachment to the fascia that covers the postero-medial surface of the parotid gland; its *upper border* forms the floor of the pharyngo-tympanic tube and the posterior boundary of the squamo-tympanic fissure, and it gives attachment to the fascia that covers the antero-medial surface of the parotid gland.

The *lateral part* of the **squamo-tympanic fissure** may be obliterated by fusion of the tympanic plate with the back of the post-glenoid tubercle. The *middle part* leads up into the tympanic cavity; the anterior process of the malleus is stuck into it; and the tympanic branch of the middle meningeal artery passes upwards through it. In many skulls a thin strip of bone is seen between the lips of the medial part of the fissure; that strip is the lower edge of the tegmen tympani (a part of the surface of the petrous temporal seen in the middle cranial fossa, p. 184); to reach the fissure the tegmen is continued downwards as the antero-lateral wall of the bony part of the pharyngo-tympanic tube, and it divides the fissure into two slits—a **petro-squamous fissure**, in front of the edge of the tegmen, and a **petro-tympanic fissure**, which is more important; it is between the edge of the tegmen and the tympanic plate and is below the tube. The chorda tympani nerve, having traversed the tympanic cavity from behind forwards, enters a small hole in the anterior wall of the cavity, runs obliquely downwards and forwards in the

antero-lateral wall of the pharyngo-tympanic tube, and issues from the skull through the petro-tympanic fissure; it then runs in a medial direction and forwards and downwards, grooving the medial side of the spine of the sphenoid; and it ends by joining the lingual nerve nearly an inch below the foramen ovale.

The **articular fossa** and the **articular eminence** are for articulation with the head of the mandible, and their margins give attachment to the articular capsule, the thickened lateral part of which, called the temporo-mandibular ligament, is attached to the **tubercle of the root of the zygoma**; but the fossa and the eminence are separated from actual contact with the head of the mandible by an articular disc of fibro-cartilage which is attached by its circumference to the capsule and divides the cavity of the joint into an upper and a lower part. The bone of the deepest part of the fossa is so thin that it is translucent.

CRANIAL CAVITY

The **cranial cavity** is the large cavity that lodges the brain. The bones which share in its formation are the frontal, the ethmoid, the sphenoid, the occipital, the two parietal, and the two temporal bones. The cavity is lined with the outermost of the three membranes or meninges of the brain, namely, the **dura mater**; the dura mater consists of two closely adherent fibrous layers, the *outer* of which clothes the bone, serving the purpose of periosteum, and is called the *endocranium.* The periosteum on the outside of the skull is called the *pericranium.* The pericranium and the endocranium are both continuous with the fibrous ribbons, called *sutural ligaments*, that lie between the articulating edges of the bones; and they are continuous also with each other round the lips of the various foramina and fissures that lead from the cranial cavity to the exterior.

Section of Skull.—The cranial cavity can be exposed for examination either by a median section which splits the skull into a right and a left half, or by a horizontal section which removes the skull-cap. The second method is the more common; the saw-cut is usually made to pass through the *frontal* bone immediately above the superciliary arches, through the two inferior angles of the *parietal* bone and the upper part of the *squamous temporal* on each side, and through the *occipital* bone immediately above the external occipital protuberance. The two parts are then examined separately: the skull-cap shows the roof of the cranial cavity; the lower part of the skull shows its floor; the front, the sides, and the back are included partly with the roof and partly with the floor.

The advantage of the median section is that it not only exposes the cranial cavity but also lays open the nasal cavity and the sphenoidal sinus. If the skull which the student has procured for himself has had the skull-cap removed, the lower part of the skull should be divided into a right and a left half. If he has an uncut specimen of skull he should remove the skull-cap by the saw-cuts indicated above, and then split the lower part of the skull into halves.

In making the sagittal section he should use a very fine saw and should make the cut a little to one or other side of the median plane in order to avoid injury to the septum of the nose, but, at the same time, he must be careful not to injure the conchæ, which project from the side-wall of the nasal cavity. The first cut should be made through the bony palate and the alveolar process of the maxilla; if they are not cut first they will break when the thicker parts of the skull are divided. The two halves can be tied together or hinged together with improvised pins and hooks when the student wants to examine both halves at once.

Thickness of Skull.—In cutting the skull the student will note that the inner table is thinner than the outer table, and that the whole thickness of the walls of the cranial cavity varies in different areas. The thicker and thinner areas are not all constant in position in different skulls, but the areas well covered with muscles are thinner than those that are more exposed, *e.g.*, the floor of the temporal fossa and the floor of the posterior cranial fossa on each side of the median plane.

The bone of the skull as a whole is thicker in some races than in others (the more primitive races usually having the advantage of thicker skull-bones); but in all races the skull-bones are thinner in women and children than in men. The skull of a child is very thin, but is more yielding and elastic than that of an adult and is less liable to fracture. There are, however, great differences in thickness in the skulls of adults of the same race and sex and in different parts of the same skull. Measurements of 448 male white American crania by Wingate Todd (1924) yielded thicknesses of between 5 mm. and 7 mm. at the posterior border of the foramen magnum and at the vertex. At the position of greatest breadth the thickness was between slightly under 3 mm. and 6 mm. Variations occur ranging from less than one-eighth of an inch to almost half an inch. There is no known relation between the thickness of the skull-bones and the quality of the intelligence, but a thick skull obviously protects the brain more efficiently from injury by violence. It is not possible to gauge the thickness of the skull

with any certainty during life, except during the course of an operation; and in the early steps of an operation on the skull it is safer to assume that the skull is thin.

Roof of Cranial Cavity

The **skull-cap** is the **roof** of the cranial cavity or **vault** of the skull. If the horizontal saw-cut has been made as indicated, the skull-cap includes part of the *frontal* bone in front, part of the *occipital* bone behind, nearly the whole of both *parietal* bones in the middle, and a very small part of the *squamous* portion of the *temporal* bone on each side at the lower border of the parietal bone.

The internal or **cerebral surface** of the vault is highly concave in every direction. The dura mater is only loosely attached to the skull-vault, except at the sutures, where, in a young adult skull, it is continuous with the sutural ligaments.

The **sutures** between the bones may be indistinct, for if their obliteration has begun it will be more advanced on the inner surface than on the outer; and if the skull is that of an old person the sutures may have disappeared. The sutures are:—The **sagittal suture**, uniting the two parietal bones; the **coronal suture**, uniting them to the frontal bone; the **lambdoid suture**, uniting them to the occipital bone; and the **squamous suture**, on each side, uniting the parietal bone to the squamous temporal. The squamous suture is at a lower level on the inside of the skull than on the outside, because the squamous temporal overlaps the parietal bone on the outside.

The following additional parts are to be noted in the vault:—

The **frontal crest** (Fig. 157) is a median ridge on the anterior wall of the cranial cavity—on the lower part of the cerebral surface of the frontal bone—and it may extend far enough up to be seen on the skull-cap.

The **sagittal groove** is a shallow, median furrow on the cerebral surface of the vault, extending from above the root of the nose to the occipital protuberance. It begins on the frontal crest, passes upwards and backwards on the frontal bone, backwards along the sagittal suture, and downwards on to the occipital bone, widening progressively during its course. The superior sagittal venous sinus lies along it in the upper border of the falx cerebri, which is attached to its lips. (The falx cerebri is a fold of the inner layer of the dura mater projected downwards from the cranial vault as a tense, median partition to keep the two halves of the cerebrum apart.)

The **granular pits** are small irregular depressions that are placed here and there alongside the sagittal groove. They are more numerous and larger in the skull of an old person than in a young skull, and the bone in their floors may be thin enough to be translucent. They lodge arachnoid granulations, which are small bud-like growths that protrude from the arachnoid mater. (The arachnoid mater is the middle and the thinnest of the three membranes that enclose the brain) [ἀράχνιον (arachnion) = a spider's web].

The **parietal foramen** when present, is in the parietal bone, close to the sagittal groove, about an inch or an inch and a half above the lambdoid suture.

The **vascular grooves** (Fig. 164) are narrow and branching for meningeal vessels. They extend from the cut edges of the vault towards the top; the largest of them are on the parietal bone and are for the branches and tributaries of the middle meningeal vessels; their direction is upwards and backwards (Fig. 181). Small vascular foramina are numerous, especially in and near the grooves. The **impressions for cerebral gyri** are the shallow, ill-defined depressions found all over the vault. They correspond to the gyri or convolutions on the surface of the brain.

Floor of Cranial Cavity

The **upper surface of the base of the skull** is the floor of the cranial cavity. Grooves for meningeal vessels are seen on it; and the impressions for gyri are better marked than on the vault. The dura mater is more firmly attached to the bone of the floor than to that of the vault.

The floor is divided into three main districts, one behind the other and at different levels, corresponding to the anterior, middle and posterior **cranial fossæ**, of which the anterior is at the highest level and the posterior at the lowest.

The bones seen in the floor of the cavity include the sphenoid bone and the petrous part of the temporal bone which are best seen from this aspect. Identify the temporal bone (blue in Fig. 157) and its petrous part, so named from its hardness [πέτρος (petros) = a stone]; it is the conspicuous pyramidal elevation lying obliquely about midway between the front and back of the cavity on each side and contains the middle and internal parts of the ear. The sphenoid bone is uncoloured in Fig. 157 and is wedged among the other bones of the skull [σφήν (sphen) = a wedge]. Its body is the middle portion; the lesser wings extend to the side in front, and the greater wings spread out from the sides of the body at a lower level to help in the formation of the floor and side-wall of the middle fossa.

Anterior Cranial Fossa

The **anterior cranial fossa** contains the lower part of the frontal lobes of the brain. It is bounded in front and at the sides by the frontal bone. Its floor is divided into:—(1) a median part, which is above the nasal cavity and is formed by the ethmoid bone and the body of the sphenoid; and (2) a right and a left lateral part, each of which is above the orbit and is made up of the orbital plate of the frontal bone and the lesser wing of the sphenoid (Figs. 157, 163).

In the **median division** the chief parts to be looked for are:—

The **crista galli** is the upstanding, median process seen in front.

The **foramen cæcum** is the small pit in front of the crista galli [*cæcum* = blind]. The foramen, however, is not always blind: at its bottom there may be a small aperture which transmits a vein.

The **frontal crest** is the median ridge seen above the foramen cæcum in the anterior boundary of the fossa; it extends upwards on to the vault and fades away there.

The **cribriform plates** of the ethmoid are a pair of narrow, horizontal plates of bone placed along the sides of the root of the crista galli; they are named "cribriform" because they are full of little holes [*cribrum* = a sieve]; they separate the cranial cavity from the nasal cavities (Figs. 164, 165).

Behind the cribriform plates there is a broad, fairly flat area of bone which is the anterior part of the upper surface of the body of the sphenoid. It is named the **jugum sphenoidale** [from a resemblance to *jugum* = yoke] and is limited behind by the **limbus sphenoidalis**. The limbus is the anterior lip [*limbus* = edge] of a shallow transverse furrow, called the *optic groove*, that leads laterally on each side into the *optic foramen*. The optic groove and foramen are, however, included in the middle cranial fossa (p. 181).

By far the greater part of the **lateral division** is formed by the orbital plate of the frontal bone; only a small part posteriorly is formed by the lesser wing. The **orbital plate** separates the cranial cavity not only from the orbit but also from the ethmoidal air-sinuses; for the medial part of the plate overlies the labyrinth of the ethmoid—roofing in the sinuses (Fig. 179). The *frontal sinus* extends backwards for a variable distance between the two tables of bone of which the plate is composed; and the upper table therefore separates the cranial cavity from part of the frontal sinus.

In the skull of an old person the suture between the orbital plate and the **lesser wing** may be obliterated, but if it is visible the outline of the wing can be made out—fairly broad at its medial end and tapering to a point at the lateral end. The posterior border of the lesser wing is the free, sharp margin of the floor of the lateral part of the fossa, and it ends *medially* in a prominent process, called the **anterior clinoid process**, that juts backwards behind the optic foramen.

Each lateral part of the floor of the anterior cranial fossa is convex, rather uneven, and slopes downwards towards the median portion, more so anteriorly than posteriorly, where both parts are smoother and more nearly horizontal. Together with the corresponding half of the median

portion it supports the frontal lobe of the brain; the ridges and **impressions for gyri** on the lateral part correspond to the sulci and gyri on the orbital surface of the brain, and therefore vary in the pattern they make; they are much better marked in some skulls than others.

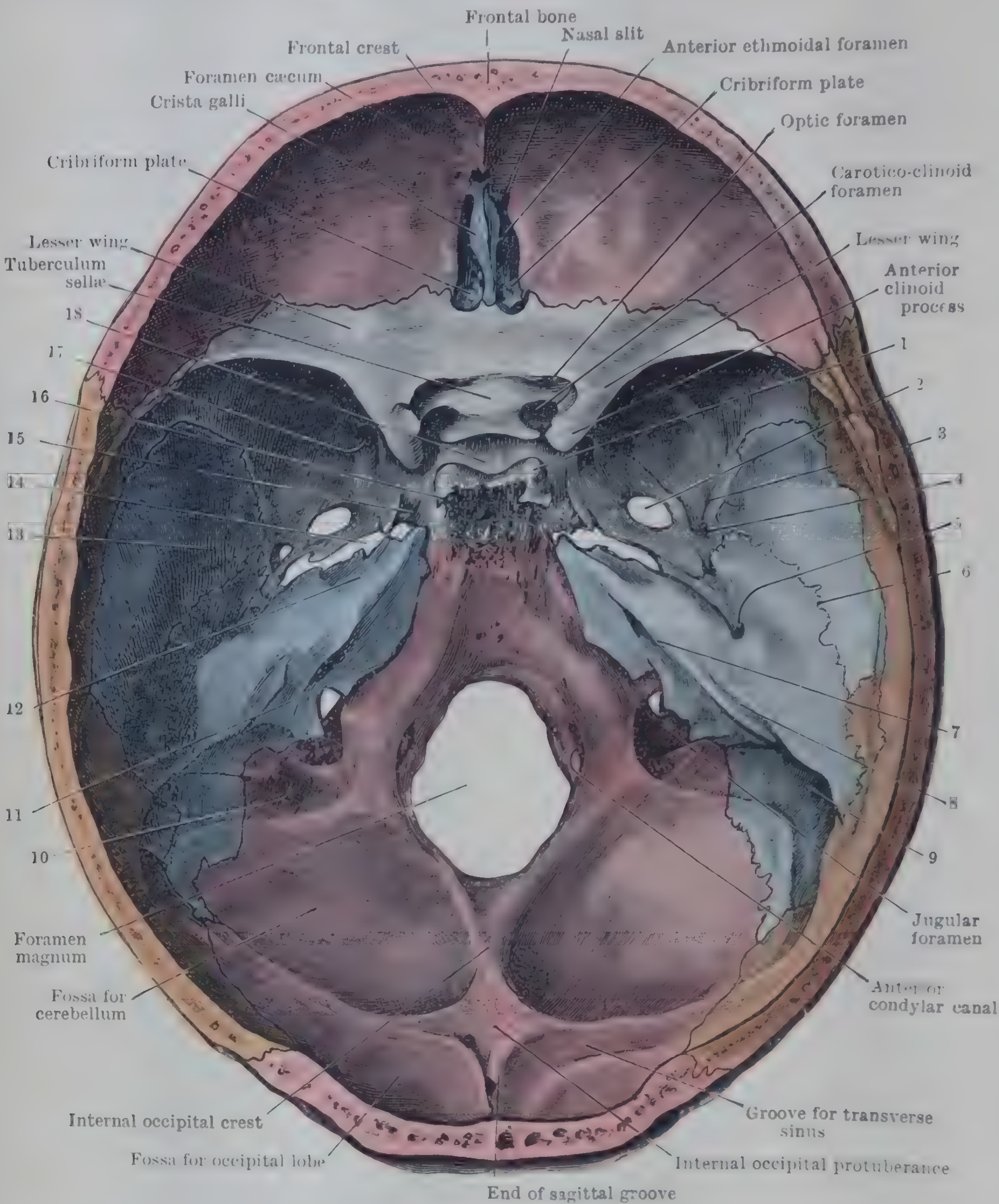


FIG. 157.—FLOOR OF CRANIAL CAVITY.

Red: frontal; occipital. **Blue**: ethmoid; temporal. **Orange**: parietal. **Uncoloured**: sphenoid.

1. Posterior clinoid process.
2. Foramen ovale.
3. Groove for middle meningeal vessels.
4. Foramen spinosum.
5. Hiatus for greater superficial petrosal nerve.
6. Occasional suture between petrous and squamous temporal.
7. Internal auditory meatus.
8. Groove for superior petrosal sinus.
9. Groove for sigmoid sinus.
10. Groove for sigmoid sinus.
11. Groove for the inferior petrosal sinus.
12. Impression for trigeminal ganglion.
13. Squamous temporal.
14. Spheno-petrous fissure.
15. Carotid groove, in front of foramen lacerum.
16. Dorsum sellæ of sphenoid.
17. Leads into foramen rotundum.
18. Hypophysial fossa.

The antero-lateral margin of the orbital surface of the frontal lobe, *i.e.*, the superciliary margin of the brain, fits into the angle between the floor and the antero-lateral wall of the fossa, which corresponds, on the exterior, to a line drawn from the root of the nose upwards and then laterally along the superciliary arch and onwards to the root of the zygomatic process of the frontal bone, and then backwards to the pterion. The gyrus rectus, which is the most medial gyrus of the orbital surface, lies on the cribriform plate and on the jugum sphenoidale behind

that; the olfactory tract and bulb, placed obliquely on the lateral part of the gyrus rectus, lie on the jugum and on the cribriform plate at the edge of the orbital plate. The **cribriform plate** is at a lower level than the rest of the floor, and the holes in it are arranged in two irregular rows; the nerve-filaments—twenty or so—which constitute the olfactory nerve come up from the nose through these foramina and end in the olfactory bulb.

In the lateral part of the fossa, especially in front and at the side, there are narrow, branching *grooves for the anterior meningeal vessels* derived from the middle meningeal and ethmoidal vessels.

The **crista galli** is the upper anterior part of the perpendicular plate of the ethmoid projected upwards into the cranial cavity. It is highest and thickest in front, where it may contain either spongy bone or an air-cavity which opens directly into the nose or into the frontal sinus. From its anterior part two processes or *alæ* project forwards to articulate with the frontal bone and form the side-boundaries of the **foramen cæcum**, which is between the frontal bone and the crista galli.

The anterior end and anterior part of the convex border of the falx cerebri are attached to the sharp, sloping border of the crista galli and to the frontal crest. The anterior part of the superior sagittal sinus lies on the frontal crest in the convex border of the falx, and its commencement may be connected with the veins of the nose by a vein transmitted by the foramen cæcum.

The **nasal slit** is a short and narrow cleft—often difficult to find—situated between the anterior parts of the crista galli and cribriform plate; it leads down into the nasal cavity (Fig. 193).

The **anterior** and **posterior ethmoidal canals** are narrow tunnels that begin at foramina of the same name between the roof and medial wall of the orbit (where they have been seen already). From these foramina they run in a medial direction, between the labyrinth of the ethmoid and the medial part of the orbital plate of the frontal bone, to open into the cranial cavity; their openings are often hidden by overhanging lips of bone. The *posterior* canal transmits the posterior ethmoidal vessels and opens at the junction of the cribriform plate with the front of the sphenoid. The posterior ethmoidal nerve, also contained in the canal, does not reach its cranial end, being distributed to the mucous lining of the ethmoidal and sphenoidal sinuses. The *anterior* canal is larger and opens at the side of the cribriform plate about the middle. It transmits the anterior ethmoidal vessels and the anterior ethmoidal nerve, which is a continuation of the naso-ciliary nerve. The nerve runs forwards on the cribriform plate and descends to the nose through the **nasal slit** or through a foramen a little lateral to the slit, and it is accompanied by small branches of the vessels.

The **lesser wing of the sphenoid** is triangular in outline and compressed from above downwards. It lies in the roof of the orbit and superior orbital fissure and in the floor of the anterior cranial fossa; posteriorly, it overhangs the middle cranial fossa. It arises by two roots separated by the optic foramen: the *anterior root*—broad and flat—is continuous with the jugum sphenoidale; the *posterior root*—much smaller—springs from the side of the body of the sphenoid and stands between the optic foramen and superior orbital fissure. The spheno-parietal venous sinus lies in the dura mater on the lower surface of the posterior margin of the wing. The **anterior clinoid process** is a flattened projection with a rounded free end; it juts backwards from the postero-medial angle of the wing and gives attachment to the anterior end of the free margin of the tentorium cerebelli.

Middle Cranial Fossa

The **middle cranial fossa** is divided into a median part and a right and a left lateral part, and its floor resembles a bird with outspread wings.

Median Part of Middle Cranial Fossa

The median part is elevated above the level of the lateral parts. It is bounded *anteriorly* by the sphenoidal limbus, and *posteriorly* by an upstanding plate of bone called the dorsum sellæ. Its floor is the body of the sphenoid and is separated therefore from the cavity of the nose by the sphenoidal sinus enclosed within the bony shell of the body of the sphenoid (Fig. 164). The parts to be looked for are the optic groove and foramina, the sella turcica, and the carotid grooves.

The **optic groove** is in the most anterior part of the floor, immediately behind the anterior cranial fossa; it may be well-defined or very shallow. On each side the optic groove ends at the **optic foramen**, which opens into the medial side of the back of the orbit, where it has been seen already (pp. 158 and 160).

Sella turcica is the name given to the middle part of the upper surface of the body of the sphenoid, from a resemblance to a Turkish saddle. The pommel is the transverse, oval elevation, called the **tuberculum sellæ**, situated directly behind the optic groove. The seat is the wide, smooth depression behind the tuberculum; it is called the **hypophysial fossa** because the hypophysis cerebri (p. 822) lies in it.

Behind the hypophysial fossa there is an upstanding square plate of bone (broken off in many skulls) called the **dorsum sellæ** or back of the saddle. The upper corners of the dorsum sellæ form the **posterior clinoid processes.** The anterior and posterior clinoid processes get their name from a fancied resemblance to the four posts of a bed [κλίνη (cline) = a bed].

The **carotid groove** is a broad, shallow, ʃ-shaped groove on the upper part of the side of the body of the sphenoid. It begins at the medial side of the foramen lacerum, ascends for a short distance, then runs forwards on the side of the sphenoid body, and finally turns upwards to end medial to the anterior clinoid process. The internal carotid artery lies in it, and its sinuous bends indicate the course of the artery in the cranial cavity.

In many skulls there is a pair of **middle clinoid processes.** Each middle clinoid process, when present, is usually a small tubercle situated a little behind the lateral end of the tuberculum sellæ. In some skulls it is a large process and joins the anterior clinoid process, converting the termination of the carotid groove into a foramen called the **carotico-clinoid foramen** (Fig. 157). Occasionally it joins the posterior clinoid process instead, or it may branch and join both the anterior and the posterior clinoid process.

The **optic foramen** is a short, wide, nearly circular canal that passes in a lateral direction, forwards and slightly downwards from the cranial cavity into the orbit, and transmits the optic nerve and the ophthalmic artery. It is bounded by the body of the sphenoid and the two roots of the lesser wing—the thin bone of the body separating it from the sphenoidal sinus. The **optic groove** connects the two optic foramina. The optic chiasma, which connects the two optic nerves, does not, however, lie in the groove, but is situated a little distance above it.

The **hypophysial fossa** lodges the hypophysis and is roofed over by a fold of dura mater, called the diaphragma sellæ, which has a hole in the middle of it for the stalk that connects the hypophysis with the brain. The **posterior clinoid processes** give attachment to the anterior ends of the circumferential margin of the tentorium cerebelli. Low down on the side of the dorsum sellæ, where its root joins the body of the sphenoid, there is a narrow groove that accommodates the medial margin of the beginning of the inferior petrosal sinus; the groove is only the width of a thick pin, but can usually be seen even when the dorsum sellæ is broken off.

The cavernous venous sinus lies at the side of the body of the sphenoid on the horizontal part of the **carotid groove**; its centre is opposite a point on the upper border of the zygomatic arch directly above the tubercle of the root of the zygoma. The carotid artery, lying in the carotid groove, is embedded in the sinus, together with the carotid plexus, the oculomotor, trochlear, ophthalmic, and abducent nerves. The maxillary nerve runs forwards towards the foramen rotundum immediately below the carotid groove and cavernous sinus. These structures are therefore all related to the body of the sphenoid—the cavernous sinus, the carotid artery, and the maxillary nerve being closely related to it and to the sphenoidal sinus within it. The two cavernous sinuses are connected by intercavernous sinuses that cross the back of the **tuberculum sellæ**, the front of the **dorsum sellæ**, and the floor of the **hypophysial fossa.** The notch between the tuberculum sellæ and the anterior clinoid process is occupied by the carotid artery as it leaves the carotid groove.

Lateral Part of Middle Cranial Fossa

Each lateral division of the middle cranial fossa is a wide, deep hollow limited *anteriorly* by the lesser wing of the sphenoid, and *posteriorly* by the upper border of the petrous temporal; it sinks to the level of the zygomatic arch and lower surface of the body of the sphenoid; and it contains the temporal lobe of the brain. The principal parts on the exterior of the skull to which it is related are the orbit *in front,* the temporal fossa *laterally,* and the infratemporal fossa and the mandibular joint *below.*

The bones in its walls are :—(1) The petrous part of the temporal bone, *i.e.,* the pyramidal mass of bone that forms its posterior wall; (2) the squamous temporal, in front of the petrous, in the side-wall of the fossa and slightly in the floor; (3) the greater wing of the sphenoid, partly in the side-wall in front of the squamous temporal and partly in the anterior wall and in the floor in front of the petrous temporal. Beyond the limits of the fossa the lower part of the parietal bone lies in the side-wall of the cranial cavity above the squamous temporal, and its antero-inferior angle articulates with the top of the greater wing.

The *anterior lip* of the hollow is the posterior margin of the anterior fossa; it overhangs the hollow, and ends laterally, on the side-wall, **opposite the pterion.** The *posterior lip* is the upper margin of the petrous temporal; it is channelled

lengthwise by a groove—sometimes well defined, but sometimes poorly marked and interrupted—which lodges the superior petrosal venous sinus; close to its medial end there is a wide, very shallow notch, called the *trigeminal notch*, on which the trigeminal or fifth cranial nerve lies.

The noteworthy feature in the *anterior boundary* of the fossa is the large, oblique gap between the wings of the sphenoid, called the **superior orbital fissure**, which opens into the orbit, where it has been examined already (pp. 147, 149).

The points to be noted in the *floor* are the foramen rotundum, foramen ovale, foramen lacerum, foramen spinosum, and the grooves for the meningeal vessels.

The **foramen rotundum** is the round hole situated almost directly below the medial end of the superior orbital fissure; it leads horizontally forwards into the upper part of the pterygo-palatine fossa and transmits the maxillary nerve; if a pin is pushed forwards through the foramen, and the skull is looked at from the side, the point of the pin will be seen entering the pterygo-palatine fossa. The foramen is situated in the root of the greater wing close to the body of the sphenoid, and it is separated only by thin bone from the sphenoidal sinus.

The **foramen ovale** is almost half an inch behind the foramen rotundum, near the posterior border of the greater wing, and it transmits the mandibular nerve; it has been seen already in the roof of the infratemporal fossa (pp. 170, 171).

The **foramen spinosum**—behind and lateral to the foramen ovale and quite close to it—also has been seen from the infratemporal fossa; it transmits the middle meningeal vessels.

The **grooves for the middle meningeal vessels** are usually sufficiently distinct to enable one to trace the course of the main trunk of the artery and its branches on the walls of the cranial cavity; their whole course is seen in a skull split into halves without previous removal of the skull-cap (Fig. 164). The **main groove** begins at the foramen spinosum, runs forwards and in a lateral direction on the part of the squamous temporal that bears the articular eminence of the lower surface of the skull. It divides into an anterior and a posterior branch at a point that varies but is usually near the side of the skull opposite a point on the upper margin of the zygomatic arch about midway between the auditory meatus and the margin of the orbit. The **anterior groove** extends from that point to the anterior inferior angle of the parietal bone *opposite the pterion*; in that region the groove is usually very deep and often roofed over and converted into a tunnel for a short distance; becoming a groove again, it extends upwards and backwards, branching over the parietal bone, the chief branch of the groove taking a line towards the point on the top of the skull midway between nasion and inion. The **posterior groove** extends backwards and upwards across the squamous temporal on to the parietal bone, branching as it goes—the chief branch taking a line towards the lambda. The meningeal vessels, since they are so closely related to the bone, are liable to be torn when the skull is injured during life—especially the veins, for they lie between the arteries and the bone. The chief point of danger is at the pterion, where the anterior branch is lodged in a deep groove and may lie in a tunnel. The grooves are in the inner table of the skull-bones, and in an injury to the head the inner table may be cracked and the vessels torn, though the outer table is not broken.

The **foramen lacerum** is a large hole, with ragged margins, already seen on the lower surface of the skull. Seen in the floor of the cranial cavity, it is situated between the petrous temporal and the sphenoid. The carotid canal opens into it laterally, and the carotid artery crosses it to reach the carotid groove on the sphenoid. A spur of bone, called the **lingula**, projects obliquely backwards from the lateral margin of the carotid groove. In some skulls the lingula is a mere spicule of bone; in others it is long enough to reach the petrous temporal and form a complete lateral boundary for the foramen lacerum. In many skulls the roof of the carotid canal is deficient in bone, or has been partly broken away; in that case the jagged margins of the incomplete roof of the canal are continuous with the margins of the foramen lacerum. The posterior end of the **pterygoid canal** is on the anterior margin of the foramen lacerum almost directly below the lingula, but it is found more easily from the lower surface of the skull.

The *posterior wall* of the lateral part of the middle cranial fossa is the anterior face of the petrous temporal, and it is nearly triangular in outline. The parts to be specially looked for in it are the trigeminal impression, the arcuate eminence, the tegmen tympani, and the hiatus for the greater superficial petrosal nerve.

The **trigeminal impression** is a shallow depression—barely wide enough to accommodate a finger-tip—on the anterior surface of the petrous temporal near its apex or medial extremity, below the trigeminal notch. The trigeminal ganglion—the chief ganglion of the trigeminal nerve—lies in it.

The **arcuate eminence** is a smooth, rounded elevation on the anterior surface of the petrous temporal near its upper margin, a little lateral to a point midway between the apex of the petrous temporal and the side of the skull; sometimes it is diffuse and ill-defined. Underneath it, in the substance of the bone, there is one of the curved canals of the internal ear, called the *superior semicircular canal*, the convexity of whose curve produces the elevation.

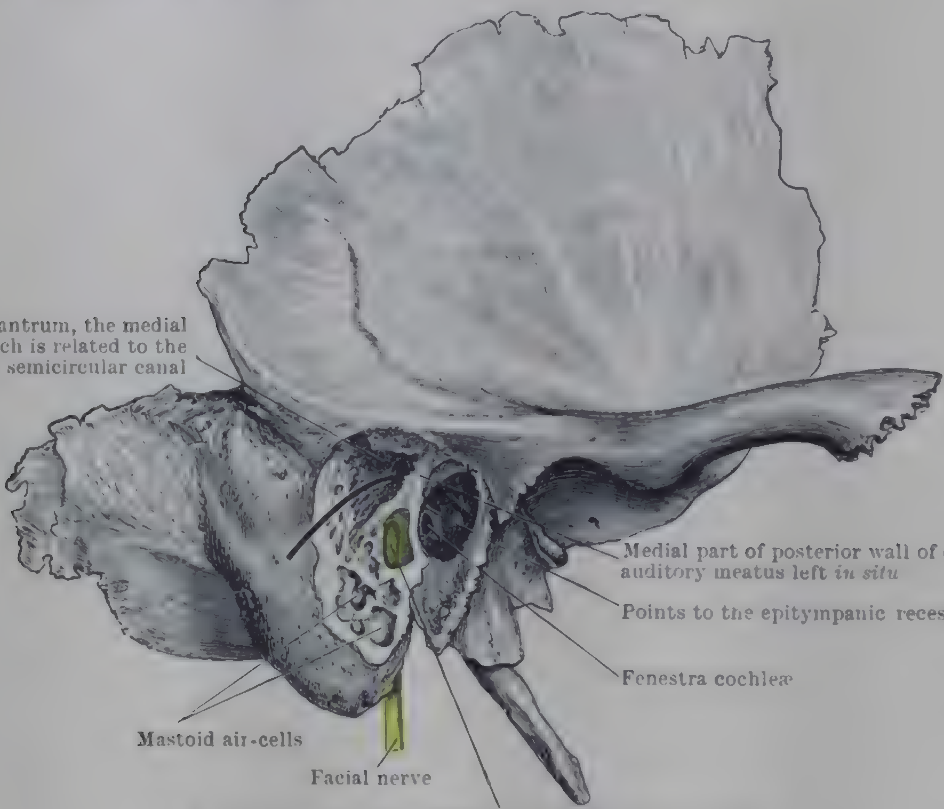


FIG. 158.—RIGHT TEMPORAL BONE PREPARED TO SHOW THE POSITION OF THE TYMPANIC ANTRUM.

The greater part of the posterior wall of the external auditory meatus has been removed, but a bridge of bone has been left at its medial end; under cover of this a bristle (thick black) passes from the tympanic antrum to the tympanic cavity through the posterior canaliculus of the chorda tympani.

The **hiatus for the greater superficial petrosal nerve** is a small slit seen lower down on the anterior surface, and about midway between the apex of the petrous temporal and the side of the skull. It communicates with the facial canal in the interior of the bone, and transmits a slender nerve from which it takes its name. This nerve arises in the substance of the temporal bone from the facial nerve; it emerges from the hiatus and lies in a groove that runs in a medial direction and downwards and forwards to the foramen lacerum.

The **tegmen tympani** is the fairly smooth area of bone that forms the lateral part of the anterior surface of the petrous temporal, and is so named because part of it forms the roof of the middle ear or tympanum (see also pp. 176, 223). It is made of thin bone; disease in the middle ear has therefore only a short way to travel to attack the membranes of the brain and the brain itself. The tegmen tympani is the roof not only of the tympanum but also of the canal for the tensor tympani and the tympanic antrum. The **tympanum** has been seen already at the far end of the external auditory meatus, and its position relative to the cranial cavity can

be gauged from its position as seen through the meatus. The **canal for the tensor tympani** was located when the lower surface of the skull was examined. The **tympanic antrum** is a small but very important cavity (see Fig. 158). It lies in the substance of the temporal bone behind the tympanum and communicates with it by a wide opening; it is about half an inch medial to the suprameatal triangle; it communicates posteriorly with the air-cells which pervade the mastoid portion of the temporal bone to a greater or lesser extent. The antrum is relatively large at birth; the mastoid cells grow as diverticula from the antrum—beginning at or shortly before birth, but not reaching full development till after puberty. If the student has a specimen of his own, he would be well advised to break through the tegmen tympani carefully and snip it away, in order to see the tympanic antrum and note its relation to the middle ear and to the exterior of the skull.

The *anterior lip* of the **lateral part of the middle cranial fossa** has a concave edge which begins medially at the anterior clinoid process and sweeps in a lateral direction and forwards and upwards to end at the side of the skull in the region of the pterion—the groove or tunnel for the anterior branch of the middle meningeal vessels being immediately behind its lateral extremity or even in it. The lip is formed chiefly by the lesser wing of the sphenoid, and is completed laterally by the frontal bone. It fits into the stem of the lateral sulcus of the cerebrum, *i.e.*, the cleft between the frontal and temporal lobes; the lateral end of the stem, where it breaks up into the rami of the sulcus, is therefore opposite the pterion.

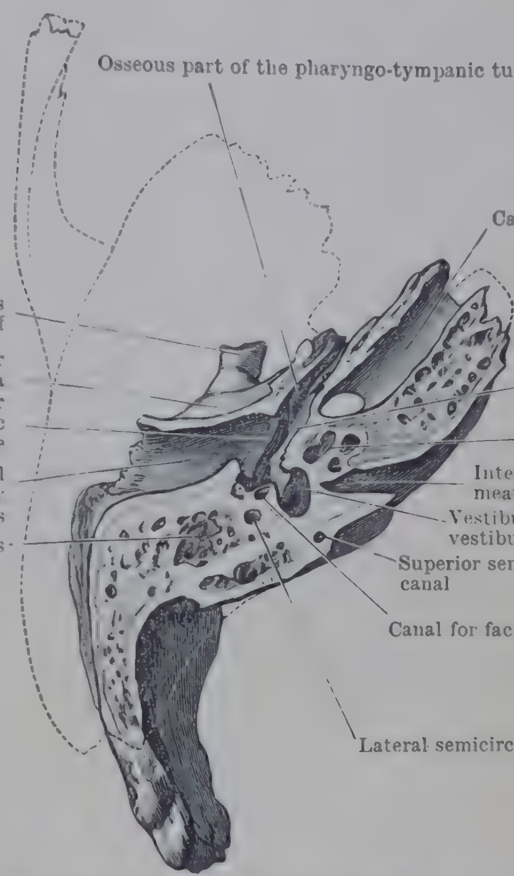


Fig. 159.—Horizontal Section through Left Temporal Bone (Lower Half of Section).

The lower margin of the temporal lobe, *i.e.*, the anterior part of the infero-lateral margin of the cerebrum, fits into the ill-defined groove that marks the junction of the side-wall of the fossa with the floor and posterior boundary; and it corresponds, on the exterior, to a line which begins near the anterior end of the upper border of the zygomatic arch, runs backwards along the upper border of the arch and the posterior root, and is continued backwards a short distance beyond the root to a point that corresponds, in the living head, to the place where the skin of the back of the root of the auricle joins the skin of the head.

The **foramen rotundum** was originally part of the superior orbital fissure, from which it was gradually cut off by the growth of bone. The **sphenoidal emissary foramen**—when present—is a little medial to the foramen ovale.

The **foramen lacerum** is a short, wide canal rather than a foramen; its lower end is on the lower surface of the skull and its upper end is in the floor of the middle cranial fossa. The carotid canal opens into its postero-lateral side near its upper end; and the carotid groove begins on the antero-medial boundary of the upper end. The **lower end** is bounded *postero-laterally* by the petrous temporal, *medially* by the basi-occipital and the body of the sphenoid, and *anteriorly* by the root of the greater wing and pterygoid process of the sphenoid. The **upper end** is bounded *postero-laterally* by the petrous temporal, *medially* and *anteriorly* by the floor of the carotid groove on the body of the sphenoid and the root of the greater wing; and the lingula—if long—completes the *lateral* boundary, which is defective if the lingula is short. The foramen *transmits* a meningeal branch of the ascending pharyngeal artery, some meningeal lymph-vessels, and small veins that connect the cavernous sinus with the pharyngeal venous plexus. It *contains* (1) some cartilage, (2) the internal carotid artery, surrounded by the internal carotid plexus of sympathetic nerves and by a plexus of tiny veins that connect the cavernous sinus and pharyngeal plexus, (3) the deep petrosal nerve, the termination of the greater superficial petrosal nerve, and the beginning of the nerve of the pterygoid canal. The cartilage fills the lower part of the foramen and is pierced by the structures transmitted. The internal carotid artery, after it

emerges from the carotid canal and as it bends up into the cranial cavity to enter the cavernous sinus, lies on the upper surface of the cartilage. While in the foramen the carotid nerve-plexus gives off the deep petrosal nerve. The greater superficial petrosal nerve (a branch of the facial) runs in a groove on the anterior surface of the petrous temporal from its hiatus to the foramen lacerum and joins the deep nerve to form the nerve of the pterygoid canal, which traverses that canal and joins the spheno-palatine ganglion.

The **pterygoid canal** is a narrow, horizontal tunnel, about half an inch long, which traverses the common root of the pterygoid process and greater wing of the sphenoid, and transmits the nerve of the pterygoid canal and an artery of the same name derived from the third part of the maxillary artery. The posterior end of the canal opens on the anterior margin of the foramen lacerum below the lingula and above the pterygoid tubercle. The anterior end opens on the posterior wall of the pterygo-palatine fossa below and medial to the foramen rotundum. The canal is in the floor of the sphenoidal sinus, and may raise a ridge in the floor.

The motor and sensory roots of the trigeminal nerve pass through the **trigeminal notch** and enter the **trigeminal impression** on the roof of the medial end of the carotid canal, where the sensory root joins the trigeminal ganglion; the ganglion also lies partly in the impression and partly overlaps the carotid artery in the foramen lacerum. Three large nerves spring from the ganglion—(1) the ophthalmic, which runs forwards towards the superior orbital fissure but divides into branches before it gets there; (2) the maxillary, which runs forwards to the foramen rotundum; and (3) the mandibular, which descends to the foramen ovale. The motor root runs under cover of the ganglion and is incorporated in the mandibular nerve at the foramen ovale.

The **hiatus for the greater superficial petrosal nerve** transmits that nerve and the petrosal branch of the middle meningeal artery. The nerve runs in a groove medially and forwards, and has to pass under cover of the trigeminal ganglion or the mandibular nerve as it approaches the foramen lacerum.

Below the hiatus there is a small aperture through which the lesser superficial petrosal nerve issues from the substance of the temporal bone; continuous with the aperture there is a narrow groove which runs medially, forwards and downwards (on the roof of the canal for the tensor tympani) to the suture between the petrous temporal and the greater wing of the sphenoid. The aperture and the groove are often very difficult to identify. The nerve lies in the groove and leaves the skull either through that suture or through the foramen ovale or through a minute, unnamed hole which, when present, is behind the foramen ovale.

Occasionally the remains of the original suture between petrous and squamous temporal can be seen in the adult near the side-wall of the skull.

The following parts—which have been briefly defined in this section—are described fully in the Section on The ORGANS OF THE SENSES: The **tympanum**; the **internal ear**, which lies in the substance of the petrous temporal medial to the tympanum; the **canals for the tensor tympani and bony part of pharyngo-tympanic tube**, which open out of the anterior part of the tympanum; the **tympanic antrum**, behind the tympanum; and the **mastoid air-cells**, which communicate with the antrum.

Posterior Cranial Fossa

The **posterior cranial fossa** is in the part of the skull that is placed above the vertebral column and the muscles of the back of the neck. It is the largest and deepest of the cranial fossæ, and lodges the hind-brain, *i.e.*, cerebellum, pons and medulla oblongata.

The **bones** in its walls are: (1) the posterior part of the body of the **sphenoid**, including the *dorsum sellæ*; (2) the posterior surface of the **petrous temporal**; (3) the inner surface of the **mastoid temporal**, in the side-wall behind the petrous temporal; (4) the posterior inferior angle of the **parietal bone**, above the mastoid temporal; (5) the whole of the **occipital bone**, except the part above the external occipital protuberance and superior nuchal lines. The **basilar part** of the occipital bone is in the anterior wall of the fossa, above and in front of the foramen magnum, which occupies the lowest part of the floor. The **condylar part** (including the jugular process) is in the floor, at the side of the foramen magnum. The lower, larger portion of the **squamous part** is in the floor, in the side-wall, and in the posterior wall, being behind the foramen magnum, behind the condylar part and behind the mastoid temporal and inferior angle of the parietal bone. In an adult over 25 years the basilar part is fused with the body of the sphenoid, the line of fusion being barely half an inch below the root of the dorsum sellæ.

The bones in the **rim** of the fossa are: (1) the **dorsum sellæ**, in the middle in front; (2) in the middle posteriorly, a prominent elevation, called the **internal occipital protuberance**, which is nearly opposite the external protuberance; (3) the **upper margin of the petrous temporal**, on each side in front; (4) on each side, posteriorly a broad, shallow, horizontal groove, the **transverse sulcus**, begins at the side of the

internal occipital protuberance and passes forwards to the base or lateral end of the petrous temporal; at that point the groove leaves the rim to become continuous with a deeper groove, called the sigmoid sulcus, which extends sinuously to the jugular foramen. A large venous sinus, called the transverse sinus, lies in the transverse groove, and the sigmoid prolongation of that sinus lies in the sigmoid groove.

A wide fold of the inner layer of the dura mater, shaped like a tent and called the **tentorium cerebelli**, roofs over the posterior cranial fossa and keeps the weight of the hinder part of the cerebrum off the cerebellum. The circumferential or basal margin of the tentorium is attached to the lips of the transverse groove and the lips of the groove for the superior petrosal sinus on the upper margin of the petrous temporal.

The fossa is divisible into a median part and a right and a left lateral part.

Median Part of Posterior Cranial Fossa

The parts to be noted in the median division are the foramen magnum, the anterior condylar canal, the jugular tubercle, the clivus, the groove for the inferior petrosal sinus, and the internal occipital crest.

The **foramen magnum** is in the lowest part of the fossa. The medial surface of the occipital condyle can be seen at the anterior part of the margin on each side, and in many skulls the condyles encroach upon the foramen and reduce the width of its anterior part. (See also p. 172.)

The internal opening of the **anterior condylar canal** is a little above the margin of the foramen magnum where it is formed by the condyle. The opening is rather hidden unless the skull is tilted; and it is often double on one or both sides. The external opening has been seen already on the lower surface of the skull (p. 173).

The **jugular tubercle** is the smooth, rounded elevation situated above and in front of the internal opening of the anterior condylar canal.

The **clivus** is the broad, sloping surface between the anterior margin of the foramen magnum and the root of the dorsum sellæ; it is formed by the upper surfaces of the basilar part of the occipital bone and of the posterior part of the body of the sphenoid; it is related to the pons and medulla oblongata of the brain. [*Clivus*=a slope.]

The **groove for the inferior petrosal sinus** lies along the suture between the basilar part of the occipital bone and the petrous temporal and is shared by both bones.

The **internal occipital crest** is the strong, median ridge between the foramen magnum and the internal occipital protuberance.

The hypoglossal nerve pierces the dura mater as two bundles which unite in the **anterior condylar canal**. When the opening of the canal is double, the two bundles may enter the canal separate or they may both enter through one of the openings, while the other transmits a meningeal artery.

The **jugular tubercle** is at the medial side of the anterior part of the jugular foramen and overlies the anterior condylar canal; immediately behind and lateral to the tubercle there is a short, shallow groove in which the ninth, tenth, and eleventh cranial nerves lie as they pass towards the jugular foramen.

The **clivus** is concave from side to side. Its upper part is related to the pons and the basilar artery, its lower part to the medulla oblongata and the vertebral arteries, and, near the foramen magnum, it is roughened by the attachments of the membrana tectoria and the upper band of the cruciate ligament. Between the two layers of the dura mater that cover the clivus there is a network of venous channels, called the plexus of basilar sinuses, which connect the right inferior petrosal sinus with the left. The abducent nerve, on each side, pierces the inner layer of the dura mater near the lateral margin of the clivus about half an inch below the dorsum sellæ, runs upwards on the clivus between the two layers of the dura mater, and crosses the inferior petrosal sinus to reach the apex of the petrous temporal; at that point, it crosses the petro-sphenoid joint below a slender fibrous band that is sometimes ossified; it then curves round the internal carotid artery to enter the cavernous sinus.

The **groove for the inferior petrosal sinus** begins at the apex of the petrous temporal, *i.e.*, at the medial end of its upper border, where the sinus is connected with the posterior end of the cavernous sinus; it runs obliquely downwards, backwards, and in a lateral direction, along the petro-occipital suture, to the jugular foramen, where the sinus, descending through the antero-medial part of the foramen, joins the commencement of the internal jugular vein.

The **internal occipital crest** gives attachment to a small fold of the inner layer of dura mater, the falx cerebelli, which intervenes between the two hemispheres of the cerebellum. A small venous sinus, called the occipital sinus, lies along the edge of the crest between the two layers of

the falx; sometimes the sinus is paired. The lower part of the crest sometimes divides to enclose a small depression related to the vermis of the cerebellum.

The tentorium cerebelli, the falx cerebri, and the falx cerebelli are attached to the **internal occipital protuberance**; in its immediate neighbourhood the superior sagittal sinus and the straight sinus end, and the transverse sinuses and the occipital sinus begin; the posterior end of the cerebrum is immediately above and lateral to it. The internal occipital protuberance is seldom directly opposite the external protuberance (it is usually a little higher), but there is so little difference in their levels that the external protuberance is usually taken as the surface guide to the position of structures near the internal protuberance. Owing to the two protuberances, that region of the occipital bone is one of the thickest parts of the skull.

Lateral Part of Posterior Cranial Fossa

The chief parts to be noted in this division are the cerebellar fossa, the transverse and sigmoid grooves, the jugular foramen, the posterior condylar canal, the mastoid foramen, and the internal auditory meatus. Points of less importance are the grooves for the meningeal arteries, the opening of the aqueduct of the vestibule, the subarcuate fossa, the notch for the glosso-pharyngeal nerve, and the external opening of the cochlear canaliculus.

The **cerebellar fossa** is the wide concavity between the transverse groove and the foramen magnum. Faint grooves made by meningeal vessels are seen in its floor.

The **transverse groove** begins at the side of the internal occipital protuberance and sweeps round the cranial wall to the lateral end of the upper margin of the petrous temporal, where it joins the sigmoid groove.

The **sigmoid groove** curves downwards and descends along the side-wall of the skull to the floor, extends in a medial direction on the floor for an inch, and, finally, curves forwards to end at the jugular foramen. Its curves resemble those of the letter S; hence the name "sigmoid" [*sigma* is the Greek name for the letter S].

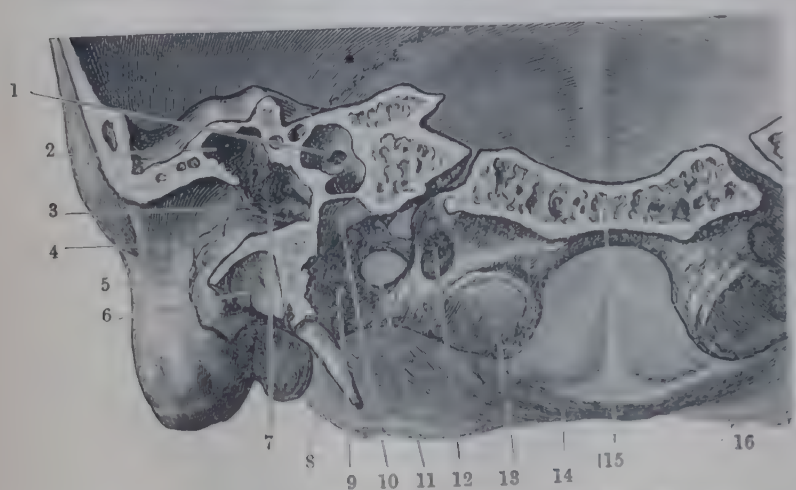


Fig. 160.—Vertical Section through Base of Skull immediately in Front of Root of Styloid Process.

1. Cochlea.
2. Entrance to the antrum.
3. Tympanic sulcus.
4. Tympanic plate.
5. Tympano-mastoid fissure.
6. Tympanic plate.
7. Tympanic cavity (floor).
8. Styloid process.
9. Jugular fossa.
10. Lower end of carotid canal.
11. Jugular foramen.
12. Anterior condylar canal.
13. Occipital condyle.
14. Foramen magnum.
15. Basi-occipital.
16. Squama of occipital bone.

The position of the two grooves corresponds, on the exterior of the skull, to a line (1) which begins at the side of the external occipital protuberance and is drawn almost horizontally, but with a slight upward convexity, to a point a little behind the place where the posterior root of the zygoma joins the supramastoid crest, and that point, on the living head, is where the skin of the upper part of the back of the root of the auricle joins the skin of the head; (2) from that point the line is drawn almost vertically downwards to a point about a finger's breadth behind the lower margin of the external auditory meatus; (3) from there, forwards to the lower border of the meatus. The first or horizontal part of the line is opposite the transverse sinus and the attachment of the tentorium; the posterior part of the infero-lateral border of the cerebrum is above it; the margin of the cerebellum is below it. The second and third parts of the line correspond to the sigmoid sinus—which is the continuation of the transverse sinus.

The sigmoid groove is deeper than the transverse groove; in some skulls its upper part is so deep (at the expense of the petrous temporal) that it is quite close to the tympanic antrum, and the sigmoid sinus would be in considerable danger during an operation on the antrum.

The **mastoid foramen** is an aperture of variable size that leads from the exterior of the skull into the sigmoid groove on the side-wall of the posterior fossa. The **posterior condylar canal**, when present, passes from the condylar fossa into the posterior cranial fossa and opens into or near the sigmoid groove on the floor of the fossa.

The posterior part of each transverse groove is situated on a thick, blunt ridge that extends in a lateral direction from the internal occipital protuberance for some distance. Above that ridge, on the posterior wall of the cranial cavity, there is a wide, well-marked depression, called the *posterior cerebral fossa*, which lodges the posterior end of the occipital lobe of the cerebrum. The right cerebral fossa is separated from the left by a thick vertical ridge which descends to the internal occipital protuberance. Along that ridge the sagittal groove, seen already on the vault of the skull, runs down to the protuberance and becomes continuous with one or other of the transverse grooves, usually the right; occasionally it splits and becomes continuous with both transverse grooves.

The **transverse groove** begins at the internal occipital protuberance, passes across the occipital squama to its lateral angle, and then crosses the posterior inferior angle of the parietal bone to reach the mastoid temporal, where it becomes the sigmoid groove. The **sigmoid groove** turns downwards, grooving the mastoid temporal and the petrous temporal, where it is separated by very thin bone from the mastoid air-cells and may be very close to the tympanic antrum; reaching the floor, it passes off the mastoid temporal on to the upper surface of the jugular process of the occipital bone, on which it passes first in a medial direction and then forwards to the jugular foramen.

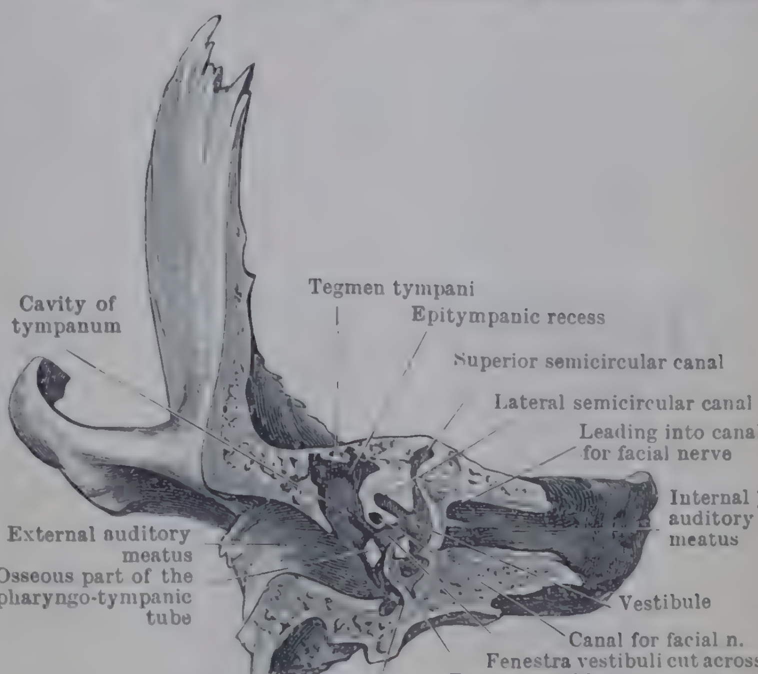


Fig. 161.—Vertical Transverse Section through Left Temporal Bone (Anterior Half of Section).

The right and left transverse grooves are seldom of equal size; the wider of the two is that which is joined by the sagittal groove, and it is usually the right; and the jugular foramen also is wider on that side than on the other.

The circumferential margin of the **tentorium cerebelli** is attached to the internal occipital protuberance, to the lips of the transverse groove, to the lips of the narrow, ill-marked groove along the upper margin of the petrous temporal, and then is prolonged medially to be attached to the posterior clinoid process. Along the transverse groove it encloses the transverse sinus; along the margin of the petrous temporal it encloses the superior petrosal sinus, which runs from the cavernous sinus to the transverse sinus; and at the trigeminal notch the trigeminal nerve crosses beneath the sinus and the margin of the tentorium. The internal margin of the tentorium, *i.e.*, the margins of the door of the tentorium, is continued forwards, on each side, across the attached, circumferential margin at the apex of the petrous temporal, to be fastened to the anterior clinoid process.

The **cerebellar fossa** is of variable depth, and is often unequal on the two sides. Its floor is thin and translucent, and may be the thinnest part of the cranial wall. The cerebral fossæ also are seldom symmetrical.

Faint, narrow grooves are seen here and there in the walls of the posterior cranial fossa for the posterior meningeal vessels, which are derived from the vertebral, the occipital, and the ascending pharyngeal arteries; and some twigs of the posterior branch of the middle meningeal artery may descend into the fossa.

The **jugular foramen** is a large aperture with irregular margins. It is in the anterior and medial part of the floor of the lateral division of the fossa, between the petrous temporal and the jugular process of the occipital bone. It leads downwards and slightly forwards to the lower surface of the skull, where it is opposite the lower margin of the external auditory meatus.

The **jugular foramen** transmits three sets of structures, and small spicules of bone projecting from its margins may partly or completely divide it into corresponding compartments. By

far the most important structures that pass through the foramen are the sigmoid sinus and the ninth, tenth and eleventh cranial nerves. The *antero-medial compartment* transmits the inferior petrosal sinus and a meningeal branch of the ascending pharyngeal artery. The *middle compartment* transmits the glosso-pharyngeal, vagus and accessory nerves—in that order from before backwards. The *postero-lateral compartment* is larger than the other two, and transmits the sigmoid sinus (as it becomes the internal jugular vein), a meningeal branch of the occipital artery, a meningeal branch of the vagus, and lymph-vessels from the meninges. (See also p. 175.)

The posterior surface of the petrous temporal is the anterior wall of the lateral part of the fossa; the only conspicuous aperture in it is an oblique opening which is the medial end of the **internal auditory meatus** (Fig. 164). The meatus is a short canal in the petrous temporal, nearly horizontal and nearly transverse; its lateral end is separated by thin bone from the internal ear. It is almost opposite the external meatus, and is about an inch and a half from the surface of the head (Fig. 161).

The **internal auditory meatus** is about 10 mm. long and 3 to 5 mm. wide. It transmits the motor and sensory roots of the facial nerve, the auditory nerve, the internal auditory branch of the basilar artery and the internal auditory vein, which joins the inferior petrosal sinus. The lateral end of the meatus is called the **fundus** or bottom. The part of the petrous temporal bone that forms the fundus separates the meatus from the vestibule and cochlea of the internal ear. In the fundus there are several apertures that transmit the auditory vessels and the facial and auditory nerves (Fig. 1020, p. 1195). If the skull has been split into halves so that one can see into the meatus, the fundus and the holes in it are visible at the far end. The position of the internal ear can be gauged by an examination of the meatuses. The fundus of the internal meatus is the medial wall of the internal ear. The lateral wall of the internal ear is the medial wall of the tympanum or middle ear; that wall can be seen through the external auditory meatus, and the bulge called the promontory seen there is produced by the basal curve of the cochlea, which is coiled like a snail-shell [κοχλίας (cochlias) = a snail, a spiral]. The arcuate eminence of the anterior surface of the petrous temporal also is a guide, for it overlies the superior semicircular canal, which stands up from the posterior part of the vestibule of the inner ear like the handle of a pail. The facial nerve passes through one of the holes in the fundus of the internal meatus and enters the facial canal to pass through the temporal bone, first in a lateral direction above the vestibule to the anterior part of the upper border of the medial wall of the tympanum, then backwards in the medial wall near its upper border, and finally downwards behind the tympanum. The canal ends as the stylo-mastoid foramen on the lower surface of the skull.

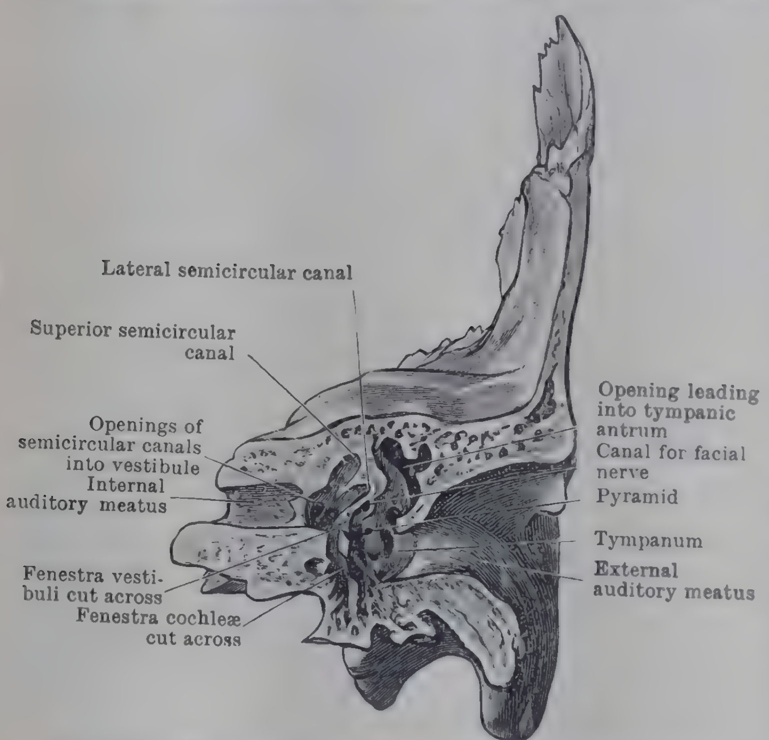


FIG. 162.—VERTICAL TRANSVERSE SECTION THROUGH LEFT TEMPORAL BONE (Posterior Half of Section).

A narrow canal about 8 mm. long, the **aqueduct of the vestibule**, passes backwards from the vestibule and opens on the posterior surface of the petrous temporal; this *external opening* is at the bottom of a small slit seen about half an inch lateral to the opening of the internal meatus; the slit is overhung by a thin lip of bone. The canal transmits a tiny artery and vein and a delicate membranous *endolymphatic duct*; this duct emerges from the external aperture and its blind, terminal portion dilates to form the *endolymphatic sac*, which lies under cover of the dura mater.

The **subarcuate fossa** is a small, ill-defined depression about midway between the opening of the meatus and the aperture of the aqueduct, but at a higher level than either of them. It is larger and better defined in the skull of a child than of an adult (Fig. 188, C, p. 224). Small vessels pass through its floor into the bone.

The **notch for the glosso-pharyngeal nerve** (Fig. 186) is a rounded notch on the anterior margin of the jugular foramen directly below the opening of the internal meatus: the ninth cranial nerve enters the jugular foramen through this notch, and the notch is cut off from the rest of the foramen by a fibrous band. This band is sometimes ossified, but more usually the margins of the notch are prolonged backwards as little spurs of bone that partially or completely divide

the jugular foramen into compartments. The notch is the upper end of a groove that runs downwards, forwards, and laterally from it, immediately in front of the jugular fossa. The groove lodges the ninth nerve; it is seen on the lower surface of the skull, for it ends at the ridge between the jugular foramen and the carotid canal.

At the bottom of the notch for the ninth nerve there is a small pit hidden under an overhanging lip of bone, although it may in some specimens be seen from the lower surface of the skull. At the bottom of the pit there is the **external opening of the cochlear canaliculus**—a narrow canal about 15 mm. long, which leads from the cochlea and conducts a small vein to the inferior petrosal sinus and a tubular prolongation from the dura mater to the cochlea.

CAVITY OF NOSE

The term **Nose** includes the **external nose**, which juts from the face, and also the **cavity of the nose**, of which merely a small part lies in the external nose.

The **cavity of the nose** extends from the posterior bony apertures on the base of the skull to the anterior bony aperture on the front—or to the nostrils when the soft parts are in place. It is above the cavity of the mouth, being separated therefrom by the hard palate; and it lies below the anterior and middle cranial fossæ and the frontal and sphenoidal air-sinuses. In round numbers its length increases from 50 mm. at the floor to 75 mm. at the roof; its greatest height, about its middle, is 50 mm., and it diminishes to 30 mm. at the anterior aperture and 25 mm. at the posterior apertures.

It is divided into **right** and **left halves** by a median partition or **septum**, and the term "cavity of nose" or "nasal cavity" is applied sometimes to the whole cavity and sometimes to one or other of the halves—according to the context. Each of the two cavities is narrow from side to side. The widest part, near the floor, measures only about 10 mm., while near the roof, except in its posterior section, it is only 1 or 2 mm.

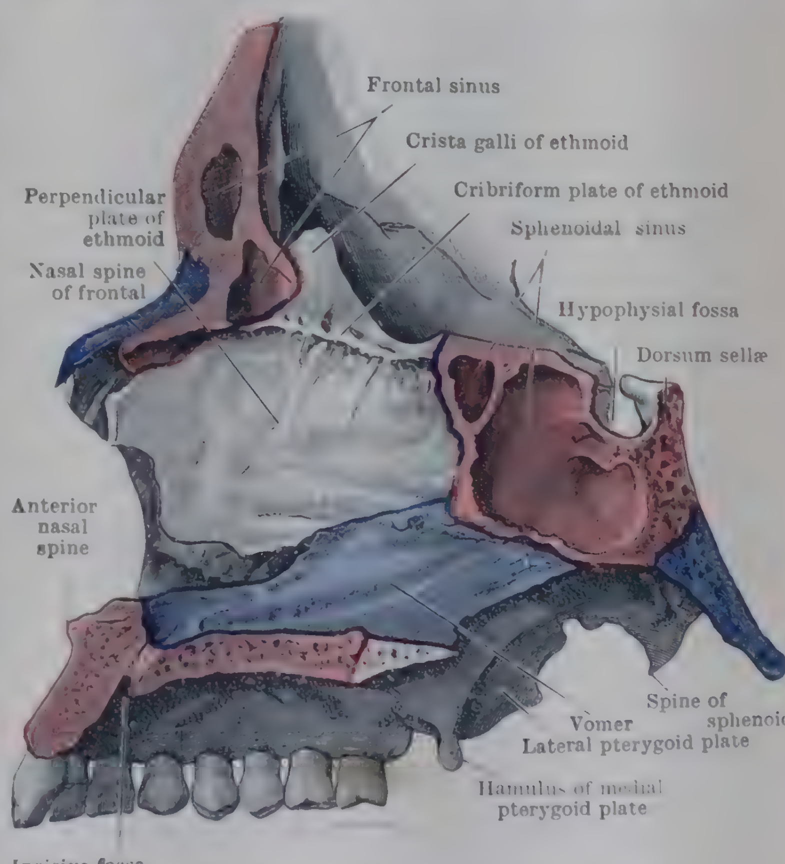


Fig. 163.—Roof, Floor, and Septum of Nose.

Red : Parts of frontal, sphenoid and maxilla.
Blue : Vomer ; basi-occiput ; part of nasal.
White : Perpendicular plate of ethmoid ; horizontal plate of palatine.

Boundaries.— Each of the two nasal cavities has a *roof*, a *floor*, a *lateral* wall, and a *medial* wall — the medial wall being the septum between the cavities.

The **roof** is very narrow from side to side except at its posterior end. It is horizontal in the middle, but slopes downwards in front and behind, and the anterior and posterior parts of the cavity are therefore of lesser vertical depth than the middle part. The **middle** part is the cribriform plate of the ethmoid. The **anterior** sloping part is formed by a small part of the frontal bone and by the nasal bone below that; and, still lower down, when the soft parts are in place, by the cartilages of the nose. The **posterior** sloping part—a very steep slope—is formed by the anterior and inferior surfaces of the body of the sphenoid.

The **roof of each nasal cavity**, in nearly the whole of its length, is only 1 or 2 mm. in width, but its most posterior part, which is formed by the lower surface of the body of the sphenoid, measures about 10 mm. across; in a dried skull, that is also the lowest part of the roof—being on a level with the zygomatic arch at the side of the skull. Though the anterior part of the lower surface of the body of the sphenoid is reckoned as part of the roof, yet the ala of the vomer and the sphenoidal process of the palatine bone, which are closely applied to it, shut it off from the nasal cavity and are the actual bones clothed with the muco-periosteum of the posterior part of the roof. The **palatino-vaginal canal** (p. 170) is situated in that part of the roof, between the sphenoidal process and the body of the sphenoid.

The part of the roof formed by the anterior surface of the body of the sphenoid looks forwards rather than downwards, and diminishes to 2 mm. in width as it is traced upwards and forwards, for the greater part of each half of the front of the body of the sphenoid articulates with the labyrinth of the ethmoid, leaving the smaller part alongside the median plane free to form a boundary for the nasal cavity. In that area there is a round opening of considerable size which leads back into the *sphenoidal sinus.*

The anterior surface and anterior part of the lower surface of each half of the body of the sphenoid is made of bone which in early life is separate and is called the *sphenoidal concha.*

The part of the nasal cavity which is highest, and also nearest the cranial cavity, is the middle part; it is roofed by the cribriform plate, which is at the level of the nasion and is perforated by the olfactory nerves; infection from the nose has, at that part, only a very short distance to travel to reach the brain and its membranes.

The nasal surface of the frontal bone is only a very narrow strip that appears in the roof of the nose in front of the cribriform plate; it separates the nasal cavity from the frontal sinus, and it slopes downwards and forwards to the nasal bone. Those two bones form the anterior sloping part of the roof; along that part of the roof the anterior ethmoidal nerve (with companion vessels) runs downwards and forwards to emerge between the nasal bone and cartilage, under the name of the external nasal nerve, for the supply of the skin of the lower half of the external nose; the nerve leaves a narrow groove on the surface of the bone on which it runs.

The **floor** is smooth, nearly horizontal from before backwards, and slightly concave from side to side. It is considerably wider than the roof—measuring 10-12 mm. across—and is slightly wider in the middle than at its ends. It is shorter than the roof, for the posterior apertures slope from above downwards and forwards, and the anterior aperture slopes downwards and backwards. Its posterior fourth or third is formed by the palatine bone, an L-shaped bone consisting mainly of a perpendicular plate which lies in the lateral wall of the nose and a horizontal plate which forms the posterior part of the bony palate. The palatine process of the maxilla forms the remainder of the floor of the nose. Near the front, close by the septum, is the opening of the incisive canal, which is covered over with mucous membrane before maceration. The **incisive canal** passes downwards through the bone and divides into two parts which open, as the lateral and median incisive foramina, into the incisive fossa on the bony palate.

The three chief constituents of the **septum** are: (1) the perpendicular plate of the ethmoid, situated above and behind; (2) the vomer, situated below and behind; (3) the septal cartilage of the nose, which, in a dried skull, is destroyed; it is situated anteriorly and fills in the wide, angular interval between the other two. The superficial area of the septum is usually too great for the height of the cavity, and it is therefore bent to one side near its middle, or it is bent first to one side and then to the other.

The **osseous septum** is composed almost entirely of the perpendicular plate of the ethmoid superiorly and the vomer below and posteriorly, but it is completed by the following small projections: (1) The *crest of the sphenoid*, which projects forwards from the median line of the front of the body of the sphenoid to articulate with the perpendicular plate. (2) The *nasal spine*, which projects from the nasal part of the frontal bone downwards and forwards between the perpendicular plate and the nasal crest. (3) A *nasal crest* is formed by the lips of the margins of the nasal bones that articulate with each other; that crest articulates, from above downwards, with the nasal spine of the frontal bone, the perpendicular plate, and the septal cartilage. (4) A *nasal crest*, to articulate with the lower edge of the vomer, is formed by sharp ridges that stand up from the horizontal part of the palatine bone and the palatine process of the maxilla where they articulate with their fellows of the other side. The anterior part of this crest stands up from the junction of the alveolar processes of the maxillæ; it is thicker and higher than the rest; and it articulates posteriorly with the vomer and superiorly with the subvomerine cartilage.

The upper part of the perpendicular plate of the ethmoid shows numerous small branching grooves that lodge olfactory nerves. Indistinct grooves for vessels may be seen on the vomer, and one long groove for the long spheno-palatine nerve and the spheno-palatine vessels, which

enter the nose through the spheno-palatine foramen in the lateral wall, cross the roof and run downwards and forwards, grooving the vomer, to reach the incisive canal.

The *cartilaginous septum* is formed almost wholly by the septal cartilage, which, however, is aided by (1) the subvomerine cartilage (*i.e.*, a small strip along its lower margin); and (2) the medial part of the right and left lower nasal cartilage, at the tip of the nose.

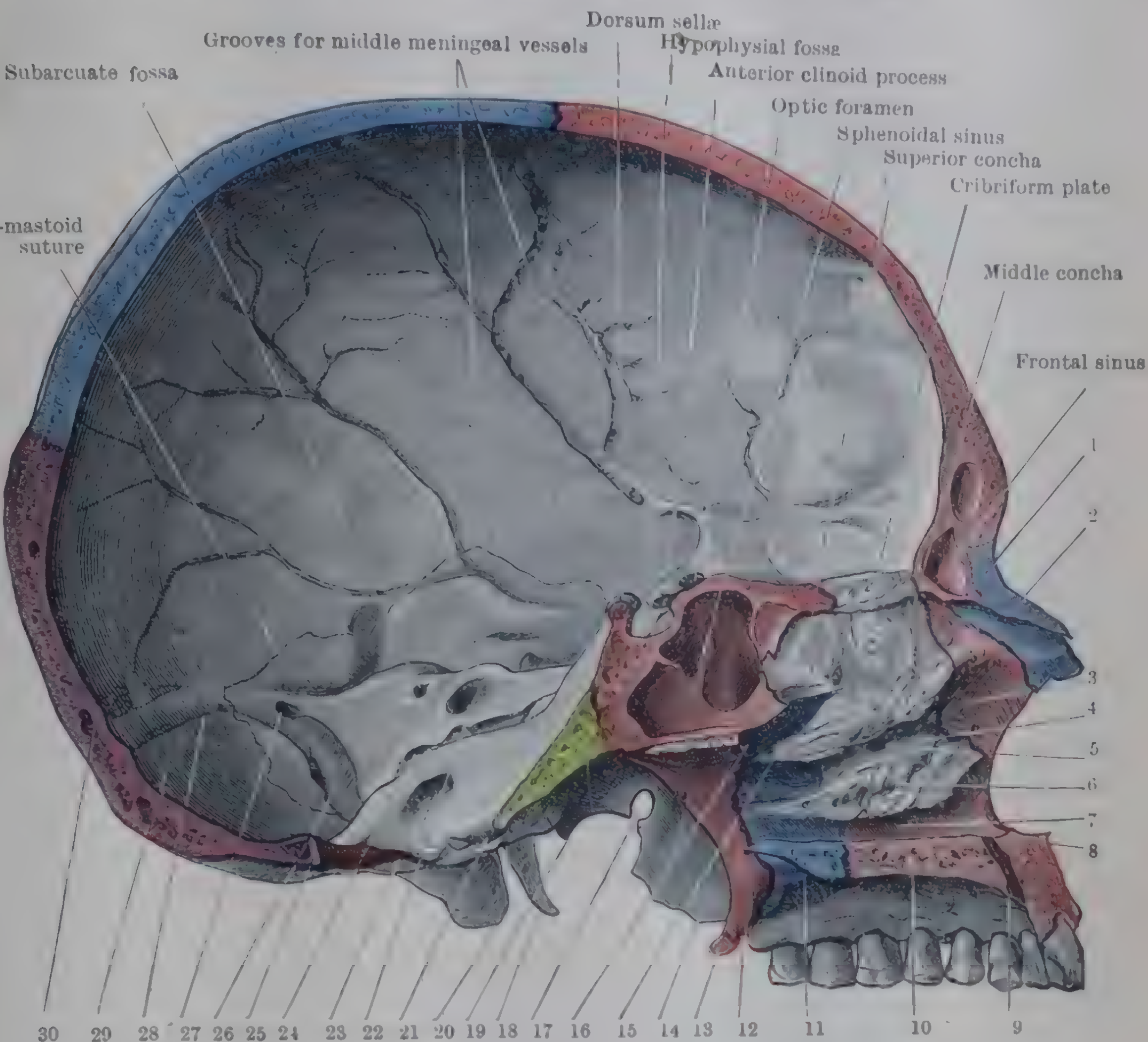


FIG. 164.—MEDIAL ASPECT OF LEFT HALF OF SKULL SAGITTALLY DIVIDED.

Red: parts of frontal, maxilla, and sphenoid. **Blue**: palatine; nasal; part of parietal.
Purple: part of occipital squama. **Yellow**: part of basi-occiput.
Uncoloured: left ala of vomer; inferior concha; ethmoid; and other bones.

1. Near nasal spine of frontal.
2. Nasal bone.
3. Frontal process of maxilla (and atrium).
4. Lower part of middle meatus.
5. Near opening of maxillary sinus.
6. Inferior concha.
7. Inferior meatus.
8. Anterior nasal spine.
9. Incisive fossa and canal.
10. Palatine process of maxilla.
11. Horizontal plate of palatine.
12. Posterior nasal spine.
13. Hamulus of medial pterygoid plate.
14. Lateral pterygoid plate.
15. Superior meatus.
16. Spheno-palatine foramen.
17. Foramen formed by ossified pterygo-spinous lig.
18. Styloid process.
19. Spine of sphenoid.
20. Mastoid process.
21. Basion.
22. Internal auditory meatus.
23. Anterior condylar canal.
24. Groove for inferior petrosal sinus.
25. Opisthion.
26. Sigmoid groove.
27. Opening of mastoid foramen.
28. Transverse groove.
29. Cerebellar fossa.
30. Internal occipital protuberance.

The **lateral wall** is very uneven and is composed of several bones, namely, the *nasal*, the *maxilla* and its *frontal process*, the *lacrimal*, the *labyrinth* of the ethmoid and its *conchæ*, the *inferior concha*, the perpendicular plate of the *palatine* and the *medial pterygoid plate* (Fig. 164; see also Fig. 1041, p. 1210).

Identify the conchæ first. The **inferior nasal concha** is the rough plate of bone that projects from the side-wall into the lower part of the nasal cavity for a little distance and then curves downwards; it is a separate bone, and if it has been broken away, the line along which it was attached is seen as an irregular, broken

ridge about half an inch above the floor of the nose. The **middle nasal concha** is attached about an inch above the inferior concha, which it resembles; it is not a separate bone, but projects from the ethmoid labyrinth a little way into the nasal cavity and then turns downwards. The **superior nasal concha** is the small ridge of bone situated a little above the posterior half of the middle concha and is also a projection from the labyrinth. If a pair of forceps is passed into the living nose and opened vertically, it must be kept close to the septum, else the upper leg will be intercepted by the conchæ.

The **nasal bone** lies in the anterior and upper part of the lateral wall, as well as in the roof. The **frontal process of the maxilla** lies immediately behind and below the nasal bone. Those two bones form also the bony skeleton of the external nose. The **lacrimal bone**, seen already in the orbit, lies behind the frontal process, but only its lower and anterior part appears in the nose.

The **medial pterygoid plate** is the most posterior bone in the lateral wall of the nose, and forms the lateral boundary of the posterior aperture.

The medial surface of the **body of the maxilla** is in the lower part of the side-wall of the nasal cavity, extending from the lower part of the anterior aperture backwards almost to the medial pterygoid plate. It is to a large extent concealed by other bones, among which there are two openings out of the maxillary sinus.

The **perpendicular plate of the palatine bone** lies in the posterior part of the lateral wall in front of the medial pterygoid plate. The horizontal plate is easily identified in the floor. The perpendicular plate lies directly above the lateral margin of the horizontal plate and extends upwards to the body of the sphenoid in the roof. It is wider, as well as longer, than the horizontal part. It separates the nasal cavity from the pterygo-palatine fossa and, behind that, it overlaps the medial pterygoid plate. Anteriorly, the greater part of it is applied to the posterior part of the medial surface of the maxilla, shutting off that part from the nasal cavity and helping to close in the opening of the maxillary sinus.

The lateral surface of the **labyrinth of the ethmoid** is the smooth plate seen already in the orbit behind the lacrimal bone. Its **medial surface** is very uneven and rough, and is now seen in the nose below the cribriform plate; it extends from the frontal process of the maxilla to the body of the sphenoid—forming the greater part of the upper half of the lateral wall of the nose. The superior and middle conchæ project from the medial surface of the labyrinth; and hidden under cover of the middle concha there is a rounded, bulging part of the labyrinth, called the **bulla ethmoidalis,** which can partly be seen when examined from the front [*bulla* = a bubble]. The bulla is bounded in front and below by a curved groove or slit called the **hiatus semilunaris.**

Meatuses of the Nose.—The lateral part of the cavity of the nose is divided into the *superior*, *middle*, and *inferior* meatuses, the *spheno-ethmoidal recess*, and the *atrium* of the middle meatus; and, when the soft parts are in place, the portion above the nostril is called the *vestibule* of the nose.

The **spheno-ethmoidal recess** is the small space above and behind the superior concha. The **superior meatus** is an oblique, cleft-like space in the posterior half of the labyrinth of the ethmoid; its slit-like orifice is below the superior concha and above the middle concha. The **middle meatus** is much larger than the superior; part of it is lateral to the middle concha and part of it is below—extending down to the inferior concha. The lower part is roomy; the part that lies under cover of the middle concha is greatly narrowed by the bulge of the bulla ethmoidalis. The **atrium** of the middle meatus is the wide region in front of the middle meatus [*atrium* = an entrance hall]. The **inferior meatus** is the space lateral to and below the inferior concha.

The **lateral wall** of the nasal cavity is more uneven and complicated than the other boundaries. It is also the most variable and most liable to injury in the dried skull, and the student may therefore have difficulty in applying any given description to the specimen he is using for study.

The groove made by the anterior ethmoidal nerve may be on the part of the **nasal bone** that lies in the lateral wall, rather than on the part in the roof.

The **frontal process of the maxilla** presents a wide area which forms the side-wall of the *atrium* of the middle meatus. At the lower boundary of that area, where the frontal process

joins the body of the maxilla, there is a horizontal ridge, called the *conchal crest*, which articulates with the anterior part of the inferior concha. At the upper boundary of the area there is a ridge called the *ethmoidal crest*. The anterior part of that ridge produces the elevation called the *agger nasi* in the unmacerated head. The posterior part articulates with the anterior end of the middle concha; the portion of the frontal process above that articulation is applied to the front of the labyrinth of the ethmoid and helps to close in the anterior ethmoidal sinuses.

The **lacrimal bone** also is applied to the labyrinth, forming a boundary to the anterior ethmoidal sinuses; but its antero-inferior portion appears in the side-wall of the nose, and its lowest part projects downwards and helps to close the opening of the maxillary sinus.

The **labyrinth of the ethmoid**, situated between the orbit and the nasal cavity, bulges into the nasal cavity and greatly reduces the width of its upper part. It is composed of exceedingly thin, fragile bone. The upper half of its medial side is a wide area which, though far from smooth, is relatively even; it shows narrow grooves which lodge the lateral group of olfactory nerves and lead up to the holes in the cribriform plate. Inferiorly, the posterior half of the area is bounded by the **superior concha**; the anterior half is continuous with the medial surface of the middle concha.

The **spheno-ethmoidal recess** is situated above and behind the posterior part of the superior concha, in front of the body of the sphenoid; and the sphenoidal sinus opens into it through a round hole.

The **middle concha** forms the roof and medial wall of the upper, narrow part of the middle meatus, and its medial surface is the lower and lesser part of the medial side of the labyrinth. It extends forwards to the frontal process of the maxilla and backwards to the perpendicular part of the palatine bone—its anterior end being at a considerably higher level than the posterior end. The lower border is convex from before backwards, its lowest point being about the level of the floor of the orbit; this border is thickened and curled in a lateral direction, so that the lateral surface of the concha is concave and the medial surface is convex.

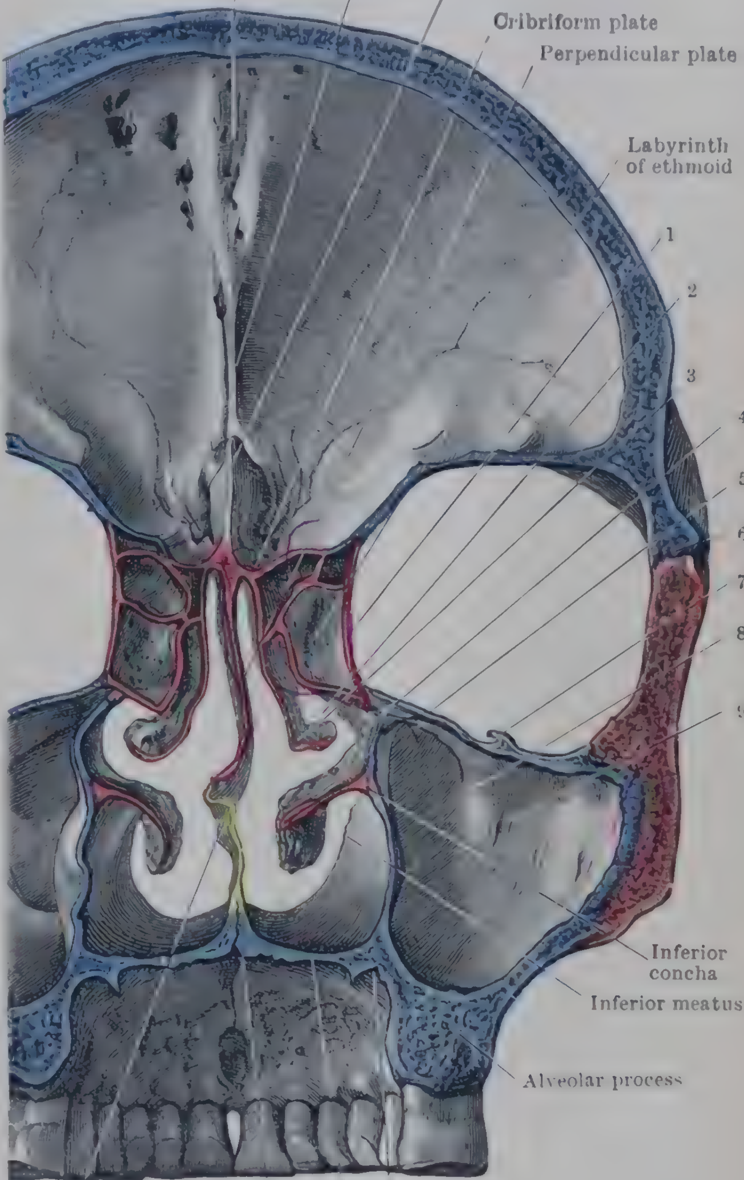


FIG. 165.—CORONAL SECTION PASSING INFERIORLY BETWEEN THE FIRST AND SECOND MOLAR TEETH.

Red: ethmoid; inferior concha; zygomatic.
Blue: frontal; maxilla. **Yellow**: vomer.

1. Orbital plate of ethmoid.
2. Middle meatus of nose.
3. Middle concha.
4. Opening of maxillary sinus.
5. Orbital surface of maxilla.
6. Zygomatico-frontal suture.
7. Infra-orbital groove.
8. Maxillary sinus.
9. Canal for the anterior dental nerve and vessels exposed.
10. Palatine process of maxilla.
11. Nasal crest of maxillæ.

The **superior meatus** is bounded inferiorly by the posterior half of the middle concha, and superiorly by the superior concha and the walls of posterior ethmoidal sinuses; these sinuses open into it by two or three orifices in the dried skull, but mucous membrane covers one or two of the openings during life. The **spheno-palatine foramen** also opens into it at its posterior part, but is covered over with mucous membrane before maceration.

The **bulla ethmoidalis** bulges from the lateral wall into the upper part of the middle meatus, and is therefore hidden under cover of the middle concha; it varies considerably in size, and it encloses some of the middle ethmoidal sinuses.

From the labyrinth, in front of the bulla, there springs a long, thin **uncinate process**; this process curves downwards and backwards (Fig. 195), first in front of the bulla and then below it, and has a considerable share in covering the opening of the maxillary sinus.

The curved interval between the bulla and the uncinate process is the **hiatus semilunaris**; as

the mucous lining passes from the bulla to the process, it dips into the hiatus to form a floor for it and convert it into a gutter-like groove. In some skulls, however, the uncinate process is closely applied to the bulla, and the hiatus is then a gutter-like groove on the process, the margins of which are curled to form the margins of the groove. The **infundibulum** [= a funnel], which leads downwards through the anterior part of the ethmoid labyrinth from the frontal sinus, opens into the hiatus.

The **middle meatus** extends from the attached margin of the middle concha down to the inferior concha, and is therefore of considerable height. The middle concha constitutes a medial wall for the upper, narrow part of the meatus; this part is at the level of the orbit, and is separated from the orbit by the lower part of the labyrinth, including the bulla. The lower, wide part of the meatus is open medially. It is situated below the labyrinth, opposite the upper part of the maxillary sinus, from which it is separated by the bones that close the opening of the sinus.

The *sinuses* that lead into the meatus open into its upper part. The *middle ethmoidal* sinuses open into it on the surface of the bulla; the *maxillary* sinus opens into the lower part of the hiatus semilunaris; the infundibulum, leading from the *frontal* sinus, opens into the upper part of the hiatus; the *anterior ethmoidal* sinuses also open into the upper part of the hiatus and into the infundibulum. In the dried skull there are one or more additional openings out of the maxillary sinus into the lower part of the meatus, but they are closed with mucous membrane when the soft parts are in place.

The **perpendicular plate of the palatine bone** is a very thin plate of bone situated in the posterior part of the side-wall of the nose. Its posterior edge articulates with the medial pterygoid plate and often overlaps it. Anteriorly, it is applied to the medial surface of the maxilla and takes a considerable share in closing the opening of the maxillary sinus. Between the upper parts of the maxilla and pterygoid process, it forms the medial wall of the pterygo-palatine fossa, from which the **greater palatine canal** descends to the bony palate; the canal is situated in the side-wall of the nose between the palatine bone and the maxilla. Two processes project upwards from the upper end of the palatine bone, namely, the sphenoidal and orbital processes; they are separated by the spheno-palatine notch, which is converted by the body of the sphenoid into the **spheno-palatine foramen**. The *sphenoidal process* inclines medially to form part of the roof of the nose. The *orbital process* is wedged in between the body of the sphenoid, the labyrinth of the ethmoid, and the body of the maxilla, and forms the posterior corner of the floor of the orbit; it often contains a cavity, called the *palatine sinus*, which opens into the sphenoidal sinus or into a posterior ethmoidal sinus. At the root of the orbital process, a ridge called the *ethmoidal crest* articulates with the posterior end of the middle concha; about 10 mm. from the lower end of the palatine bone, a ridge called the *conchal crest* articulates with the posterior end of the inferior concha.

The **inferior concha** extends between the conchal crests of the palatine bone and the maxilla, and its anterior attachment is the higher. It reaches a little farther forward and a little farther back than the middle concha does. Its lower border is slightly thickened, curled laterally, convex from before backwards, and is only a little distance above the level of the lower margin of the anterior bony aperture of the nose. The inferior concha passes across the lower part of the opening of the maxillary sinus and sends off processes which assist in closing the opening.

The **inferior meatus** extends from the attached margin of the inferior concha to the bony palate; the medial surface of the lower part of the maxilla is its lateral wall; and the concha provides it with a roof and a partial medial boundary. It is related laterally to the maxillary sinus and inferiorly to the mouth. The **naso-lacrimal canal** opens into it under cover of the anterior part of the inferior concha.

The junction of the middle meatus and its atrium is opposite the fossa for the lacrimal sac in the orbit, and the mucous lining of the nose is separated from the sac by the lacrimal bone and the frontal process of the maxilla. The **naso-lacrimal canal** is situated in the side-wall of the nose between the nasal cavity and the maxillary sinus. It is 10 or 12 mm. in length, and it is bounded laterally and antero-medially by the walls of a deep groove in the maxilla, while postero-medially it is bounded by the lower part of the lacrimal bone and the inferior concha.

The apertures which lead into or out of the nose are the following :—

The *posterior bony aperture*; the *anterior bony aperture*, or, when soft parts are present, the *nostril*; the *naso-lacrimal canal*; and the *openings of the sinuses*, namely, sphenoidal, ethmoidal, frontal, and maxillary. The **sphenoidal sinus** opens into the spheno-ethmoidal recess; the **posterior ethmoidal sinuses** open into the superior meatus; the **middle** and **anterior ethmoidal sinuses**, the **frontal sinus** *via* the infundibulum, and the **maxillary sinus** open into the middle meatus. The *naso-lacrimal canal* opens into the inferior meatus.

Besides the foregoing there are certain apertures in the dried skull which are covered over with mucous membrane before maceration, viz.: The *spheno-palatine foramen* opens out of the pterygo-palatine fossa into the posterior part of the superior meatus; there is an additional opening out of the maxillary sinus into the middle meatus; the *incisive canal* leads down from the anterior part of the floor of the nose into the incisive fossa; and the *foramina in the cribriform plate* in the roof

transmit the olfactory nerves from the nose to the median part of the anterior cranial fossa.

General Relations of the Nose (Fig. 165).—**Superior,** from before backwards: the frontal sinus; the anterior or ethmoidal part of the median division of the anterior cranial fossa; the sphenoidal sinus, separating the nose from the posterior part of that fossa and from the median division of the middle cranial fossa. **Inferior**: the mouth. **Posterior**: the nasal part of the pharynx. **Lateral**: the pterygoid fossa, the pterygo-palatine fossa, and the greater palatine canal opposite the posterior section of the cavity; farther forward, the ethmoidal sinuses, the infundibulum, and the orbit, opposite the upper half of the middle section of the cavity, while opposite the lower half there are the maxillary sinus and the naso-lacrimal canal; the anterior section is situated in the external nose and is related laterally to the exterior.

PARANASAL SINUSES

The **paranasal air-sinuses** (Figs. 165, 166) are cavities in the interior of certain of the skull-bones, namely, the *frontal*, the *ethmoid*, the *sphenoid*, the *maxilla*, and the *palatine*. They all communicate either directly or indirectly with the cavity of the nose. The sphenoidal, ethmoidal, and maxillary communicate directly; the frontal and the palatine, indirectly. They are all lined with mucous membrane which is continuous, round the lips of the apertures of communication, with the mucous lining of the nose; and disease can readily spread from the nose to the sinuses. During a severe "cold in the head", the inflammation often extends from the nasal mucous lining to the mucous lining of sinuses, giving rise to frontal headaches (frontal sinus), pain in the cheek (maxillary sinus), pain between the eyes (ethmoidal sinuses), deep-seated pain at the back of the eyes (sphenoidal sinus). (See also p. 1213, where references to radiographs are given.)

The walls of the sinuses are composed of compact bone; for, in the ethmoid, spongy bone is not formed, and in the other pneumatic bones the sinuses take the place of the spongy substance and its marrow, which have been absorbed to make room for them. They are lined with endosteum, which is blended with the mucous lining; and the mucous lining, like that of the nose, is covered with ciliated epithelium.

At birth the ethmoidal and sphenoidal sinuses are present but are very small; the maxillary sinus is a mere groove; the frontal appears during childhood. They all enlarge gradually till puberty, and rapidly after puberty till they attain their full adult size; in old age they enlarge further, owing to the absorption of the diploë adjoining them.

The sinuses act as resonating chambers for the voice; and by means of them the bones containing them, without increase of weight, gain increase of bulk and the shape necessary for the formation of the walls of the cavities of the nose, mouth, and orbits. They are relatively larger in men than in women.

The **maxillary sinus** (Figs. 165, 166) is a large cavity that occupies the body of the maxilla. It is *lateral* to the lower half of the nasal cavity, *below* the orbit, *in front of* infratemporal fossa, and *above* the molar and premolar teeth—its deepest part being above the first molar and second premolar tooth. The opening out of it is on the medial side; in a separated maxilla the opening is very wide, but, when in position in the skull, is overlapped by adjoining bones and reduced to two small apertures, or perhaps three. When the mucous membrane is in place, only the uppermost of these apertures is left uncovered, to open out of the **uppermost** part of the sinus into the lower or posterior part of the hiatus semilunaris of the middle meatus.

The **maxillary sinus** is the largest of the sinuses; it is variable in size and may differ in the two sides of the same skull. Average measurements, in round numbers, are 35 mm. in height, 30 mm. in antero-posterior depth, and 25 mm. in width. In shape it resembles a pyramid laid on one side. The **apex** is situated in the zygomatic process of the maxilla. The **base** or **medial wall** separates it from the inferior meatus and the lower, wide part of the middle meatus, and is formed by the medial or nasal surface of the maxilla and the bones that almost completely

close the large opening in the upper part of that surface, namely, portions of the uncinate process of the ethmoid, the palatine, the lacrimal, and the inferior concha.

The secretions of the mucous lining of the sinus are swept towards the orifice in the medial wall by the cilia of the epithelial covering of the mucous membrane; in inflammatory conditions, when the quality of the secretion clogs the action of the cilia or the quantity is too great for them to cope with, the sinus fills up, since the orifice is at its uppermost part.

The **floor** of the sinus is the alveolar process of the maxilla, and is the thickest wall of the sinus, though the process is excavated by the sockets for the teeth. The teeth whose roots are in relation to the floor vary from the three molars as a minimum to the molars, premolars, and the canine as a maximum. The roots of the first two molars produce eminences in the floor, and, though usually covered with thin bone, they may perforate the floor. Incomplete septa springing from the intervals between teeth may partially divide the sinus into compartments. The floor is below the level of the floor of the nose; the lowest part is about

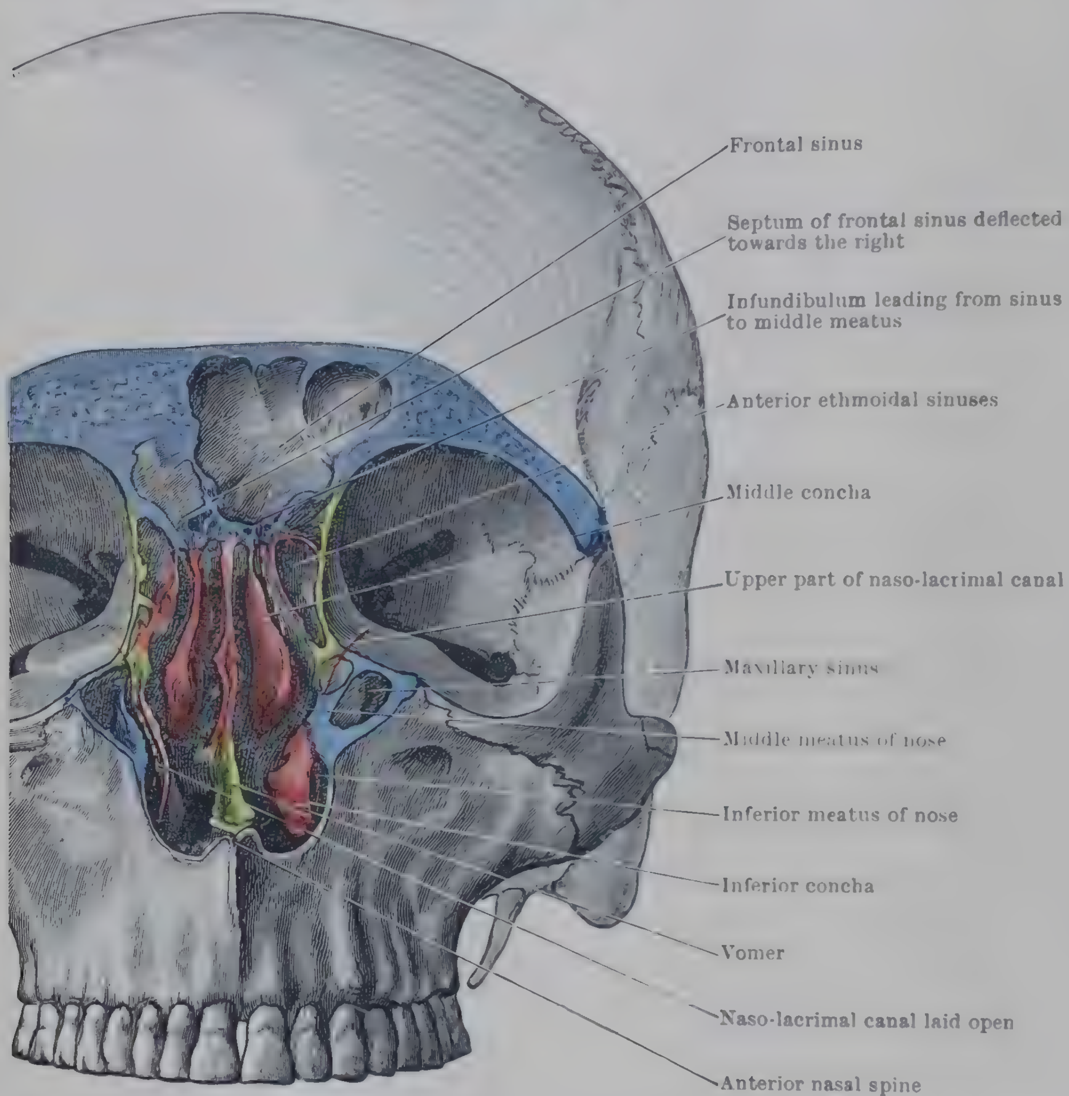


FIG. 166.—PART OF THE FRONTAL, NASAL, AND MAXILLARY BONES REMOVED IN ORDER TO DISPLAY THE RELATION OF THE VARIOUS CAVITIES EXPOSED.

Red: ethmoid; inferior concha. **Blue**: frontal and maxillary (where cut). **Yellow**: lacrimal; vomer.

10 mm. below the level of the nose, and overlies the roots of the first molar and second premolar teeth. The **posterior wall** is the bone of the posterior surface of the maxilla, which separates the sinus from the infratemporal and pterygo-palatine fossæ. The **posterior dental canals**, which convey the vessels and nerves to the molar and premolar teeth, are in the lower part of the posterior and **lateral** walls. The **roof** is the bone of the orbital surface of the maxilla, which separates the sinus from the orbit. The **infra-orbital groove and canal** are in the roof and may produce a ridge, especially at the angle between roof and anterior wall. The **anterior wall** is the bone of the anterior surface of the maxilla. The branches of the infra-orbital vessels and nerve to the canine and incisor teeth descend through canals in the anterior wall, but occasionally one or more of the canals may be defective; the corresponding vessels and nerve then lie between the bone and the mucous lining. The upper and anterior part of the sinus extends far enough forwards to be in front of the naso-lacrimal canal as well as lateral to it.

The maxillary sinus is the first sinus to appear; though, at birth, it is merely a groove on the medial side of the bone in the region of the middle meatus, yet that groove began to appear in the fourth month of intra-uterine life.

The **frontal sinus** is a cavity in the frontal bone; it is separated from its fellow by a complete bony septum which is usually bent to one or other side. It is immediately above the supra-orbital margin and above the root of the nose. If large, it extends backwards in the roof of the orbit between the two tables of the orbital plate. The frontal sinus may open directly into the nasal cavity through an opening in the nasal part of the frontal bone, but more commonly one of the anterior ethmoidal sinuses is converted into a passage, called the **infundibulum**, by means of which the sinus drains into the middle meatus, for the upper end of the infundibulum opens into the sinus and its lower end opens into the upper or anterior end of the hiatus semilunaris.

The **frontal sinus** varies greatly in size in different skulls, and may vary on the two sides of the same skull—the left usually being the larger. Average measurements are 30 mm. in height, 25 mm. in transverse width, and 20 mm. in antero-posterior depth. The configuration of the brow in the living person gives no indication of its size; in a well-formed skull one or both may be absent, or it may extend laterally as far as the temporal fossa and backwards in the roof of the orbit as far as the optic foramen. The septum between the right and left sinuses is usually median inferiorly and bent to one side above. The sinus is related *inferiorly* to the orbit, the nose, and the anterior ethmoidal cells; *postero-superiorly* to the cranial cavity and the brain.

An indication of the frontal sinus may be met with at the second year, but it cannot be definitely recognized till the seventh.

The **ethmoidal sinuses** are numerous small, thin-walled, intercommunicating cavities that occupy the labyrinth of the ethmoid. They are therefore between the orbit and the nasal cavity, and below the cranial cavity, from which they are separated by the medial part of the orbital plate of the frontal bone. They are divided into three groups—anterior, middle, and posterior. The **posterior sinuses** open into the superior meatus of the nose by one or more apertures. The **middle sinuses** open into the middle meatus on the surface of the bulla ethmoidalis by one or two apertures. The **anterior sinuses** open into the hiatus semilunaris of the middle meatus and into the infundibulum.

The walls of the **ethmoidal sinuses** are completed by the bones with which the ethmoid labyrinth articulates—the body of the sphenoid, the orbital process of the palatine bone, the orbital plate of the frontal bone, the lacrimal bone, the frontal process and the medial margin of the orbital surface of the maxilla. They are related *laterally* to the orbit; *medially* to the upper half of the cavity of the nose; *posteriorly* to the sphenoidal and palatine sinuses; *superiorly* to the sphenoidal sinus, the frontal sinus, the anterior cranial fossa, and to the ethmoidal canals between the orbital plate and the ethmoidal labyrinth; *inferiorly* the posterior sinuses are related to the superior meatus, into which they open, and the middle and anterior sinuses are related to the lower part of the middle meatus.

The ethmoidal sinuses begin to develop during the latter half of intra-uterine life, and the papery bone of the ethmoid is deposited around them in the cartilage of the nasal capsule.

The **sphenoidal sinus** is a large cavity in the body of the sphenoid bone. It is situated above the cavities of the naso-pharynx and nose, and below the median part of the cranial cavity. It is divided into right and left halves by a complete bony septum, which is usually bent to one or other side: each half may be referred to as a sphenoidal sinus, and it opens into the spheno-ethmoidal recess of the nose by a round aperture 4 or 5 mm. in diameter.

The **sphenoidal sinus** may be small and limited to the anterior part of the body of the sphenoid; or it may occupy the whole of the body and extend into the roots of the wings and pterygoid processes, and backwards into the basilar part of the occipital bone. Its average dimensions are about 20 mm. each way.

Inferiorly it is related to the cavity of the naso-pharynx and posterior part of the nose and to the pterygoid canal with its contained nerve and vessels. *Anteriorly* it is related to the upper part of the middle section of the cavity of the nose and to the posterior ethmoidal sinuses. *Laterally* it is related: (1) to the optic nerve in the optic foramen, and to the apical part of the orbit; (2) behind that, to the cavernous venous sinus, in the walls of which the internal carotid artery, the third, fourth, sixth, and ophthalmic nerves are imbedded; (3) to the maxillary nerve as it runs forwards along the lower border of the cavernous sinus and as it passes through the foramen rotundum. *Superiorly* it is related: (1) to the frontal lobes of the brain and the olfactory tracts, lying on the anterior part of the body of the sphenoid; (2) more remotely, to the optic chiasma, which is above the optic groove; (3) to the hypophysis cerebri, lying in the hypophysial fossa; (4) to the pons and the basilar artery, lying on the clivus.

The rudiments of the sphenoidal sinuses appear in the fifth month of intra-uterine life or a little later. They are recesses of the nasal cavity that are partly cut off from it and are enclosed within

the sphenoidal conchæ (p. 225) when they begin to ossify. But those rudiments do not begin to extend into the body of the sphenoid till the seventh or the eighth year.

The **palatine sinus**, when present, occupies the orbital process of the palatine bone, and it opens either into the sphenoidal sinus or into a posterior ethmoidal sinus.

Mandible

The **mandible** or lower jaw-bone lies below the anterior part of the cranium and is the skeleton of the lower part of the face. It has a horseshoe-shaped **body** and a pair of flat, broad **rami**, which stand up from the posterior part of the body. Each ramus is surmounted by two processes, the anterior of which is named the **coronoid process**, and the posterior is the **condyloid process** ; the condyloid process has an articular part, called the **head**, supported on a more constricted part called the **neck**.

The right and left halves of the **body** of the mandible are fused together in the median plane in front but are widely separated behind. Their junction is called the **symphysis menti** [σύν (syn) = together ; φύω (phyō) = grow ; *mentum* = the chin]. The halves are joined together by fibrous tissue at birth, but they are fused together into one bone during the second year.

On the front of the mandible, along the line of the symphysis, there is a faint, vertical ridge. This ridge swells out inferiorly into a triangular elevation, of varying prominence, called the **mental protuberance**; the lower angles of the triangle form the *mental tubercles* ; in the region of the protuberance, the bone is bent forwards to produce the prominence of the **chin**. The forward projection of the lower part of the middle of the mandible to make the chin is a Human characteristic : among lower animals, not even the higher apes (Gibbon, Gorilla, Orang-utan, and Chimpanzee) have chins as an outstanding feature ; and the prominence of the chin is not so marked in the primitive races of Man as in the higher, though the mandible as a whole may be a heavier bone.

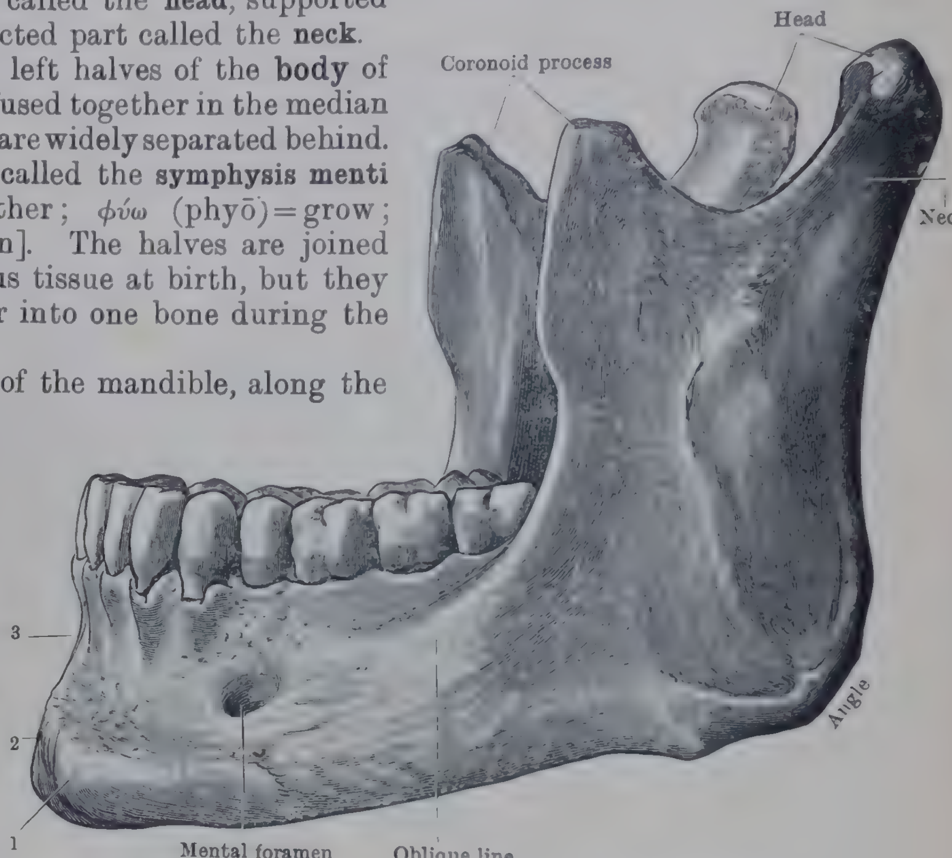


FIG. 167.—MANDIBLE AS SEEN FROM THE LEFT SIDE.
1. Mental tubercle. 2. Mental protuberance. 3. Symphysis.

Each half of the body of the mandible has an outer and an inner surface and an upper and a lower border. The surfaces slope so that the lower border of the whole bone makes a wider arch than the upper border.

The upper part is called the **alveolar** part, because it is occupied by a row of pits or **alveoli** forming the sockets for the teeth. They are visible on the *upper border* if the teeth have fallen out after death. On each side the sockets for the two incisors, the canine, and the two premolars are single, but those for the three molars are double, for each mandibular molar has two roots—an anterior and a posterior. When teeth are removed during life the walls of the sockets are gradually absorbed until no evidence of them is left ; the upper border of the mandible in the region of the lost teeth is smooth, and the vertical diameter of the bone is reduced.

The *lower border* is the **base** of the mandible. On or behind this border, at the

side of the symphysis, there is a broad, rough mark or depression called the **digastric fossa.** The rest of the border is smooth and rounded and has a slight fullness or downward convexity about its middle.

The **outer surface** is slightly convex, but has a broad, shallow depression alongside the symphysis below the incisor teeth. An oblique opening is seen about an inch from the symphysis, below the second premolar or the interval between the premolars; it is called the **mental foramen** and is about midway between the upper and lower borders if the sockets are present, but is near the upper border if the walls of the sockets have been absorbed. Below the mental foramen there is an ill-defined ridge called the *oblique line*; it extends from the mental tubercle to the anterior border of the ramus but is not well marked till it approaches the ramus.

The **inner surface** is undulating—being convex and concave at different parts. Low down on the back of the symphysis there is a rough mark which, when well developed, is divided into two pairs of little eminences called the **genial tubercles** [γένειον (geneion) = the chin].

At the side of the symphysis, a little above the digastric fossa, there is a smooth, shallow depression, about the width of a thumb-print, called the **sublingual fossa.** Farther back there is an elongated, shallow depression, the **submandibular fossa,** which extends on to the ramus; inferiorly it reaches the lower border of the mandible; superiorly it is bounded by an oblique ridge, called the **mylo-hyoid line,** which begins at the level of the socket of the last molar tooth and passes downwards and forwards to the posterior margin of the digastric fossa; the lower or anterior part of the line is faint, and separates the submandibular and sublingual fossæ from each other.

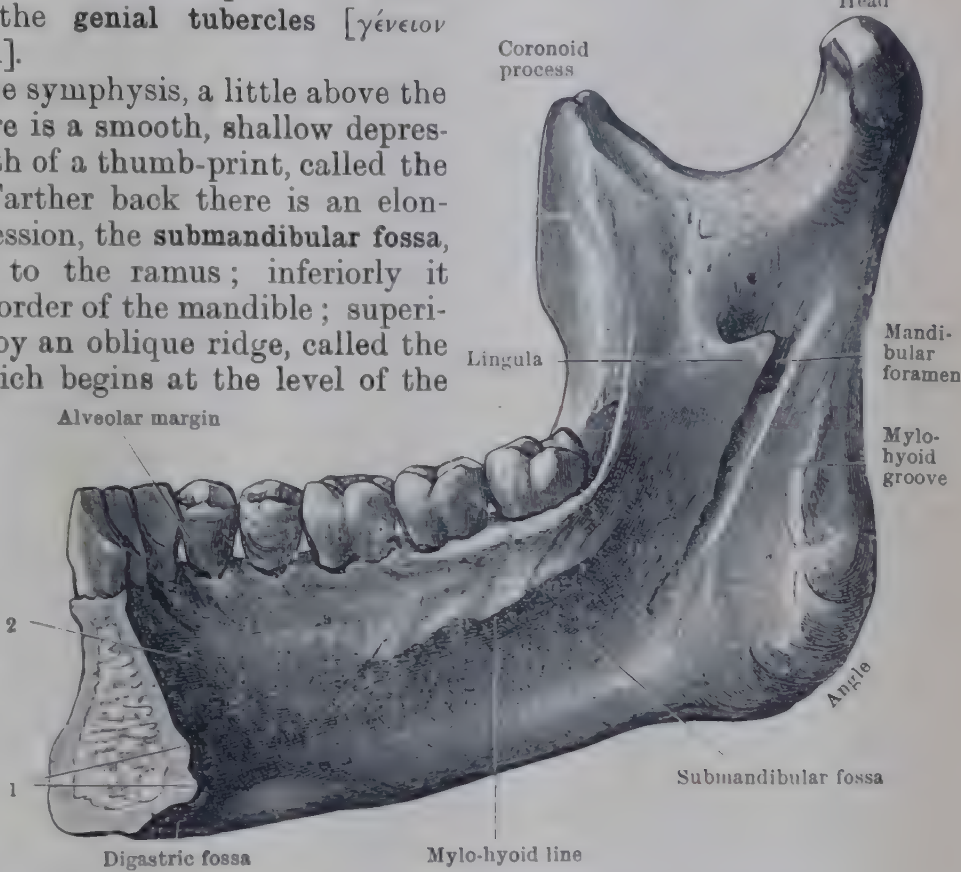


FIG. 168.—MEDIAL SURFACE OF RIGHT HALF OF MANDIBLE.

1. Upper and lower genial tubercles. 2. Above sublingual fossa.

The **ramus** of the mandible is, properly, the broad, flattened plate that rises up above the level of the posterior part of the body; but, to simplify the description of the attachment of muscles, it is convenient to include the bone down to the lower border under the term *ramus*; at the same time it is not necessary to divide the lower border: it is the lower border of the mandible, irrespective of division into body and ramus. Each ramus has a lateral and a medial surface, an anterior and a posterior border, and an upper end or border surmounted by the coronoid and condyloid processes, which are separated by a wide gap called the **mandibular notch.**

The **lateral surface** is fairly flat, and rather rough. Where the ramus and body join, at the lower border of the bone, a faint groove may be detected; if the finger-tip is placed on the corresponding point in a living person the pulsing of the facial artery can be felt as it crosses the lower border of the mandible to enter the face. The **medial surface** is more uneven. About its centre there is an oblique opening, the **mandibular foramen,** leading into a **canal** which runs downwards and forwards in the substance of the bone and carries the vessels and nerves for the teeth. The spur of bone that overlaps the foramen anteriorly is the **lingula.** A narrow groove, called the **mylo-hyoid groove,** begins at the lower margin of the

foramen, runs downwards and forwards and fades away in the sub-mandibular fossa. The **anterior border** of the ramus is sharp, and is continuous with the oblique line of the body. The **posterior border** is smooth and rounded; the point where it meets the lower border is the **angle of the mandible**—a landmark easily felt in the living subject.

The **coronoid process** is flattened and pointed; it is triangular in outline, and is named from its resemblance, when looked at sideways, to the beak of a bird [κορώνη (corōnē) = a sea-crow]. Its anterior border is continuous with the anterior border of the ramus, and both can be felt inside the mouth above and behind the last molar tooth. Its posterior border bounds the mandibular notch anteriorly. Its surfaces are continuous with those of the ramus; on its medial side a low blunt ridge begins near its top and extends down to the medial margin of the socket of the last molar tooth.

The **condyloid process** has two parts—an articular head or condyle supported on a constricted neck.

The **head** of the mandible is elongated transversely with its long axis directed medially and slightly backwards. It includes only the part that is smooth and coated with cartilage; it has therefore an upper and a posterior surface and a small, negligible anterior surface. The head articulates with the articular fossa and eminence of the temporal bone—but not directly: an articular disc of fibro-cartilage separates the head from the temporal bone, and, since its circumference is attached to the capsular ligament of the joint, it divides the joint-cavity into an upper and a lower compartment. When the mandible is at rest, with the mouth shut, the upper surface of the head is in contact with the disc below the articular fossa; as the mouth is opened the mandible rotates, and at the same time the head and the articular disc travel downwards and forwards till they come to lie beneath the articular eminence. The head can be felt in front of the auricle, and the finger can follow its movements as the mouth is opened and shut.

The **neck** of the mandible is obliquely compressed from before backwards. The *medial* and *lateral surfaces* are narrow, but widen out inferiorly as they merge into the surfaces of the ramus. The *posterior surface* is smooth, and is continuous with the back of the head and the posterior border of the ramus. The *anterior surface* is rough and hollowed out, and is overhung by the anterior margin of the head; it is continuous inferiorly with the medial surface of the ramus, and the sharp margin between it and the lateral surface is the posterior boundary of the mandibular notch.

The **alveolar part** is thicker behind than in front; it is covered on both surfaces with mucous membrane, and it gives attachment to the gums around the mouths of the sockets. The socket of the canine tooth may produce a vertical eminence on the labial surface of the bone, and the incisor sockets also may do so.

The mucous membrane of the mouth covers the **outer surface** of the body down to a line drawn from the last molar socket to the apex of the mental protuberance. The lower part of the buccinator arises from the lateral surface opposite the *molar sockets*; the incisive muscle, opposite the *incisor sockets*; the mentalis, from a point opposite the bottom of the *canine socket*; the depressor labii inferioris, from a line that joins the mental tubercle and foramen; the depressor anguli oris, from the anterior part of the **oblique line** below the mental foramen. The **mental foramen** opens obliquely upwards and slightly backwards, and it transmits the mental vessels and nerve; it may be double on one or both sides. The facial artery lies on the mandible at the junction of body and ramus. The **lower border** of the mandible gives attachment to the deep fascia of the neck; and the platysma is inserted into the anterior half of it.

The mucous membrane covers the **inner surface** of the body down to a line drawn from the posterior end of the mylo-hyoid line to a point immediately above the genial tubercles. A small vascular foramen is situated opposite the interval between the incisor sockets on each side; and another is placed in the symphysis above the genial tubercles; the genio-glossus and genio-hyoid arise from the upper and lower **genial tubercles** respectively; the anterior belly of the digastric from the floor of the **digastric fossa**; the mylo-hyoid from the **mylo-hyoid line**, the posterior end of which gives attachment also to fibres of the superior constrictor and the buccinator and to the lower end of the pterygo-mandibular ligament. The two mylo-hyoid lines are the sides of an arch which is smaller than the arches made by the upper border and the lower border; for the surface above the lines slopes upwards and outwards, and the surface below slopes, to a still greater degree, downwards and outwards. The sublingual gland lies in the **sublingual fossa**; and the submandibular gland lies in the **submandibular fossa**.

The **mandibular foramen** transmits the inferior dental vessels and nerve; their mylo-hyoid branches run along the **mylo-hyoid groove**, which may be partly converted into a tunnel. The medial pterygoid muscle is inserted into the rough patch that separates the foramen and groove from the angle of the mandible. The spheno-mandibular ligament is attached to the **lingula**; the stylo-mandibular ligament is attached to the **posterior border** *of the ramus* and also to the angle. The **angle** is usually everted and is slightly obtuse in a well-formed adult jaw, more obtuse in childhood, and still more in old age after the teeth have been lost. In a young adult the slope of the jaw from angle to chin expresses almost the whole degree of obtuseness of the angle, for the posterior border of the ramus is nearly vertical; but not so in old edentulous persons, for in them the posterior border of the ramus slants downwards and forwards, chiefly owing to the backward tilt of the condyloid process. In mandibles of old people the increase of obtuseness is not so much in the angle proper as in the angle between the anterior margin of the ramus and the upper margin of the body.

The masseter is inserted into the **lateral surface** of the ramus and covers the ramus and the coronoid process, leaving the head and neck without a covering of muscle; the temporalis is inserted into the medial surface and the margins of the **coronoid process** and also into the anterior margin of the ramus and the blunt ridge on the medial side. In some specimens an oblique canal traverses that ridge; the canal transmits the buccal nerve. The coronoid process varies considerably in length, but its tip usually lies under cover of the anterior part of the zygomatic arch.

The long axis of the **head** is nearly horizontal and is directed latero-medially and backwards. The posterior surface is slightly convex; so also is the upper surface, which overhangs the front of the neck and ends in little tubercles that overhang the sides of the neck. The capsular ligament of the mandibular joint is attached to the margins of the articular surfaces of the head; a thickened part of the capsule, called the temporo-mandibular ligament, is attached to the lateral side of the **neck**. The lateral pterygoid muscle is inserted into the front of the neck and the capsule. If the finger is placed in the auditory meatus, the meatus can be felt widening as the mouth is opened, for when the mouth is shut the back of the head exerts pressure on the meatus, though it is separated by a portion of the parotid gland; the lateral side of the head and neck also is overlapped by the parotid gland and is crossed by the temporal and zygomatic branches of the facial nerve, which may be rolled between the finger and the bone. The external carotid artery ends behind the neck; the superficial temporal artery, accompanied at that level by the posterior facial vein, runs upwards behind the lateral end of the head; the maxillary artery passes forwards medial to the root of the neck; the auriculo-temporal nerve winds round the medial side and the back of the neck and joins the superficial temporal artery. The vessels and nerves to the masseter pass in a lateral direction,

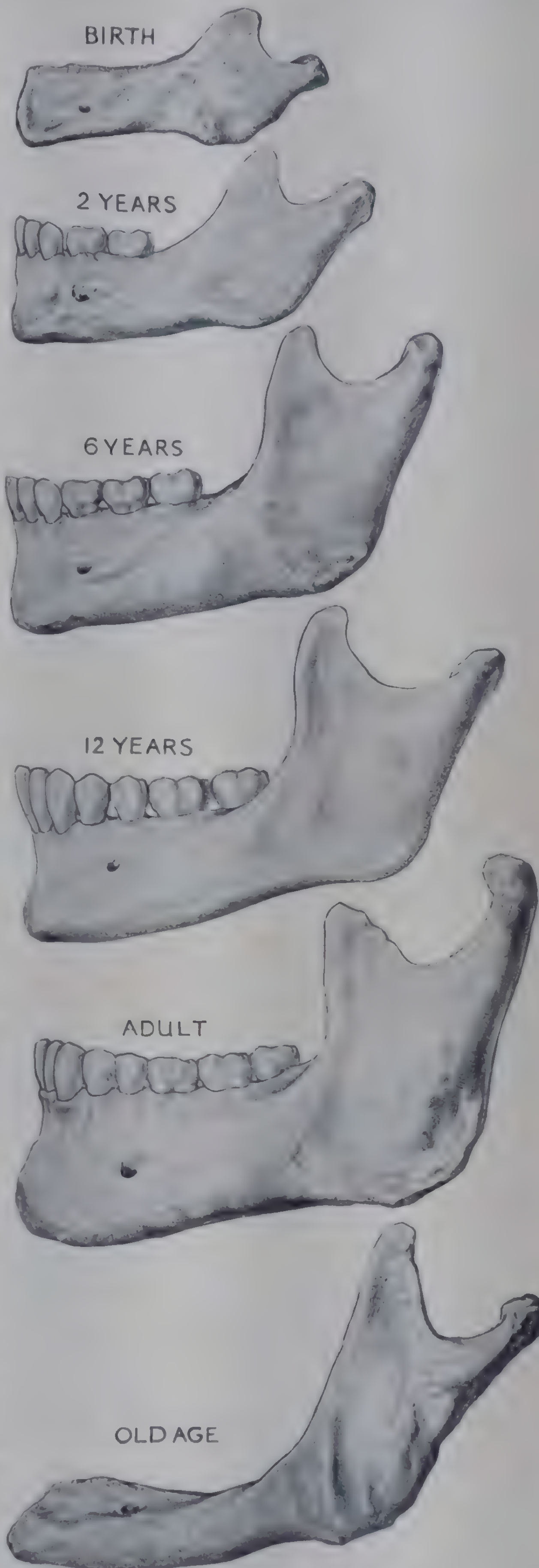


Fig. 169.—Form of Mandible at different Ages. By the sixth year the first permanent molar has erupted behind the milk teeth; by the twelfth year the milk teeth have been replaced by the corresponding permanent teeth, and the second permanent molar has erupted.

through the **mandibular notch**, in front of the neck. When the mandible is in position in the head, a stilette inserted in front of the neck of the mandible can be thrust from one mandibular notch to the other; it passes below the foramen ovale, and therefore would transfix the mandibular nerve.

Differences due to Age.—At birth the two halves are united by fibrous tissue; the body is a mere shell that encloses the rudimentary *teeth*, which are imperfectly separated from one another; the *mandibular canal* is relatively wide and is near the lower border; so also is the *mental foramen*, which is opposite the cavity for the first milk molar tooth. The *ramus* is relatively short; the *condyloid process* is almost in line with the body, and the angle is therefore very obtuse; the *head* is relatively large, and the *coronoid process* rises to a higher level than the head.

During the first year the halves unite from below upwards, and union is completed during the **second** year. As the teeth erupt and the child begins to chew, the depth of the body increases by the growth of the walls of the sockets, the lower part thickens, the rami enlarge and the angle becomes less obtuse, being about 140° in the fourth year. As growth advances the depth increases, and the body elongates, especially behind the mental foramen to provide room for the permanent molars; the mental foramen assumes its adult position and the angle is reduced to 110°.

In **old age** after teeth are lost the walls of the sockets are absorbed; the chin appears therefore more prominent, and the mental foramen is near the upper border. The angle opens out to 140° and the condyloid process is bent back so that the mandibular notch is wider.

Structure.—The body of the mandible is thicker than the rami, and it is thickest near the rami at the level of the mylo-hyoid and oblique lines, for there the mandible is subject to the greatest strain when the elevating muscles bring it into contact with the resisting upper jaw. The tables of compact bone are exceptionally dense and are very thick where they join together at the lower border. The lingual walls of the sockets are considerably thicker than the labial walls, except in the case of the **third molar** socket, where the labial wall is the thicker. The spongy substance is open-meshed below, but finer and more condensed in the walls of the sockets. The *canal* of the mandible is in the spongy substance, about the level of the mylo-hyoid line, and does not have a definite wall; the mental foramen branches off the canal, and so do the channels that carry blood-vessels and nerves to the teeth.

Development and Ossification.—The **mandible** begins to ossify during the sixth week of intra-uterine life—before any other bone in the body, except the clavicle. Each half is developed from (1) the membrane that overlies Meckel's cartilage, (2) the anterior portion of Meckel's cartilage, (3) certain accessory cartilages that appear between the eleventh and fourteenth weeks. The greater part of the mandible is developed from the membrane. The extreme anterior end of Meckel's cartilage disappears, but a part of it is incorporated in the mandible from a point near the symphysis backwards to the level of the mental foramen. One of the accessory cartilages forms the head and a narrow wedge-like part in the ramus; another forms a narrow strip along the front of the coronoid process; and some accessory nodules take a share in forming the symphysial part of the bone. These different structures are not ossified from separate centres. Each **half** of the mandible is ossified from **one** centre, and it appears in the membrane that overlies the anterior part of Meckel's cartilage. The ossifying process spreads through the membrane and envelops and invades the cartilages. Some small nodules, called *ossicula mentalia*, which appear at the symphysis shortly before birth and fuse with the mandible shortly after birth, may be derived from independent ossific centres in the accessory cartilages. (See Low, 1909; Fawcett, 1924, 1930.)

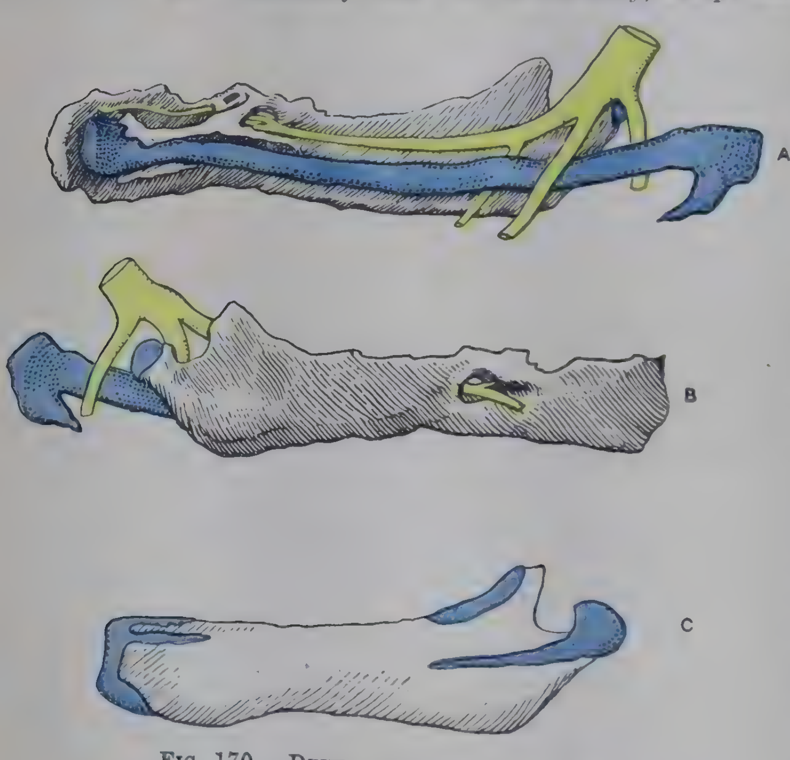


Fig. 170.—Development of Mandible.

A, As seen from the medial side; B, from the lateral side; C, showing accessory (metaplastic) cartilages (blue).

(In A and B Meckel's cartilage is coloured blue.)

Meckel's cartilage is the cartilage of the first or **mandibular** arch of the embryo. Its posterior end is in the region of the ear; its anterior end almost meets its fellow of the other side. The posterior end ossifies to form two of the auditory ossicles, namely, *incus* and *malleus*; part of its anterior end is included in the mandible. The rest disappears; but the mylo-hyoid groove is the remains of the furrow in which part of it lay; and the *spheno-mandibular ligament* is derived

from the fibrous sheath around it, though it has been argued that that ligament is the remnant of a muscular slip.

Growth.—The mandible grows in width between its angles as well as in length, height, and thickness. Increase of thickness is brought about chiefly by addition to the outer surfaces.

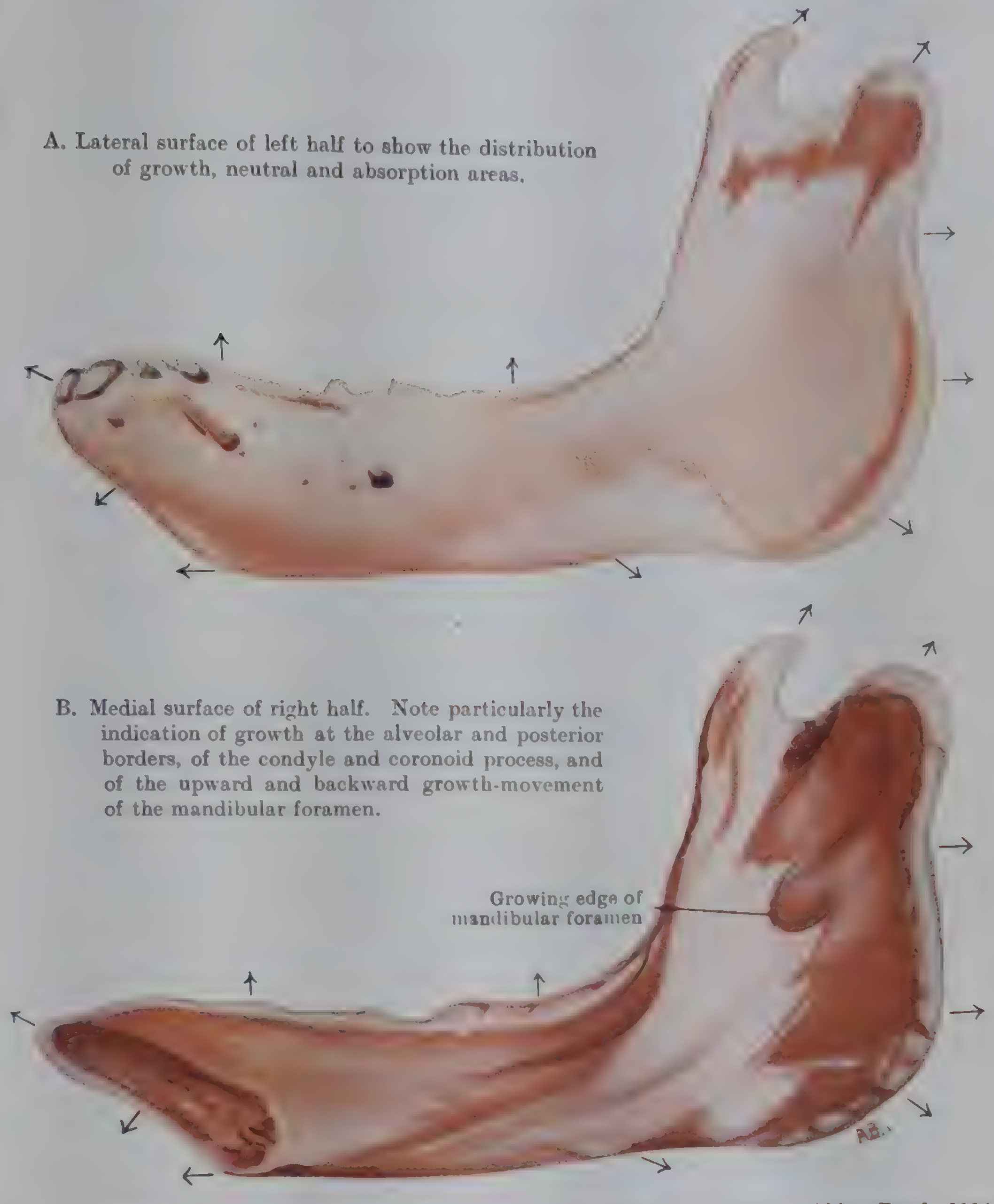


FIG. 171.—MANDIBLE OF MADDER-FED PIG TO SHOW THE SITES OF GROWTH. (After Brash, 1934.)

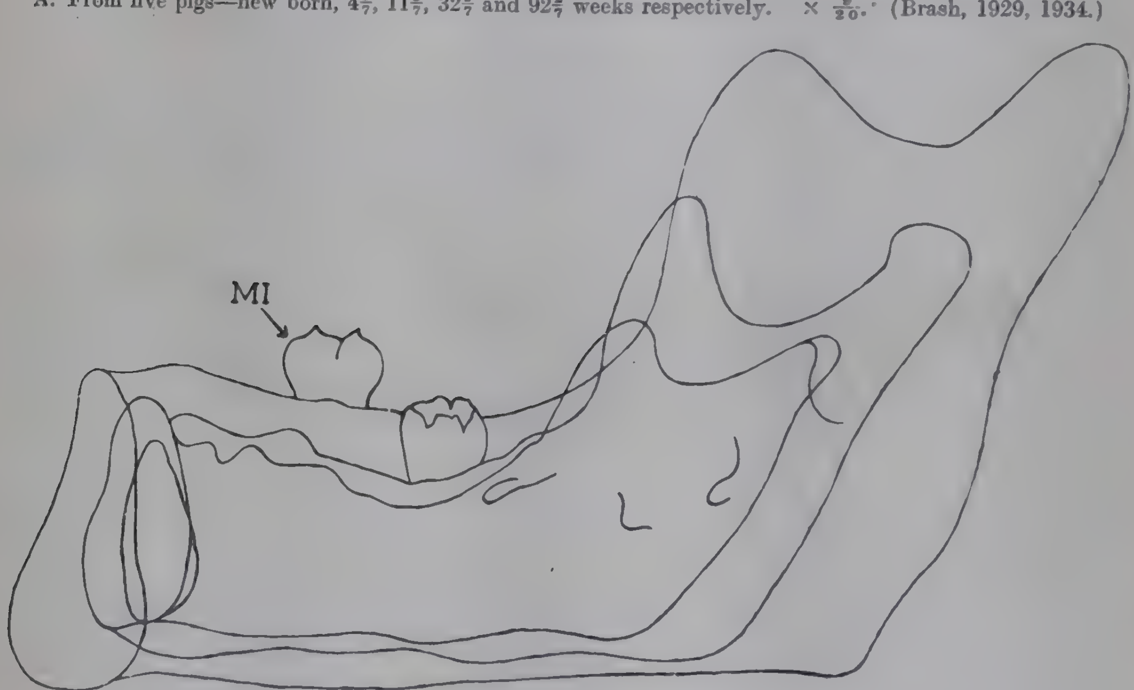
The animal was $20\frac{1}{7}$ weeks old and the madder had been omitted from the food for 19 days. The new bone added during that period is white in contrast to the old, red bone; and the main directions of growth are indicated by arrows.

Increase in height of the body is due mainly to growth at the alveolar border, and there is an associated continuous upward and forward movement of the teeth in the bone before, during, and after their eruption. The lengthening process is chiefly backwards. It takes place partly by addition to the posterior border, and, owing to the lateral slope of the body from before backwards, that accounts for increase of width also. But the main increase depends upon the obliquity of the ramus and its processes in a young jaw. The growth of the condyloid process is not only upwards but also backwards and sidewards, and it thus contributes to the total length as well as to height and width—a contribution that diminishes as the ramus becomes more vertical. The coronoid process grows upwards and backwards by addition to its tip. As the process grows, its sloping, anterior margin is encroached upon by the rising alveolar border, which thus becomes longer. This is the chief means of providing more room for the teeth as they rise with the alveolar border. As growth proceeds, modelling absorption maintains the shape of the condyle and the undulating curves of the anterior margin of the ramus and coronoid process. During the upward and backward growth of the ramus and coronoid process, the mandibular foramen maintains its relative position by a corresponding extension of its anterior lip, and the mandibular canal is thus lengthened. The mental foramen also changes its position during growth by moving backwards relative to the teeth (Fig. 169). In the young jaw its sharp edge is below and behind, but in the adult it is below and in front, an indication of its direction of movement as in the case of the mandibular foramen and of the nutrient canals of long bones (p. 117). (For further details and historical references see Brash, 1924, 1926, 1929, 1934.)

Teeth

There are two sets of **teeth**: the *deciduous* or milk teeth, which are shed during childhood; and those that are potentially *permanent*. For an account of the teeth and their arrangement in the jaws, see the Section on the Digestive System, pp. 566-574.

A. From five pigs—new born, $4\frac{3}{7}$, $11\frac{3}{7}$, $32\frac{1}{7}$ and $92\frac{2}{7}$ weeks respectively. $\times \frac{9}{20}$. (Brash, 1929, 1934.)



B. From three human mandibles—2 years, 6 years, and adult respectively—superimposed on the analogy of the known directions of growth in the pig. $\times \frac{1}{1}$.

FIG. 172.—SUPERIMPOSED OUTLINES OF PIG AND HUMAN MANDIBLES TO DEMONSTRATE THE DIRECTIONS OF GROWTH AND FORWARD MOVEMENT OF MOLAR TEETH.

Hyoid Bone

The **hyoid bone** lies in the front of the neck at the root of the tongue between the mandible and the larynx. It is named from its resemblance to the letter U [the Greek letter υ aspirated thus ὑ = hy; εἶδος (eidos) = shape]. It does not articulate with any other bone. It has a *body*, a pair of *greater horns*, and a pair of *lesser horns*.

The **body** is the middle part or bottom of the U. It can be felt in the

median line of the neck about a finger's breadth above the laryngeal prominence when the chin is held up. When the chin is depressed the hyoid bone is at or above the level of the point of the chin and is closer to the larynx. If one swallows or gulps while the finger is placed on the hyoid bone, the bone is felt rapidly ascending, for the tongue, the hyoid bone, and the larynx are all suddenly jerked upwards in the movement of swallowing.

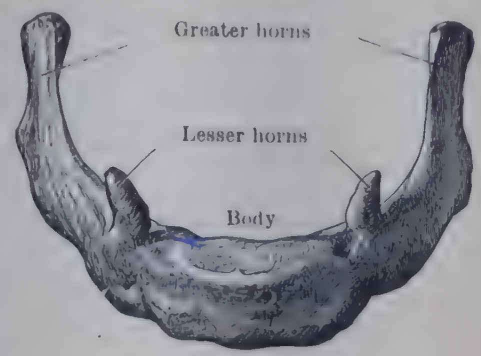


FIG. 173.—HYOID BONE.

The **greater horns** are the limbs of the U. They spring from the body about a finger's breadth from the median plane and extend backwards in the sides of the throat; they can be gripped between finger and thumb, but the tip of the greater horn, though often referred to as a landmark, is overlapped by the anterior edge of the sterno-mastoid muscle and cannot always be felt easily.

The **lesser horns** are small pointed nodules of bone that project upwards from the junction of the body with the greater horns.

The **body** is compressed from before backwards and is curved from side to side with the convexity forwards. It has an upper and a lower border, and an anterior and a posterior surface. The **anterior surface** is divided into an upper and a lower part by a transverse ridge on which there is sometimes a small median tubercle; the upper part looks upwards rather than forwards and is divided by a median ridge into right and left halves. The genio-hyoid is inserted into the upper part and a small adjoining area of the lower part. The anterior fibres of the hyoglossus arise at the side of the genio-hyoid; part of the mylo-hyoid is inserted below the genio-hyoid. The deep fascia of the neck is attached below the mylo-hyoid. The levator glandulæ thyroideæ, when present, arises below the attachment of the fascia near the median line.

The **lower border** gives insertion to the sterno-hyoid. The median thyro-hyoid ligament passes upwards behind the body to be attached to the **upper border**, which gives attachment also to the hyo-epiglottic ligament and, occasionally, to some fibres of the genio-glossus. The **posterior surface** is smooth and concave; it is separated by some fat and a *bursa* from the median thyro-hyoid ligament, which, in turn, is separated by a pad of fat from the stem of the epiglottis. When the larynx is pulled up during swallowing, the posterior surface of the hyoid bone overlaps the thyroid cartilage of the larynx, and the bursa lessens the friction between them.

The **greater horns** not only pass backwards, but have an upward and lateral inclination as well; they taper as they pass backwards, but each ends in a slightly swollen **tip**, to which the lateral thyro-hyoid ligament is attached. They are compressed, so that each has a lateral and a medial surface and an upper and a lower border, but the compression is oblique, and the surfaces are sometimes named upper and lower respectively, and the borders medial and lateral.

The **medial surface** is related to the thyro-hyoid membrane, which passes upwards between it and the mucous membrane of the pharynx to be attached to the **upper border**. The **lateral surface** is continuous with the front of the body. It gives origin to the middle constrictor near the upper border, and to the hyo-glossus below that; the attachment of the fascial sling of the digastric tendon and the insertion of the stylo-hyoid are close to the junction with the body. The deep fascia of the neck is attached near the lower border. The **lower border**, in its anterior two-thirds, gives insertion to the thyro-hyoid; the superior belly of the omo-hyoid is inserted into the anterior third, superficial to the thyro-hyoid, and overlaps the insertion of the sterno-hyoid on the body.

The **lesser horn** is situated on the upper aspect of the junction of the body and the greater horn, and is often in line with the transverse ridge on the front of the body. It projects backwards and slightly in a lateral direction as well as upwards; usually it is only a few millimetres in length, but may be 10 or 12 mm. A few fibres of the middle constrictor arise from its lateral surface, and the stylo-hyoid ligament is attached to its tip.

Development and Ossification.—The hyoid bone is developed from the cartilages of the second and third pharyngeal arches, the anterior ends of which are fused together. On each side, the greater horn and the greater part or whole of the body are derived from the cartilage of the third arch. The lesser horn and possibly the upper median part of the body are derived from the cartilage of the second or hyoid arch, which gives rise also to the stylo-hyoid ligament, the styloid process, and one of the auditory ossicles, namely, the *stapes*. Occasionally the stylo-hyoid ligament is ossified, and may be mistaken for a foreign body in the wall of the pharynx.

The hyoid bone is **ossified** from three pairs of centres. A pair (which soon unite into one) for the body and one for each greater horn appear shortly before birth, and one for each lesser horn appears during the first year. The greater horn is united to the body of the bone by a plate of cartilage which ossifies at middle age. The lesser horn is united by a synovial joint, which may disappear in old age.

The Skull at Birth

At birth the skull, compared with other parts of the skeleton, is large—especially the vault. The facial region, however, compared with the rest of the skull, is small (Fig. 176); in the adult the facial region, including the mandible, accounts for about one-half of the whole skull, but in the new-born child it is only one-eighth, for the teeth and the air sinuses are only rudimentary, and the mandible, the maxillæ, and the nasal cavities are therefore relatively small. A boy's head at birth is larger than a girl's, but so also is his body.

In the **vault**, the edges of the bones are not yet serrated, and they are separated by linear intervals filled with strips of fibrous tissue continuous with the pericranium on the outer surface of the bones, and with the dura mater on the inner

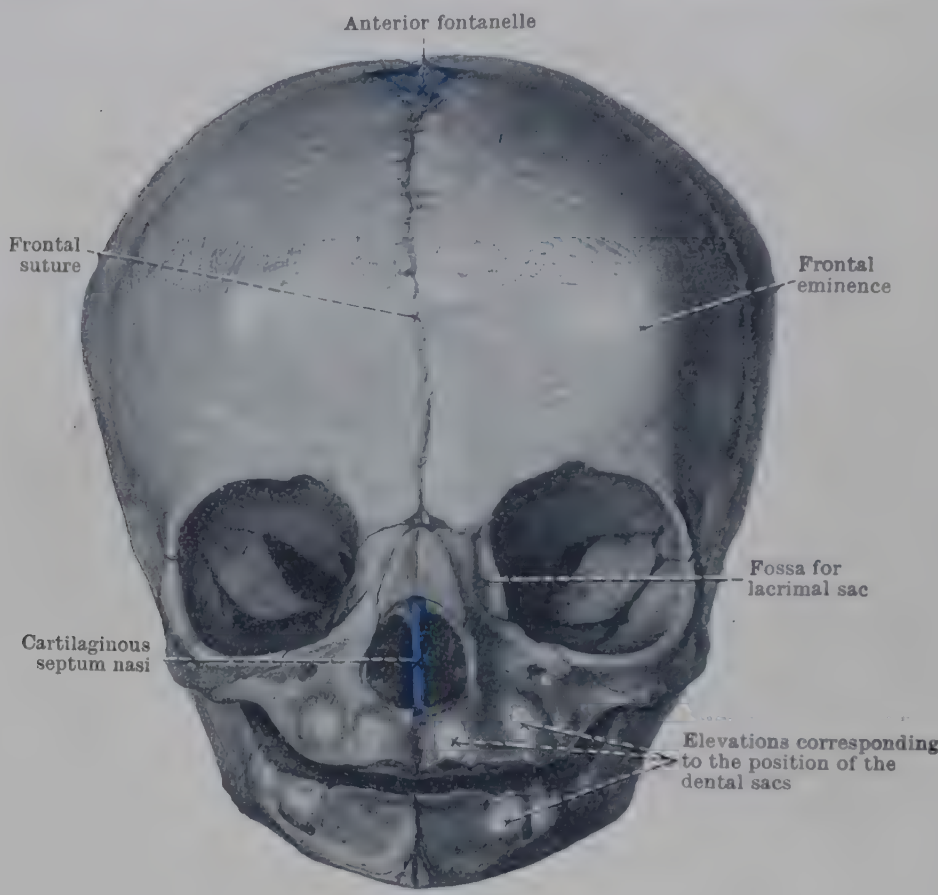


Fig. 174.—Frontal Aspect of Skull at Birth. (Cf. Pl. V, Fig. 1, p. 150.)

surface. Owing to the presence of these intervals, the bones of the vault have a degree of mobility that enables the head to be moulded into the required shape during the birth of the child. The bones are very thin, but they are little liable to fracture, for, in addition to their mobility, they are less brittle than in an adult, and the pericranium is very tough.

In certain situations there are areas, rather than linear intervals, between the bones of the vault. Those areas are called fontanelles. They are seven in number—anterior, sagittal, posterior, right and left antero-lateral and postero-lateral.

The **anterior fontanelle** is much the largest and is easily felt in the fore part of the top of the head in the new-born child. It is lozenge-shaped and measures about an inch and a half antero-posteriorly and an inch across. It is situated between the two halves of the frontal bone and the two parietal bones. The ossifying process going on in those bones spreads into the fibrous membrane of the fontanelle; the bones meet and the fontanelle is closed during the second year.

The **sagittal fontanelle** is a small unossified space at the *obelion*; it extends like a cleft from the sagittal suture into the upper part of each **parietal bone**; it is often quite closed at birth. The parietal foramina in the adult are derived from it and indicate its position.

The **posterior fontanelle** is situated at the apex of the occipital bone between the two parietal bones. It is closed two months after birth.

The **antero-lateral fontanelle** is situated at the anterior inferior angle of the parietal bone. It is closed three months after birth.

The **postero-lateral fontanelle** is situated at the postero-inferior angle of the parietal bone. It is closed at the end of the first year.

From irregularities in ossification, **sutural bones** may be developed in various sutures and at the fontanelles. Those formed at the antero-lateral fontanelle, being in the region of the pterion, are called **epipteric bones**.

At birth the *occipital* bone is in four separate pieces, and on each side of the squama there is a cleft that partially separates the upper (interparietal) part of the bone from the rest; occasionally the two clefts meet. The *sphenoid* bone is in three parts—a median and a pair of lateral parts—in addition to the two sphenoidal conchæ (p. 225). The median part comprises the body with the lesser wings; each lateral part comprises the greater wing and the pterygoid process. The dorsum sellæ is still cartilaginous, and ossifies slowly (Fig. 306 B, p. 335). The lower surface of

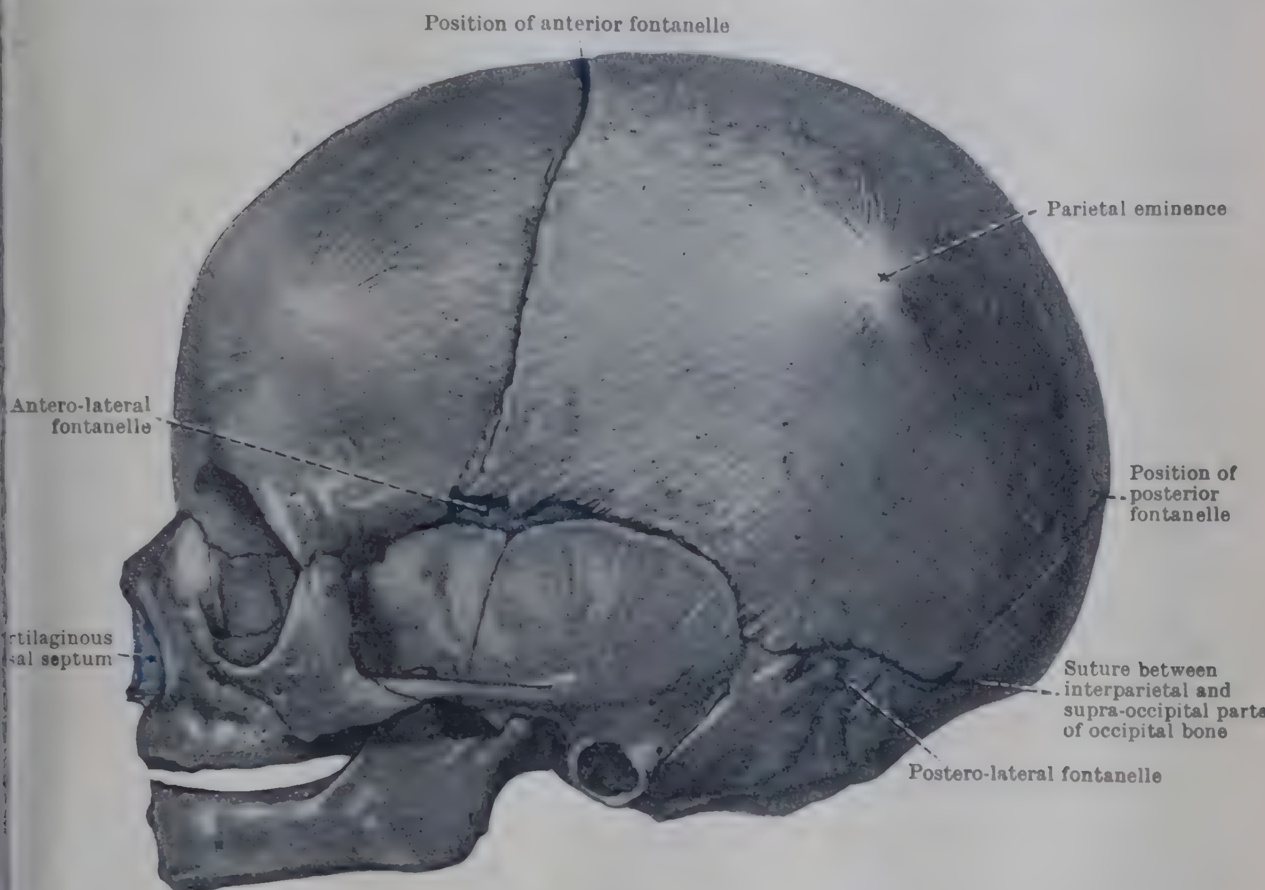


Fig. 175.—Lateral Aspect of Skull at Birth. (Cf. Pl. V, Fig. 2, p. 150.)

the body, between the conchæ, has a bullate appearance which it maintains for some years. The rudiments of the sphenoidal sinuses are present in the conchæ. The *temporal* bone is in four parts—petro-mastoid, squamous, tympanic, and the styloid process. The mastoid process has not begun to develop. The jugular fossa is poorly marked. The subarcuate fossa is large. The hiatus for the greater superficial petrosal nerve is an open groove. There is no *osseous* part of the external auditory meatus, for the tympanic part of the temporal bone is not a plate as yet, but is a mere ring—incomplete superiorly. The tympanic membrane is therefore near the surface of the head; the obliquity of the membrane is greater than in the adult; it looks downwards and forwards more than in a lateral direction. The styloid process and stylo-mastoid foramen also are near the side of the head, but they gradually recede from it, after the second year, when the mastoid process begins to grow and the tympanic ring begins to become a plate. The articular fossa is shallow and relatively large, and it looks in a lateral direction as well as downwards.

The halves of the *mandible* are separate. The ramus is relatively short but wide, the angle is very obtuse, and the coronoid process is at a higher level than the head. The body has little substance beyond the walls of a wide groove incompletely divided into compartments for the dental sacs; the mental foramen is near the lower border. (See also p. 204.)

The *maxilla* is vertical and of small height, for the maxillary sinus is a mere groove in the lateral wall of the middle meatus; the distance between palate and orbit is therefore short. The alveolar process is small, reaching only a little below the level of the zygomatic arch; and it is hollowed out for the dental sacs.

The perpendicular plates of the *palatine bones* are short; the *posterior apertures* and *cavity of the nose* are low. But the *bony anterior aperture* is relatively large and is a broad ovoid in outline; its lower margin is not far below the inferior orbital margin; for the nasal cavity is situated almost entirely between the orbits. The *nasal bones* are nearly flat.

The *ethmoid* is small. Its *perpendicular plate* is still cartilaginous, and is united to the labyrinth by a fibrous lamina. The *labyrinth* is already bony and contains the *sinuses* in the form of narrow pouches.

The *vomer* consists of two small plates of bone—a right and a left—separated by cartilage, but united along their lower edges; and they are not completely fused till puberty.

The *orbital opening* is large and nearly circular, and it has sharp margins; the orbital fissures

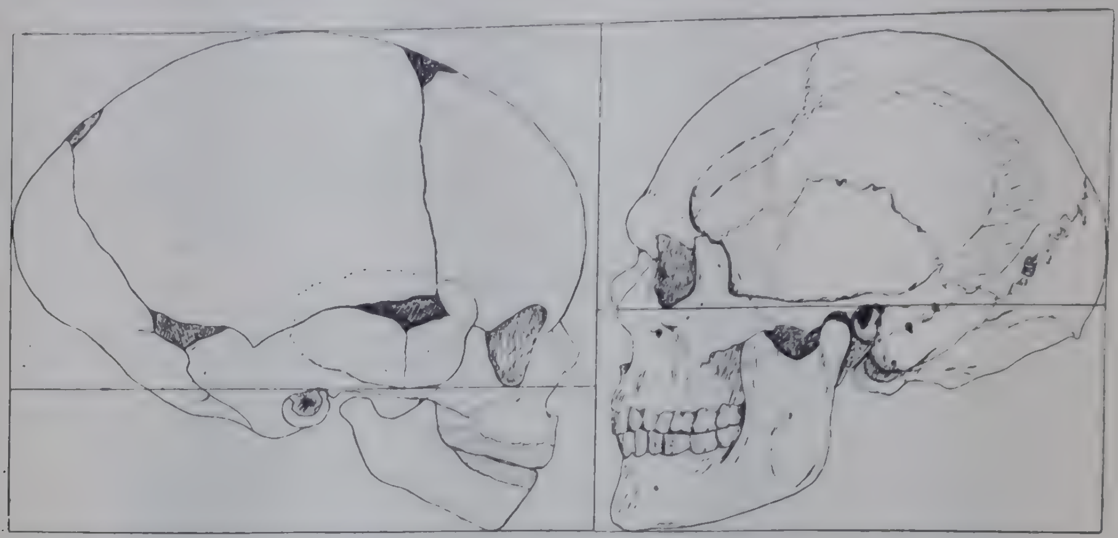


FIG. 176.—SKULLS OF NEW-BORN CHILD AND ADULT MALE, CONTRASTED IN LATERAL VIEW TO DEMONSTRATE THE ALTERATION IN PROPORTIONS. (Brash, 1924.)

They are oriented on the Frankfurt plane, the child's skull × $\frac{1}{2}$, that of the adult × $\frac{1}{4}$ nat. size.

are wide; the fossa for the lacrimal gland is deep, and the fossa for the sac looks forwards rather than sidewards. The supra-orbital notch is near the middle of the supra-orbital margin.

The *frontal* bone is divided into halves by the frontal suture. The frontal eminences are very prominent; their prominence, combined with the absence of superciliary arches, gives the bulging appearance to the child's forehead. The *parietal eminences* are even more prominent and convex, and are situated at the widest part of the head, and that is not always the case in the adult. The frontal and parietal eminences are more convex in the child than in the adult because the child's head is a smaller sphere.

Growth and Age-Changes of Skull

The skull grows rapidly from birth till the seventh year, but in the brain-box the greatest increase takes place during the first year. At the seventh year the orbits are almost as large as in the adult; the cribriform plates of the ethmoid, the body of the sphenoid, the petrous parts of the temporal bones and the foramen magnum have reached their full size; the jaws have enlarged in preparation for the eruption of the teeth and enlarge during their eruption—the chief enlargement being in the alveolar processes (Brash, 1926). For some years after the seventh, growth is slower, but at puberty a rapid increase in the rate of growth takes place in all directions, especially in the frontal and facial regions, owing to the great increase in size of the air-sinuses.

In the base of the skull, where cartilage is the precursor of bone, growth takes place in the cartilage between centres of ossification and so, for a time, growth takes place between bones such as the basi-sphenoid and basi-occipital which are joined by cartilage (Fig. 306 B). After the cartilage has ossified, growth can only take place on a surface of the bone covered with membrane—named periosteum, endosteum, or outer layer of dura mater, according to its position.

In the *vault of the skull* growth no doubt takes place between the edges of the bones until they meet and articulate with their neighbours but the essential mode of growth in the vault is by deposit of bone on the external surface and absorption from the internal surface. Consequently, sutures which are perpendicular to the surface, such as the sagittal suture or, to a less extent, the coronal, maintain their position during growth. Sutures which are set obliquely to the surface, so as to bevel the edges of the bones, migrate as the skull grows. This is because growth of the overlapping superficial edge of one bone, such as the squamous temporal, carries it over the surface of its neighbour. The deep edge of the neighbouring bone, being part of its internal surface, is absorbed according to the rate of absorption on the inner surface of the skull. If the two processes keep pace the suture will retain its width.

Simple accretion outside and absorption inside produce enlargement of the cranial cavity with a simultaneous reduction in curvature. Differential growth and modelling take place, as in the long bones, to produce and maintain the proper proportions and shape of the skull and the correct thickness of the bones.

In the *bones of the face* growth and modelling are accomplished in a similar manner by surface accretion and absorption wherever it is necessary to change the surface contours. It has been

known since the time of John Hunter that "modelling absorption" (p. 116) can occur in a marrow cavity or on the surface of a bone. Brash (1934) used bones from madder-fed animals to demonstrate the essential principles of bone-growth in the skull and the similarity of the growth processes in the skull to those in long bones. He also adduces evidence that the same processes are applicable to the human skull.

Up to maturity the age of the person can be ascertained approximately from the skull and the teeth. The dates of eruption of the teeth are given on page 573.

During the *first year* the portions of the temporal bone and of the sphenoid unite; the jugum sphenoidale is ossified by extension medially from each lesser wing; and the perpendicular plate of the ethmoid begins to ossify. During the *second year*, the halves of the mandible unite; the anterior fontanelle closes up; the cribriform plate ossifies and unites with the other parts of the ethmoid; and the mastoid process appears. The lateral parts of the occipital bone unite with the occipital squama during the *third year*, and with the basi-occiput during the *fourth or fifth year*. The halves of the frontal bone have almost completely united at the *sixth year*, and during that year the first of the permanent teeth—a first molar—erupts.

When the third molar is present the *seventeenth year* has been passed. If that tooth is present, and also the plate of cartilage between the body of the sphenoid and the occipital bone, the age is between 17 and 25. If the sphenoid and occipital are completely fused the age is over 25, for before that time (earlier in the female) the cartilage that unites the body of the sphenoid to the ethmoid and to the occipital bone disappears.

After maturity, the wear of the teeth and the degree of obliteration of the sutures may give a rough indication of the age. The work of Wingate Todd & Lyon (1924-1925) shows that the condition of the sutures in the interior of the skull-vault is a more reliable indication of age than the condition on the exterior. Fusion of the outer tables is less regular, slower and often incomplete although fusion starts about the same time. The irregularity of fusion on the outer surface may account for the common statement that the inner table starts to fuse about ten years earlier than the outer table.

In the interior of the skull, fusion of the sagittal suture normally begins at about 22 years of age and should be completed by 31 years. The coronal suture follows at 24 years and is for the most part fused by about 30 years though not completely so till about 40 years. Its lower pteric part is delayed a couple of years. The lambdoid suture does not start to fuse until about 26 years but joins rapidly at first and then lags so that fusion is not complete until after 40 years. Other sutures close considerably later

The work of Todd & Lyon on adult skulls and Bolk (1915) on young skulls indicates that failure of one suture to conform to pattern is likely to be associated with similar anomalies in the remaining sutures, *i.e.*, there is likely to be a slowing up or an acceleration of closure in other sutures as well, the whole pattern being slowed or speeded up in its presentation. Very considerable variation is possible as shown by Bolk's finding that 19 per cent of 1820 Dutch skulls aged 3-20 years showed some premature closure and there were 71 cases of premature closure of the sagittal suture. It must be noted, however, that the normal mode of growth by accretion and absorption can produce a normally shaped skull without the assistance of sutures. Complete obliteration of the sutures does not normally take place till an advanced age.

In old age the skull-vault may be thicker owing to deposit of bone on the inner surface (Humphry, 1858); but in nearly all cases the skull-bones are thinner, and the skull is lighter owing to absorption of diploë and the associated extension and enlargement of the sinuses. Consequent on loss of teeth there is diminution of the size of the jaws owing to absorption of the walls of the sockets; the chin protrudes and the angle of the mandible becomes more obtuse. For a review of the literature on age-changes in the skull see Ashley-Montagu (1938).

Sex Differences in the Skull

There is little difference between the skulls of boys and girls till the age of puberty; but the skull of a woman is, as a whole, smaller than that of a man, and the air-sinuses are small relatively to the size of the skull. The capacity of the cranial cavity is one-tenth less than in a man of the same race, and that is more or less in conformity with the relative size of the whole body of women and men of respective average build. Very often it is not possible to say with certainty whether a given adult skull is that of a man or of a woman, but the sex may be determined if the following differences are well marked.

The skull of a *woman* is lighter than that of a man and retains more of the character of a young skull; the muscular ridges are less pronounced; the mastoid processes are relatively small. The glabella and superciliary arches are less prominent; the forehead is therefore more vertical, and the frontal eminences appear to bulge more; the upper margin of the orbital opening is sharper (a fact appreciated better by touch than by sight); the parietal eminences are more convex. The facial region is rounder, and the jaws and teeth are smaller. The vertex is said to be more flattened and the relative height of the skull to be less.

Development and Morphology of the Skull

At an early stage of development, the cerebral vesicles are enclosed in a membranous envelope derived from the mesoderm and called the **primordial membranous cranium.** In certain lower vertebrates (*e.g.*, elasmobranch fishes) a complete, thick-walled cartilaginous capsule—the

primordial cartilaginous cranium—is developed in the membranous envelope. In mammals, cartilage is developed only in the basal part; the roof, the greater part of the sides, and even part of the base of the skull remain membranous till bone is formed in them.

The **notochord** or chorda dorsalis [νῶτον (nōton) = the back] is imbedded in the basal part of the membranous envelope, but does not extend through the whole length of the base; its cephalic extremity reaches only to a point beneath the anterior end of the middle cerebral vesicle; and in the mammalian cartilaginous base it is related to that part which extends from the foramen magnum to the root of the dorsum sellæ. The cartilaginous base can therefore be divided into a **chordal** part and a **prechordal** part.

In the **human embryo** chondrification of the base of the cranium begins early in the second month and has almost attained its maximum about the end of the third month. Cartilage appears in the following situations.

(1) A basal or parachordal plate of cartilage forms behind the hypophysis cerebri and round

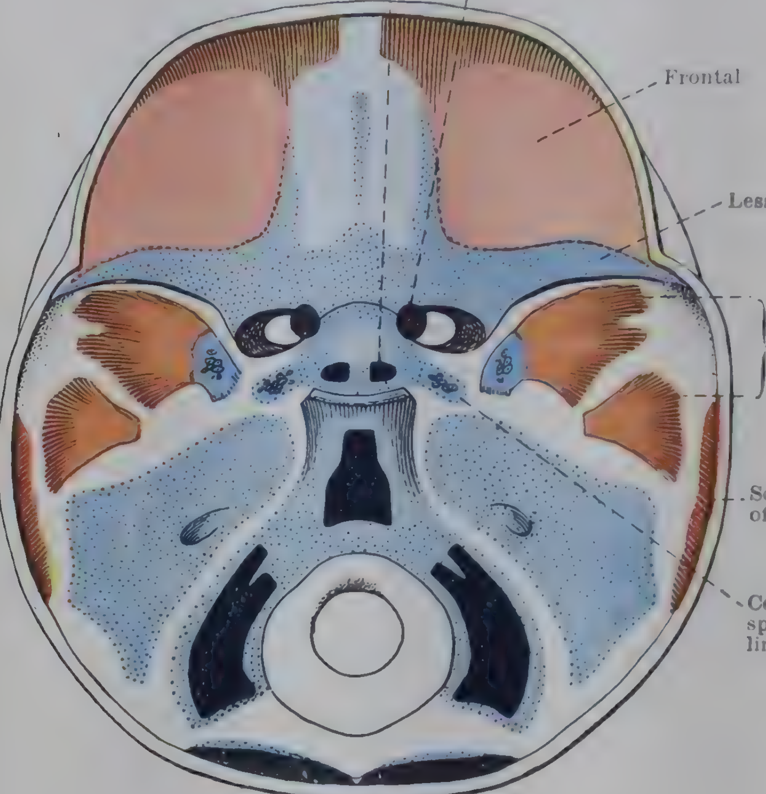


Fig. 177.—Ossification of Base and Side-walls of Skull of a Four and a Half Months' Fœtus (Schultze's method).

Cartilage, blue; cartilage-bone, black; membrane-bone, red.

the terminal part of the notochord (Levi, 1900; Fawcett, 1910). The notochord lies in a groove on the posterior part of the cerebral surface of the plate, pierces it to reach its pharyngeal surface and then turns upwards to terminate in the anterior end of the plate (Robinson, 1903). Extensions grow from its sides to form the cartilaginous precursors of the *condylar parts of the occipital bone*; and they grow backwards to form the thin plate of cartilage in which the part of the *occipital squama* below the superior nuchal lines ossifies; the halves of the plate are tardy in uniting, so that the part immediately behind the foramen magnum remains membranous till shortly before birth and is the commonest site for a cerebral meningocele.

(2) Chondrification takes place in the mesoderm around the internal ear, giving rise to the **auditory capsule**, in which the *petrous* and *mastoid* parts of the *temporal* bone ossify.

(3) A small transverse strip of cartilage appears in front of the parachordal plate and gives rise to the *dorsum sellæ* (Fawcett, 1910).

(4) Farther forward, a nodule of cartilage appears above and in front of the end of the notochord and gives rise to the cartilaginous *body of the sphenoid* bone. It enlarges and sends forwards two extensions which pass one on each side of the cranio-pharyngeal canal—*i.e.*, the passage through which the pharyngeal part of the hypophysis enters the cranial cavity. These extensions join together in front of the canal to form the anterior part of the cartilaginous body of the sphenoid, and so provide the canal with cartilaginous boundaries. The boundaries grow medially and usually occlude the canal during the third month, though occasionally it may remain open.

(5) Chondrification occurs in the region that corresponds to the root of the *pterygoid process* and the root of the *greater wing* of the sphenoid, including the *lingula* and the part around the *foramen rotundum*.

(6) Chondrification occurs in the whole of the region of the lesser wing; in the cartilaginous state it is therefore bigger than the greater wing.

(7) Chondrification occurs in the region of the nose to form a cartilaginous **nasal capsule** during the third month. A cartilaginous plate, called the **paranasal cartilage**, appears in the lateral wall of the nasal cavity. It gives rise to the *labyrinth* of the ethmoid (including its *conchæ*) to the *inferior concha*, and to the *sphenoidal concha*; part of it is included in the maxilla; and part persists through life as the *cartilages of the side* of the nose. Chondrification in the primitive septum takes place partly by extension from the cartilaginous sphenoid, and partly by the development of independent **paraseptal cartilages** in each side of the anterior part of the septum. The perpendicular plate of the ethmoid ossifies in the cartilaginous septum, but a great part of the cartilaginous septum persists throughout life; and the pair of subvomerine cartilages are persistent parts of the paraseptal cartilages. The cartilaginous roof is formed partly by fusion of the cartilage in the side-wall with that in the septum, and partly by independent chondrification of the mesoderm around the filaments of the olfactory nerve. Chondrification in the floor is very incomplete.

All the various chondrified areas of the mesoderm fuse together and form a cartilaginous platform in the base of the skull from which the cartilages of the pharyngeal arches are suspended. Most of the cartilage is ossified; part is replaced by bone ossified in the surrounding membrane; parts persist as the cartilages in the *sides* and *septum* of the nose and in the *foramina lacera*; and parts survive till maturity in the cartilaginous joints that unite the sphenoid to the ethmoid and to the occipital and between the occipital and the petrous temporal.

Some of the bones of the skull are ossified in the cartilage of the base, namely: the occipital bone, except the part of its squama above the nuchal lines; the petrous and mastoid parts of the temporal bone; the body of the sphenoid, the lesser wings, the roots of the greater wings and of the pterygoid processes; the ethmoid; the inferior concha.

Some of them are ossified in the membrane that overlies the cartilages of the nose, namely, the vomer, the lacrimal, the nasal, and the upper part of the maxilla.

Some are ossified from the membrane that underlies the mucous lining of the bucco-pharyngeal cavity, namely, the lower part of the maxilla, the palatine, and the greater part of the pterygoid process.

The frontal, the parietal, the squamous temporal, the upper part of the occipital squama, and the greater wing of the sphenoid (all but its root) are ossified in the membranous brain-envelope. The zygomatic bone ossifies in membrane which is continuous with the brain-case round the lateral margin of the orbit. The tympanic plate ossifies in membrane that overlies the cartilaginous auditory capsule.

Although the skull never shows evidence of segmentation, probably owing to the need of stability even in the early evolutionary forms, it is assumed that the chordal part of the base has arisen by the fusion of segments equivalent to vertebræ, because of—(1) the presence of myotomes in the head region, (2) the connexion with the series of pharyngeal arches, and (3) the segmental arrangement of nerves. The guide to the disposition of the nerves is their points of exit through the dura mater, for that is derived from the inner part of the primitive brain-envelope; owing to the evolutionary changes that have taken place in the outer parts of the mammalian brain-envelope, the apertures through which the nerves leave the skull—though very constant in position—do not in every case correspond to the points where they pierce the dura, *e.g.*, the oculomotor and the abducent nerves in the human head.

The mammalian occipital bone is regarded (Froriep, 1882) as the equivalent of four fused vertebræ, and there is reason to believe that in some vertebrates the occipital region of the primordial cranium is increased by inclusion of vertebræ from the cephalic end of the vertebral column. The primitive cranial nerves are related to the chordal part of the primordial cranium (except the olfactory and the optic nerves, which are parts of the brain); Gegenbauer (1872) concluded, from a study of the metameric arrangement of cranial nerves, that the chordal part was the equivalent of nine fused vertebræ, and he called the chordal part the **vertebral** part of the cranium. The prechordal part he called **evertebral** or non-vertebral, and regarded it as a new formation developed to contain and protect the enlarging brain and the organs of smell and sight.

The outstanding features that distinguish the human skull are the large size of the brain-case, the small size of the face, and the fact that the skull is poised on the end of the backbone. Its position on the vertebral column reacts on its outward configuration; the occipito-vertebral joints are placed so that the fore and hind parts of the head nearly balance each other; there is therefore an absence of the prominent ridges and crests for the attachment of the muscles and ligaments required to hold the head in position in lower mammals. The small size of the face is due chiefly to reduction of the bulk and length of the jaws and reduction of the size of the teeth. Diminution of the mandible reacts on the form of the skull, for the muscles of mastication do not need to be so large, and there is corresponding reduction in the fossæ that lodge them and in the surfaces and crests that give origin to them.

For a complete account of the development of the vertebrate skull, with full references, see de Beer (1937), and for variations of the bones of the skull, the standard works of Le Double (1903, 1906).

INDIVIDUAL BONES OF CRANIUM

Frontal Bone

The *main part* of the **frontal bone** is the shell-like bone in the front of the skull above the orbital openings. A *nasal part* is in the roof of the nose; and a pair of *orbital plates* roof in the greater part of the orbits.

Six ~~Four~~ surfaces can be recognized in the main part of the bone—frontal in front, cerebral behind, and a pair of temporal surfaces at the sides. [illegible] orbital surf

The ~~*frontal*~~ *surface* is rounded from side to side and from above downwards. The most pronounced parts of the convexity are a pair of **frontal eminences** seen about 35 mm. above the orbit. The surface ends inferiorly in a pair of concave edges separated by an articular area called the **nasal notch.** The concave edges are **supra-orbital margins.** Each margin ends later-

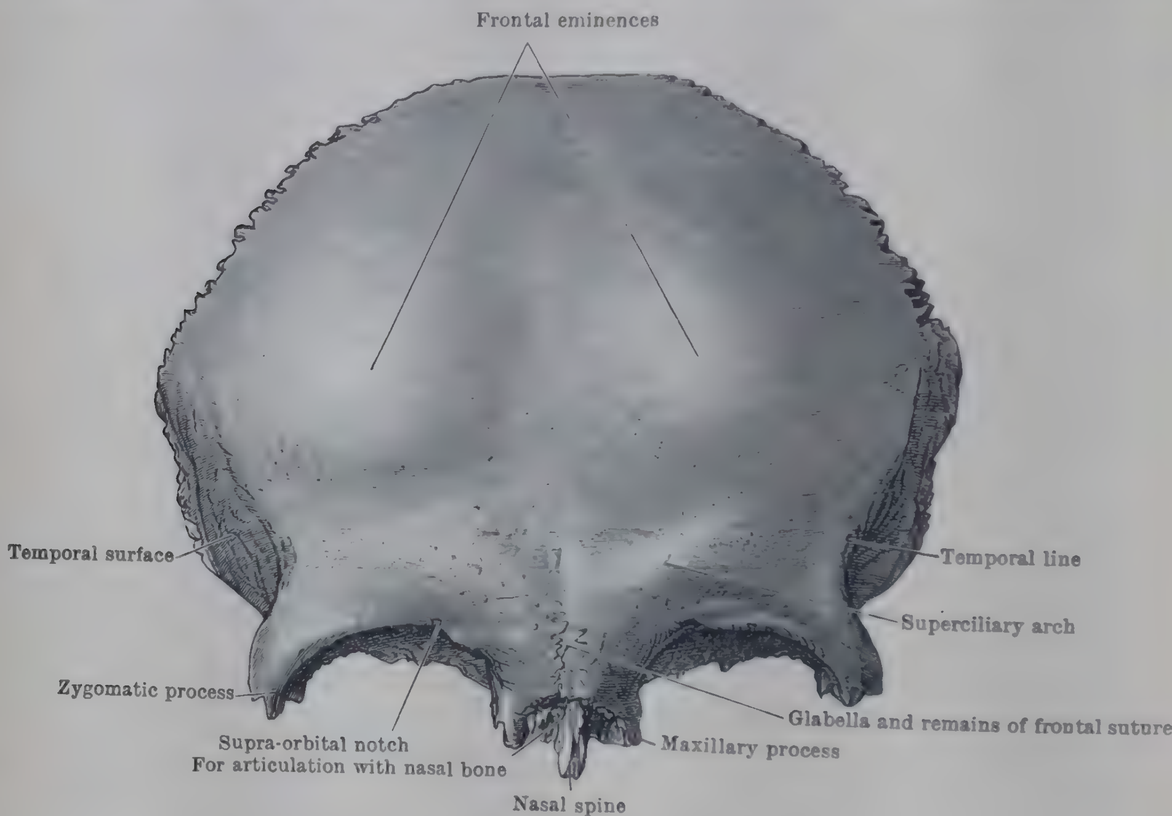


Fig. 178.—Frontal Bone (Anterior View).

ally in a prominent **zygomatic process.** The medial end descends to a slightly lower level as the **maxillary process.** Between its medial and intermediate thirds the margin is crossed by a groove, often converted into a foramen—the **supra-orbital notch** or **foramen.** Above the nasal notch the **glabella** forms a low elevation in which the remains of the frontal suture may be seen. On each side, the glabella is continuous with a curved elevation, of varying length and prominence, called the **superciliary arch,** which is a little above the supra-orbital margin.

From the zygomatic process the **temporal line** curves upwards and backwards, as a ridge separating the frontal from the *temporal surface.*

The *cerebral surface* is concave; it is marked by **impressions for the gyri** of the brain, and by narrow grooves for meningeal vessels; on each side of the median plane there are **granular pits,** varying in number and size, for the lodgment of arachnoid granulations. On the lower part of the surface there is a median ridge, called the **frontal crest,** which fades away as it is traced upwards. A groove called the **sagittal sulcus** begins on the crest and extends upwards to the margin of the bone, widening as it proceeds. A small hole, called the **foramen cæcum,** which is situated usually between the ethmoid and the lower end of the frontal crest, may sometimes be seen in its entirety on the separate frontal bone.

Each **orbital plate** is a thin, brittle, curved plate which is convex upwards and has a triangular outline. Its upper or *cerebral surface* is convex and uneven, showing ridges and depressions corresponding to the sulci and gyri of the frontal lobe, which lies on it; it shows also narrow grooves for meningeal vessels.

The larger, lateral part of the *inferior surface* is smooth and concave, and forms the greater part of the roof of the orbit, extending forward to the supra-orbital margin. In its antero-medial part there is either a very small depression **(trochlear fossa),** or a spicule of bone

(trochlear spine), or both, for the attachment of the trochlea or pulley of the superior oblique muscle of the eyeball. Laterally the surface is overhung by the supra-orbital margin and the zygomatic process, so that a wide depression or **fossa for the lacrimal gland** is formed. The medial part of the inferior surface is a wide strip that overlies the labyrinth of the ethmoid, roofing in ethmoidal sinuses; it presents therefore a number of irregular depressions that correspond to the sinuses. Anteriorly the opening from the frontal sinus is seen (see p. 199). Farther back there are two narrow, nearly transverse grooves which, with corresponding grooves on the ethmoid labyrinth, form the **anterior** and **posterior ethmoidal canals**. The medial margins of the two orbital plates are parallel with each other. Their posterior halves, or more, are separated by an interval called the **ethmoidal notch** because it is occupied by the cribriform plates of the ethmoid when the bones are articulated. The anterior halves of the margins are united to the nasal part of the bone.

The **nasal part** is the small portion of bone in front of the ethmoidal notch. From its centre the **nasal spine** projects downwards and forwards into the nasal septum between the nasal crest of the nasal bones and the perpendicular plate of the ethmoid, articulating with both. On each side of the root of the spine the nasal part presents a smooth, grooved surface that slopes from above downwards and forwards and forms part of the roof of the nasal cavity.

Articulations.—The zygomatic process articulates with the frontal process of the zygomatic bone. Behind that, a rough, triangular area articulates with the greater wing of the sphenoid. Above that, the whole serrated *parietal margin* articulates with the two parietal bones. The

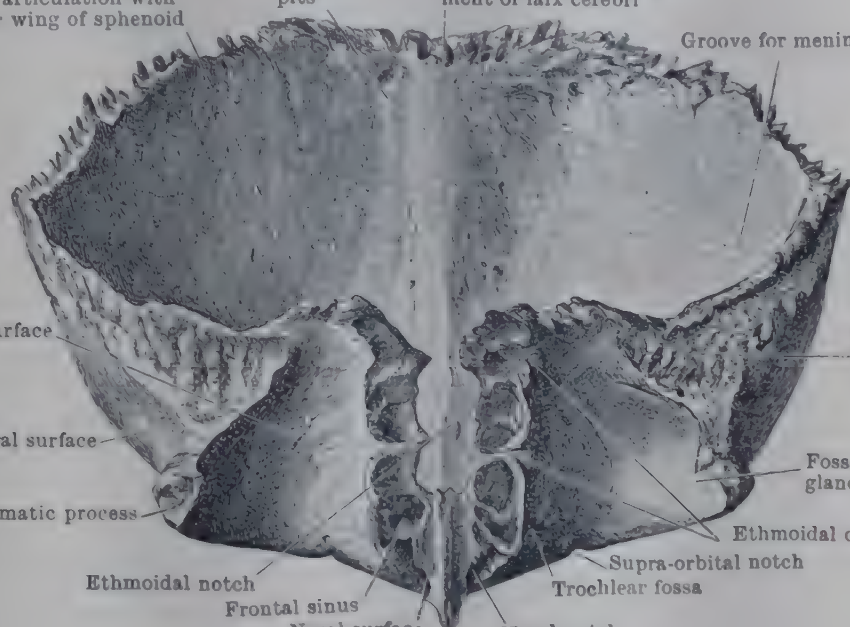


FIG. 179.—FRONTAL BONE AS SEEN FROM BELOW.

posterior margin of the orbital plate articulates with the lesser wing of the sphenoid. The medial part of the inferior surface articulates with the labyrinth of the ethmoid. The maxillary process articulates with the frontal process of the maxilla and with the lacrimal bone. Each half of the floor of the nasal notch articulates with the upper end of the nasal bone. The nasal spine articulates with the nasal bones and the perpendicular plate of the ethmoid.

Ossification.—Ossification begins in membrane from one centre for each half. Each centre appears about the sixth or seventh week in the region above the zygomatic process. Three pairs of centres are said to appear a little later—in the zygomatic processes, in the nasal spine, and at the trochlear fossæ. Fusion between these and the rest of the bone is complete about the sixth or seventh month of intra-uterine life. At birth the halves of the bone are separated by the *frontal suture*. Obliteration of the suture begins usually at the level of the frontal eminences, and gradually proceeds till, at the fifth or sixth year, the suture is almost closed, traces being left only above and below. In about 8 per cent of Europeans the suture persists in the adult.

Structure and Variations.—Like other bones of the skull-vault the frontal bone has two tables of compact substance with a layer of **diploë** between them. The diploë disappears from the part that encloses the frontal air-sinuses. The zygomatic process is dense throughout and is shaped so as to meet the pressure transmitted through the zygomatic bone from the closed jaws.

The commonest variation is a persistence of the frontal suture. A persisting frontal suture is called a **metopic suture**; it is more common in some races than in others, and has been said to be more frequent in the brachycephalic than in the dolichocephalic type. Ashley-Montagu (1937) believes it to be an inherited condition. An example of persistence of the metopic suture with absence of the coronal suture is recorded by Rau (1934). Sutural bones may occur at the

anterior fontanelle ; their fusion with one or other half of the frontal explains how the metopic suture is not always in line with the sagittal suture ; occasionally they coalesce to form a *bregmatic bone*. In rare cases the frontal bone articulates directly with the orbital surface of the maxilla behind the lacrimal—a condition which exists normally in the skulls of the chimpanzee and gorilla. There is sometimes a small arterial groove close to the medial side of the supra-orbital notch ; occasionally there is a second supra-orbital foramen a little lateral to the middle of the supra-orbital margin. Frequently the bone of the floor of the lacrimal fossa is cribriform. Independent ossicles (*supranasal bones*) have been found in the anterior part of the metopic suture ; and a *metopic fontanelle, metopic canals* and *ossicles* (ossa interfrontalia) have been described.

Parietal Bones

The **parietal bones** form a great part of the vault. They articulate with each other, with the frontal *anteriorly*, with the occipital *posteriorly*, and with the temporal and the sphenoid *inferiorly*. Each bone has an outer and an inner surface, four borders, and four angles.

The **outer surface** is convex. The most convex region is the **parietal eminence**, and it marks the position of the ossific centre. At a variable distance from the inferior border of the bone, and more or less parallel to it, there are two parallel curved lines about half an inch apart. These are the **superior** and **inferior temporal lines**, and are continuous with the two branches

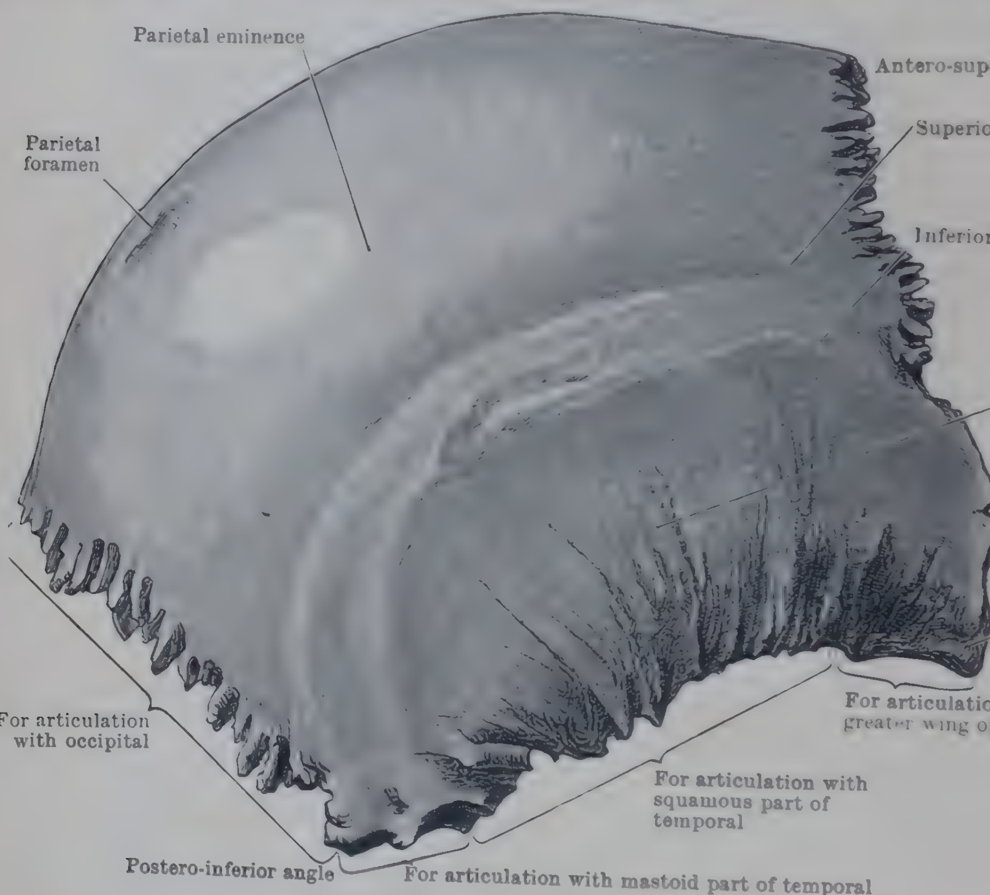


FIG. 180.—RIGHT PARIETAL BONE (Outer Surface).

of the temporal line of the frontal bone. The **parietal foramen** is a small aperture near the upper border of the bone and about an inch from its postero-superior angle.

The **inner surface** is concave. It displays impressions for the gyri of the brain and also well-marked grooves for the branches of the middle meningeal vessels ; the grooves radiate from the antero-inferior angle and the lower margin of the bone. Close to the upper margin there is a series of pits for arachnoid granulations, and along the margin the bone is grooved to form one half of the **sagittal groove**. At the postero-inferior angle the bone is slightly grooved by the transverse sinus.

The *anterior*, *superior*, and *posterior borders* are deeply serrated. The **anterior border** articulates with the frontal bone, forming with it the *coronal suture*. In the upper part of the suture the frontal bone overlaps the parietal, while the parietal overlies the frontal below. The **posterior border** is united with the occipital bone to form the *lambdoid suture*. The **superior border** articulates with its fellow to form the *sagittal suture* which shows, until synostosis occurs, a characteristic arrangement of reciprocal pegs and sockets. The **antero-superior angle** is almost rectangular ; the **postero-superior angle** is obtuse. The **inferior border** is sharp and curved, and is shorter than the others. It articulates with the squamous part of the temporal bone, which overlaps the parietal bone ; the parietal bone, at its lower edge, is therefore bevelled at the

expense of the outer table, and it is grooved or fluted. The **antero-inferior angle** is acute; it articulates with the greater wing of the sphenoid and is wedged into the angle between the greater wing and the frontal bone. It is bevelled at the expense of its inner table anteriorly, but inferiorly it is thinned at the expense of its outer table. The **postero-inferior angle** is truncated and deeply serrated, and articulates with the mastoid part of the temporal bone.

Ossification.—The parietal bone ossifies in membrane by two centres that appear, one above the other at the parietal eminence, in the eighth week of intra-uterine life, and gradually unite during the fourth month. Ossification spreads radially towards the edges and angles; but at the angles the membranous condition persists for some time—hence the fontanelles. Ossification is a little delayed also in the region of the parietal foramina, so that a sagittal fontanelle is sometimes present at birth.

Structure and Variations.—The parietal bone is made of two tables of compact bone with a layer of diploë between them. It is thin towards its lower part and is thickest along the upper border. Occasionally the outer table is very thin above the temporal lines.

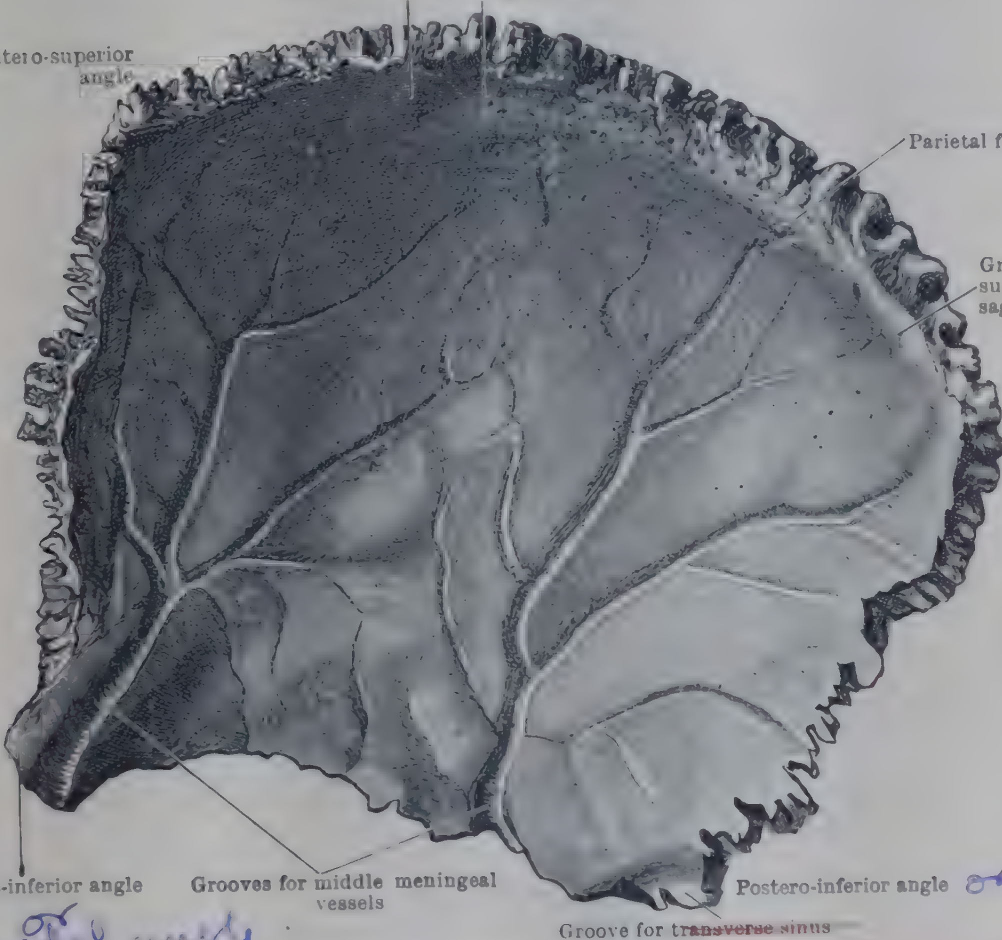


FIG. 181.—RIGHT PARIETAL BONE (Inner Surface).

The parietal bone is sometimes divided into an upper and lower part by an antero-posterior suture; in one case it was incompletely divided into an anterior and a posterior part by a vertical suture; and a tripartite condition also has been recorded. The parietal foramina vary greatly in size, and to some extent in position. They are sometimes absent on one or both sides. They correspond in position to the sagittal fontanelle. Sometimes the ossification of the sagittal fontanelle is incomplete and a small transverse fissure remains. Occasionally in the region of the anterior fontanelle an ossicle of variable size may be met with. According to its fusion with adjacent bones it may disturb the direction of the sagittal suture.

Occipital Bone

The four parts of the **occipital bone** are arranged around the foramen magnum. The expanded plate behind the foramen is the **squamous part**. The thick, rod-like portion in front of the foramen is the **basilar part**. The pair of **condylar parts** are at the sides of the foramen.

The **squamous part** resembles a Gothic arch in outline, and it is curved in every direction. Inferiorly it forms a small portion of the middle of the posterior boundary of the foramen magnum, and it unites, on each side of that, with the condylar part of the bone.

The **external occipital protuberance** is a prominence about the centre of its *external surface*, and a pair of **superior nuchal lines** curve from it towards the lateral angles of the bone; above them there is occasionally another pair of curved ridges called the **highest nuchal lines**. The part below the superior nuchal lines is divided into a right and a left half by a median ridge, the **external occipital crest**, which extends from the protuberance to the foramen magnum. From the middle of the crest a pair of **inferior nuchal lines** extend towards the lateral margins of the bone.

The *internal surface* is concave and is divided into four fossæ by a cruciate arrangement of grooved ridges that meet at a prominence called the **internal occipital protuberance**, at one side of which there may be a fossa for the confluence of sinuses. The upper pair of fossæ lodge the occipital lobes of the cerebrum, and the hemispheres of the cerebellum occupy the lower pair. The ridge that extends from the protuberance to the foramen magnum is the **internal occipital crest**; the *grooves for the transverse sinuses* pass sidewards from the protuberance; the *sagittal groove* descends to it and usually runs into the right transverse groove.

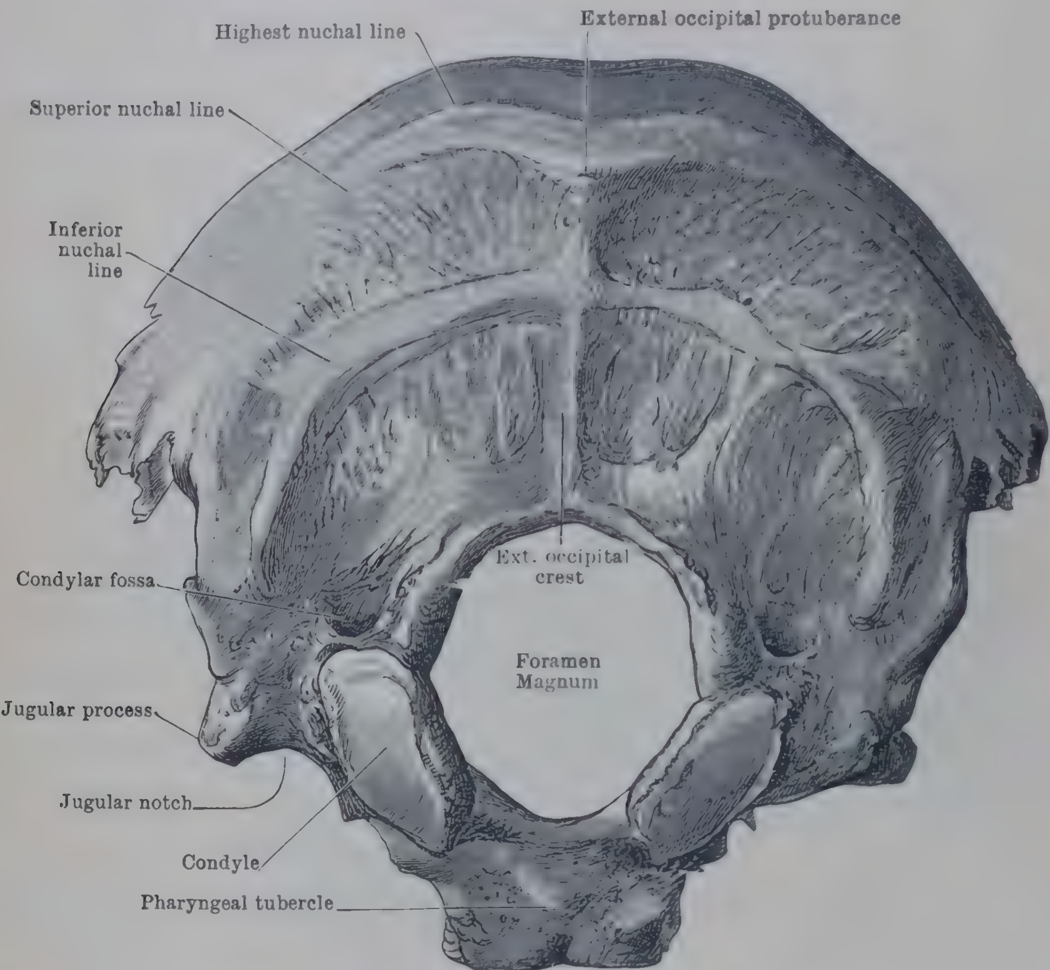


FIG. 182.—OCCIPITAL BONE AS SEEN FROM BELOW.

The **superior angle**, more or less sharp and pointed, is wedged in between the two parietal bones, and the **superior borders**, much serrated, articulate with them—forming the **lambdoid suture**. The **lateral angle** and **border** articulate with the mastoid portion of the temporal bone.

Each **condylar part** is placed at the side of the foramen magnum; on their lower surfaces they bear the **occipital condyles**, by which the skull articulates with the atlas. The condyles are elongated and oval; they are situated at the side of the anterior half of the foramen magnum; their anterior ends are closer together than their posterior ends; their articular surfaces are convex from before backwards and look in a lateral direction as well as downwards. Each articular surface is supported on a boss of bone through which the **anterior condylar canal** passes. The canal opens externally into a depression immediately lateral to the anterior part of the condyle; its internal opening is a little above the margin of the foramen magnum. The wide depression behind the condyle is the **condylar fossa**; the *posterior condylar canal* (when present) opens into it. The bone lateral to the posterior half of the condyle is the **jugular process**; its *anterior* border, free and rounded, is the posterior margin of the jugular foramen and bounds the **jugular notch**. *Laterally*, the jugular process is united by cartilage to the petrous part of the temporal bone. *Posteriorly*, it joins the occipital squama. Its *lower* surface is rough. The *upper* surface is grooved by the sigmoid sinus, and the internal opening of the posterior condylar canal is in or near the groove. The **jugular tubercle** is a smooth eminence on the upper surface of the condylar part between the foramen magnum and the anterior part of the jugular

foramen; its posterior part is often slightly grooved by the ninth, tenth, and eleventh cranial nerves.

The **basilar part** extends forwards and upwards from the foramen magnum. Its anterior extremity is usually sawn across, as, after the twenty-fifth year, it is fused with the body of the sphenoid bone; the sawn surface is quadrilateral in outline. Posteriorly, where the basilar part bounds the foramen magnum, it is broad and thin. At the centre of its *lower surface* there is a small elevation called the **pharyngeal tubercle**. The *upper surface* is the posterior part of the clivus of the skull, and it is transversely concave. Each *lateral margin* is faintly grooved for the inferior petrosal venous sinus, and, below that, it is rough for the cartilage that unites it to the petrous part of the temporal bone.

The **foramen magnum** is variable in size and outline, but is usually ovoid, with the long axis antero-posterior. Anteriorly the condyles encroach upon it, and reduce its transverse diameter.

Ossification.—The part above the nuchal lines (*interparietal part*) is ossified in membrane, and the rest in cartilage.

The **basilar part** is ossified from one centre which appears in the sixth week of intra-uterine

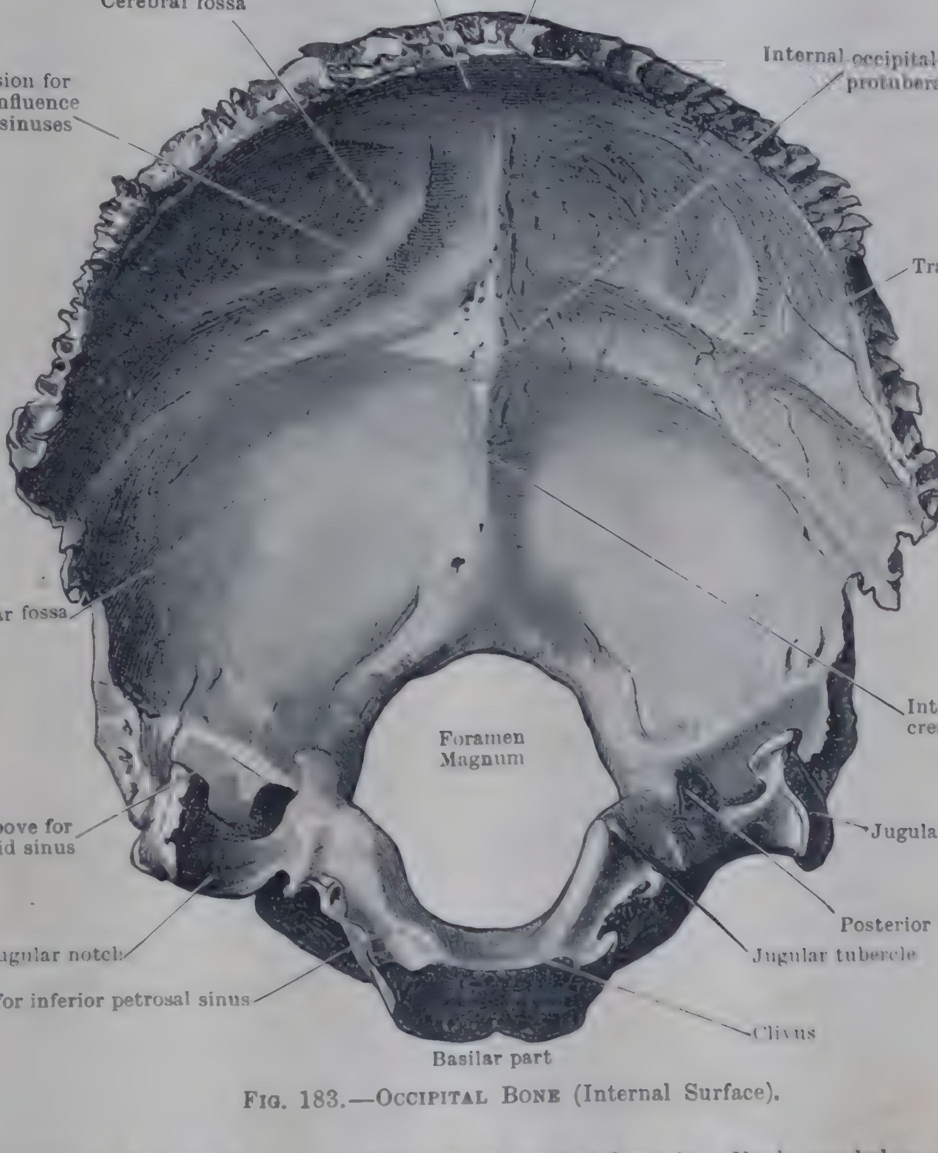


FIG. 183.—OCCIPITAL BONE (Internal Surface).

life; the anterior fourth of each condyle also is ossified from it. Each **condylar part** (including only the posterior three-fourths of the condyle) is ossified from one centre which appears at the eighth week. The *supra-occipital part* of the **squama** (*i.e.*, the part below the highest nuchal line) is ossified from a pair of centres that appear at the position of the protuberance in the seventh week and rapidly unite; the *interparietal part* also is ossified from a pair of centres that appear in the eighth week and soon fuse; osseous union of the two parts of the squama begins in the median plane during the third month but is not quite completed at birth.

At birth the four component parts are separable bones united by cartilage. The two condylar parts fuse with the squama during the third year, and with the basilar part during the fourth or fifth year. The basilar part is united to the sphenoid by cartilage (Fig. 306 B) which begins to disappear between the eighteenth and twentieth years (earlier in the female), and is completely replaced by bone by the twenty-fifth year.

The single basilar centre may be the result of the speedy fusion of two centres—an anterior and a posterior—each of which may be a fused pair; and each of the two interparietal centres may

be a fused pair. Small centres are sometimes seen in the cartilage between the squama and the condylar part; and occasionally an independent centre appears in the posterior margin of the foramen magnum at the end of the fourth month and produces a nodule, called the *ossicle of Kerkring*, which fuses with the squama before birth.

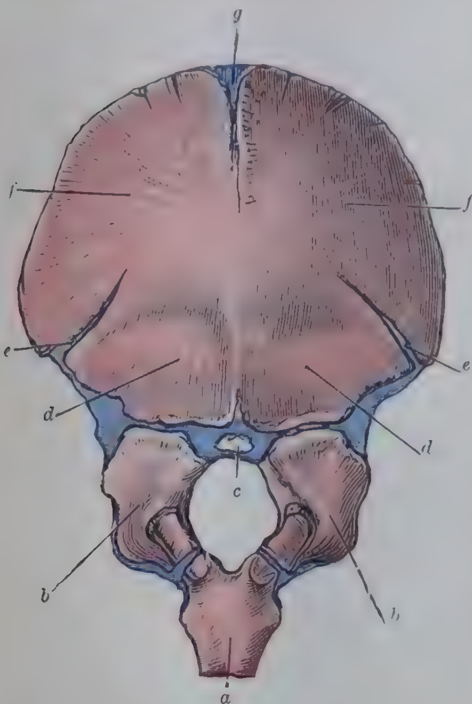


FIG. 184.—OSSIFICATION OF OCCIPITAL BONE.

a, Basilar centre ; *b*, Condylar part ; *c*, Ossicle of Kerkring ; *d*, Supra-occipital ; *e*, Fissure between supra-occipital and interparietal ; *f*, Interparietal ; *g*, Fissure between interparietals.

Osseous union between the upper and lower parts of the squama and between its right and left halves is incomplete near the margins of the bone at birth. Occasionally in the adult a suture extends medially from the lateral angle of the squama and indicates partial failure of union between its supra-occipital and interparietal parts. In some skulls the suture is complete, and the upper part of the squama is a separate *interparietal bone*.

Structure and Variations.—The squama shows thickenings of compact bone at the ridges and crests, and it is thickest at the protuberances; the floors of the lower pair of fossæ are thinner than the upper pair and their lower parts have no diploë. The basilar part is made of spongy substance surrounded by compact substance which is thickest on the lower surface. In the condyles the spongy substance is arranged radially to the convex articular surfaces. The anterior condylar canal is surrounded by very dense bone.

The *torus occipitalis transversus* is the term applied to an occasional elevation which includes the external occipital protuberance and extends laterally along the superior nuchal line. Occasionally an emissary vein pierces the bone opposite the occipital protuberance. In about 15 per cent. of skulls the anterior condylar canal is double; much more rarely there are three or even four foramina. The most striking of the many variations is the separation of the upper part of the squama to form the *interparietal bone*. The interparietal bone may exist as separate, symmetrical halves; or it may be in three pieces—or even four, in which case the upper two are called *pre-interparietal* bones. Instances are recorded of a separate epiphysis between the basi-occipital and the sphenoid called the *os basioticum* or the *os pre-basi-occipitale*. An oval pit, called the *pharyngeal fossa*, is sometimes seen in front of the pharyngeal tubercle; it marks the site of the pharyngeal bursa. Occasionally the basilar part is pierced by a small vein. The **third occipital condyle** is an occasional process which juts from the anterior border of the foramen magnum and articulates with the odontoid process. The third condyle may have a double origin—one part ossified in the sheath of the notochord, and the other in the hypochordal bow of the lowest occipital vertebra; that view gains support from a fœtal skull in which the condyle was represented by two tubercles. The *paramastoid process* is an occasional eminence on the lower surface of the jugular process; it may be a mere elevation, rough or smooth; or it may be a projecting spine whose apex articulates with the transverse process of the atlas. The size and shape of the foramen magnum vary much in different people and races, as also the disposition of its plane. The atlas is often fused with the occipital bone. Sometimes there is evidence of the intercalation of a new vertebral element (*pro-atlas*) between the atlas and the occipital bone.

Temporal Bones

Each **temporal bone** lies about the middle of the lower half of the side of the skull, and enters largely into the formation of the cranial base. It is placed between the occipital behind, the parietal above, the sphenoid in front, and the occipital and sphenoid medially and below. It has four main parts—squamous, petrous, mastoid, and tympanic.

The **squamous part** is a thin, scale-like plate of bone placed vertically in the side of the skull. It has a semicircular upper border, and cerebral, temporal and infratemporal surfaces; the zygomatic process projects forwards from the lower part of its temporal surface; most of its infratemporal surface is occupied by the articular eminence and fossa.

The anterior part of the **upper border** is nearly vertical and articulates with the greater wing of the sphenoid. The remainder of the border is bevelled at the expense of the inner table, overlaps and articulates with the parietal bone, and ends posteriorly by joining the mastoid part at an angle that accommodates the posterior inferior angle of the parietal bone.

The **cerebral surface** joins the petrous part inferiorly, and the remains of the suture between them can often be seen in the adult skull. The surface is marked by *impressions for gyri*, and it is crossed by a groove or grooves for branches of the middle meningeal vessels. The **temporal surface**, smooth and slightly convex, is larger than the cerebral surface.

The **zygomatic process** or **zygoma** springs from the lower and anterior part of the temporal surface by two roots, and curves forwards to end in an oblique, serrated edge which articulates with the temporal process of the zygomatic bone. The *upper border* of the process is continuous with the posterior root. The *posterior root* is a salient ridge that extends backwards above the external auditory meatus and becomes continuous with a blunt, low ridge, called the **supramastoid crest**, which curves upwards and becomes continuous with the temporal lines of the parietal bone. The *lower border* of the zygomatic process is continuous with the *anterior root*, which is a broad, thick bar of bone that turns abruptly in a medial direction to join the side of the skull. The lateral end of the root is prominent and is called the **tubercle** of the root of the zygoma; the medial end is continuous with the **articular eminence**—the lower surface

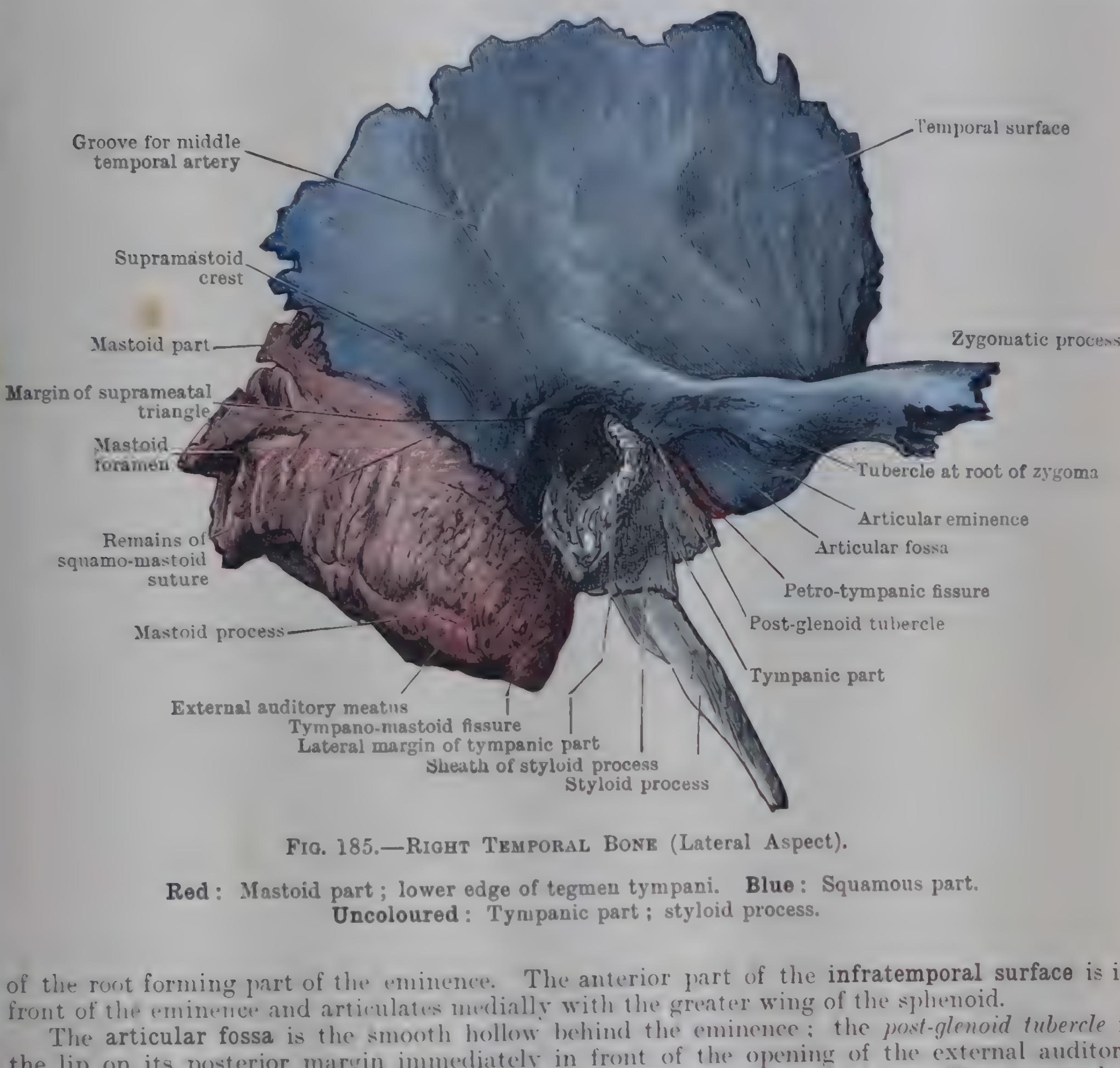


FIG. 185.—RIGHT TEMPORAL BONE (Lateral Aspect).

Red: Mastoid part; lower edge of tegmen tympani. **Blue:** Squamous part. **Uncoloured:** Tympanic part; styloid process.

of the root forming part of the eminence. The anterior part of the **infratemporal surface** is in front of the eminence and articulates medially with the greater wing of the sphenoid.

The **articular fossa** is the smooth hollow behind the eminence; the *post-glenoid tubercle* is the lip on its posterior margin immediately in front of the opening of the external auditory meatus. The sloping plate behind the fossa is the tympanic part of the bone. The narrow cleft between them is the **squamo-tympanic fissure**. A thin edge of bone (the lower edge of the tegmen tympani) is usually seen in the medial part of the fissure, dividing it into two clefts—the *petro-tympanic fissure* behind the edge and the *petro-squamous fissure* in front (see pp. 176, 223).

Behind the external auditory meatus, and below the supramastoid crest, the squamous element extends downwards as a pointed process, called the *post-auditory process*; this process forms the lateral wall of the tympanic antrum and helps to form the posterior wall of the meatus. Its lower end unites with the tympanic part. In the adult the process is occasionally sharply defined posteriorly by an oblique irregular fissure—the remains of the squamo-mastoid suture—which is often not closed till puberty. The **suprameatal triangle** is a small depression immediately above and behind the meatus.

The **tympanic part** of the temporal bone is a curved plate the concave **upper surface** of which forms the anterior, lower, and part of the posterior wall of the external auditory meatus. *Medially* it is fused with the petrous temporal. Its **anterior surface** is free and concave and has three borders. The *upper border* forms the posterior boundary of the squamo-tympanic and petro-tympanic fissures. The *lower border* is sharp and uneven, and partly ensheathes the root of the styloid process. The *lateral border*, curved, thick, and rough, gives attachment to the cartilage of the auricle. The part of the plate that curves upwards in the posterior wall of the meatus is united with the mastoid temporal and with the post-auditory process of the squamous temporal; but between it and the mastoid there is a narrow cleft—often very indistinct—called the **tympano-mastoid fissure**.

The **external auditory meatus** is a canal about 15 mm. long; it is directed obliquely medially and a little forwards, with a slight upward convexity. It is oval in outline, the long axis of the oval being nearly vertical near the lateral end, but oblique from above downwards and backwards near the medial end. The upper margin of the lateral orifice overhangs the lower margin, but the medial orifice, which is closed by the tympanic membrane, is so oblique that the lower wall of the meatus is almost, or quite, as long as the upper wall.

The **mastoid part** lies behind the squamous and tympanic parts. *Anteriorly* it is fused with those parts, and, more deeply, with the petrous part. Its *upper border* articulates with the parietal bone, and its *posterior border* with the occipital squama. *Inferiorly* it sends down a blunt projection, called the *mastoid process*, the root of which is bounded medially by a well-marked **mastoid notch**. Between the notch and the lower part of the occipito-mastoid suture there is an uneven strip of bone on which the occipital artery makes a shallow groove nearly parallel to the notch. The *lateral surface* is convex and slightly roughened; the **mastoid foramen** opens on it near its posterior border or into the occipito-mastoid suture. The *medial surface* is in the side-wall of the posterior cranial fossa. The *sigmoid groove* courses over the anterior

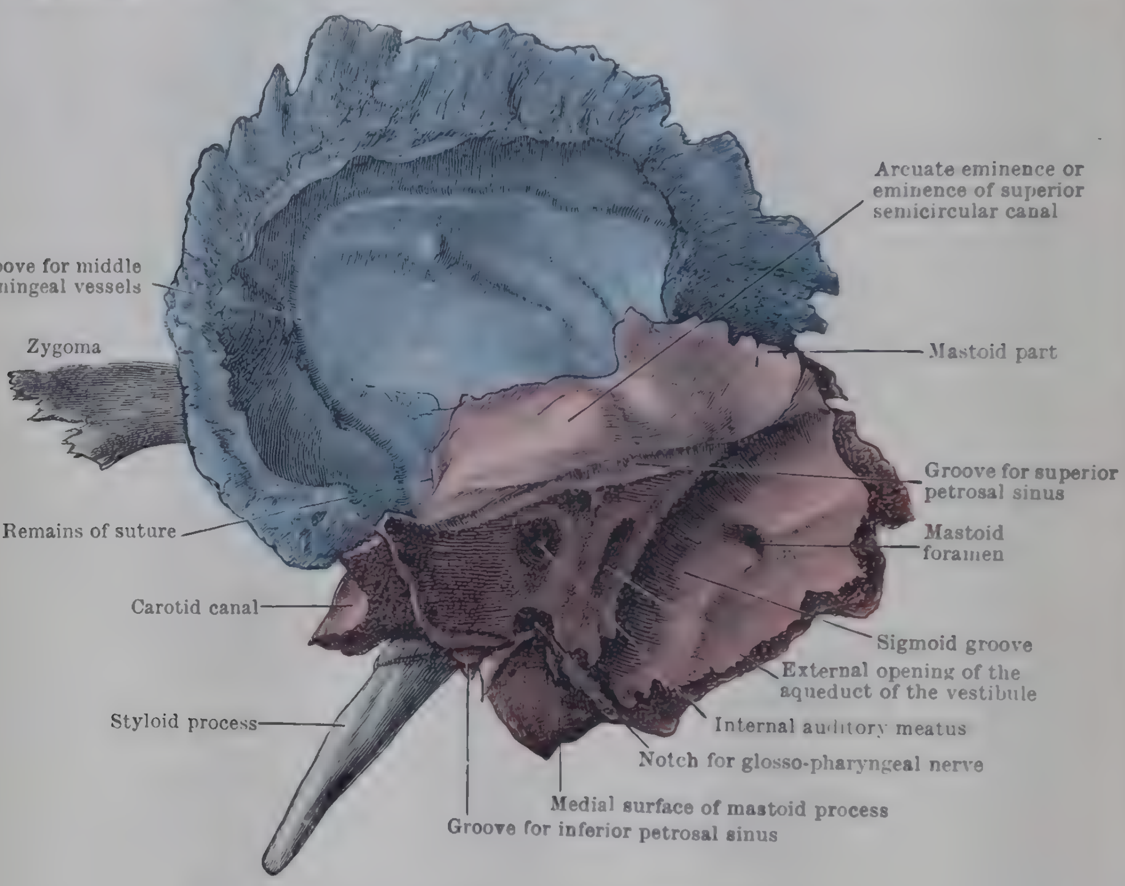


FIG. 186.—RIGHT TEMPORAL BONE (Cerebral Aspect).
Red: Petro-mastoid. **Blue**: Squamous. **Uncoloured**: Zygoma; styloid process.

part of this surface, and is partly on the petrous temporal. It has on it the internal opening of the mastoid foramen.

The **petrous part** is shaped like a three-sided pyramid. By its base it is partly united obliquely to the other parts of the temporal bone, and is partly free, forming the medial wall of the tympanic cavity. Its apex is directed medially, forwards, and a little upwards. Its three surfaces are arranged as follows: The **anterior** looks upwards, slightly forwards, and a little laterally, and it forms part of the posterior wall of the middle cranial fossa. The **posterior** is directed backwards and medially, and it forms part of the anterior wall of the posterior cranial fossa. The **inferior** is seen on the lower surface of the skull and is directed downwards. The margins are named anterior, superior, and posterior.

The **anterior margin** is partly united to the squamous temporal, but its medial part is a free edge that articulates with the posterior border of the greater wing of the sphenoid and forms an acute angle with the anterior border of the squamous part; within the angle is wedged the posterior corner of the greater wing. At the apex of the angle the openings of two canals are seen. These canals are separated by a thin, bony septum, and they lead backwards and laterally to the tympanic cavity. The upper is the *canal for the tensor tympani*. The lower is wider, and is the *bony part of the pharyngo-tympanic tube*.

The **posterior margin** is in part articular. Posteriorly and laterally it corresponds to the upper margin of an area on the inferior surface which articulates with the jugular process of the occipital. Medial to that it is irregularly notched, and bounds the jugular foramen anteriorly. The remaining, antero-medial part articulates with the basilar part of the occipital bone; the inferior petrosal sinus runs along the articulation, grooving both bones.

The **superior margin** is a sinuous edge grooved lengthways for the superior petrosal sinus, and slightly depressed near the apex where it is crossed by the trigeminal nerve.

The **inferior surface** of the petrous part is rough and uneven. On it the following parts are to be noted :—The **styloid process** projects downwards, forwards, and medially from behind the lower edge of the tympanic plate. The **stylo-mastoid foramen** is between the root of the styloid process and the mastoid notch. The **jugular fossa** is the concavity medial to the root of the styloid process. A small area behind and lateral to the fossa is united by cartilage to the jugular process of the occipital bone. A tiny aperture on the lateral part of the wall of the fossa is the medial end of the **mastoid canaliculus**, which opens laterally in the tympano-mastoid fissure. The oval or circular opening in front of the jugular fossa is the lower end of the **carotid canal**; the canal passes upwards for a short distance, and then, becoming horizontal, it passes medially and forwards, and ends at the apex as an oblique opening with jagged margins. On the lateral wall of the ascending part of the canal there are two or more small openings of **carotico-tympanic canaliculi**, which communicate with the tympanum. On the ridge between the carotid canal and the jugular fossa, there is the lower opening of the **tympanic canaliculus**, which leads up to the tympanum. The groove on the small area between the medial parts of the canal and fossa leads up to the **notch for the ninth nerve** on the margin of the jugular foramen. The *external opening of the cochlear canaliculus* is at the bottom of a pit in the notch. The **quadrate area** is the rough part medial to the opening of the carotid canal; a strip along its antero-lateral border articulates with the greater wing of the sphenoid and helps to form the groove for the cartilage of the pharyngo-tympanic tube; its postero-medial border is united to the occipital bone by dense fibrous tissue or cartilage—the gutter between the two bones being called the *petro-basilar fissure*.

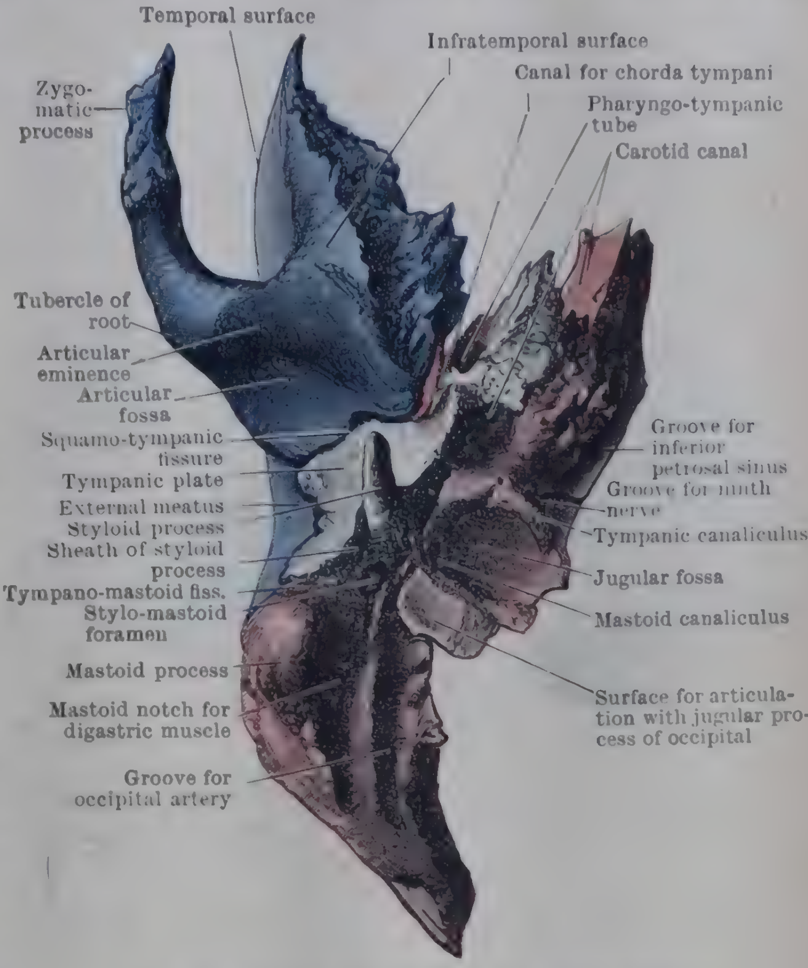


FIG. 187.—RIGHT TEMPORAL BONE (Inferior Aspect).

Red : Petro-mastoid, including lower edge of tegmen tympani. **Blue** : Squamous. **Uncoloured** : Tympanic part ; styloid process.

The **anterior surface** of the petrous part bears the impress of gyri of the cerebrum ; in addition, there is a distinct but shallow depression near the apex for the trigeminal ganglion. Lateral to the middle of the anterior surface, there is an elevation, the **arcuate eminence**, which marks the position of the superior semicircular canal of the ear. A little below and medial to this, there is the small slit or *hiatus for the greater superficial petrosal nerve*, which is continued downwards and medially as a narrow groove ; lateral to them there are a smaller opening and groove for the lesser superficial petrosal nerve. The bone forming the lateral part of the anterior surface, lateral to and in front of the arcuate eminence, is the **tegmen tympani** ; it roofs over the tympanic cavity and antrum and the canal for the tensor tympani. The anterior part of the tegmen is turned down so that its lower edge lies between the tympanic plate and the squamous temporal. It thus divides the squamo-tympanic fissure into a petro-squamous portion anteriorly and a petro-tympanic portion posteriorly which leads into the tympanic cavity (see Figs. 185, 187, 188). The line of fusion between the petrous and squamous parts of the bone is often indicated by a faint, irregular **petro-squamous suture** along the lateral margin of the anterior surface of the petrous temporal.

The most conspicuous feature on the **posterior surface** of the petrous part of the bone is an oblique, oval aperture which leads into the internal auditory meatus. The **internal auditory meatus** is a canal about 10 mm. long that passes laterally and slightly downwards into the bone and ends blindly, except that the bony substance at the **fundus** or far end has a number of small holes in it for the facial nerve and the nerves and vessels of the internal ear (Fig. 1020). Lateral to the meatus and above it, close to the upper border, there is an irregular depression called the **subarcuate fossa**, with one or two small foramina opening into it. It is often faintly marked ; it is seen best in young bones (see Fig. 188, C), where it forms a distinct recess. About half

an inch lateral to the meatus there is the *external aperture of the aqueduct of the vestibule*, often concealed in a narrow curved fissure overhung by a sharp scale of bone. The ridge above it corresponds to the upper half of the posterior semicircular canal.

Ossification.—The temporal bone of man represents the fused periotic, squamosal, and tympanic elements; the squamosal and tympanic are membrane bones, but the periotic is ossified in the cartilaginous auditory capsule. The cartilages of the first and second pharyngeal arches are also intimately associated with its development. The human temporal bone is characterized by the large proportionate size of the squamosal, the comparatively small size of the tympanic, the absence of an auditory bulla, and the large size of the mastoid process.

The **squamous part** is ossified from one centre that appears at the root of the zygoma about the end of the second month.

The **petro-mastoid part** is ossified from four centres, named pro-otic, opisthotic, pterotic, and epiotic. They appear during the fifth month and are more or less fused at the end of the sixth. The *pro-otic* centre appears near the arcuate eminence. It forms the part of the bone medial to that eminence, the roof of the internal auditory meatus, the upper part of the internal ear and part of the medial wall of the tympanum. The *opisthotic* centre appears at the promontory. It forms part of the medial wall of the tympanum, the lower part of the internal ear,

Fig. 188.—A. Parietal Surface of Right Temporal Bone at Birth. B. The same with Squamo-zygomatic Portion removed.

The squamo-zygomatic part is coloured blue; the petro-mastoid red. The tympanic ring is left uncoloured. (The lettering is the same in both A and B.)

a, Tympanic ring. *b*, Medial wall of tympanum. *c*, Fenestra cochleæ. *d*, Fenestra vestibuli. *e*, Tympanic antrum. *f*, Mastoid temporal. *g*, Foramen for transmission of vessels in squamo-mastoid suture. *h*, Squamo-zygomatic, removed in figure B to show how its post-auditory process forms the lateral wall of the tympanic antrum.

The tympanic ring is illustrated from the medial side in Fig. 1008, p. 1183.

C. Cerebral Surface of Right Temporal Bone at Birth.

a, Squamo-zygomatic. *b*, Petro-squamosal suture and foramen (just above the end of the lead line). *c*, Subarcuate fossa. *d*, Aquæductus vestibuli. *e*, Aquæductus cochleæ. *f*, Internal auditory meatus. *g*, Upper end of carotid canal.

the floor of the internal meatus and part of the walls of the carotid canal. The *pterotic* centre appears in the roof of the tympanum. It forms the tegmen tympani; the part of it in the roof of the canal for the tensor tympani sends down a thin process that forms the lateral wall of the pharyngo-tympanic tube and appears in the squamo-tympanic fissure. The *epiotic* centre (or centres) appears in the base of the petrous part. It gives rise to the bone that encloses the posterior and lateral semicircular canals and forms the mastoid portion.

The **styloid process** is developed from the cranial part of the cartilage of the second pharyngeal arch. It is ossified from two centres. The upper centre (*tympano-hyal*) appears shortly before birth and fuses with the petro-mastoid during the first year. The lower centre (*stylo-hyal*) appears in the cartilage shortly after birth; but the lower part ossifies slowly; it does not fuse with the upper part till after puberty, and may never do so.

The **tympanic part** is ossified from one centre which appears in the third month at the lower margin of the membranous, lateral wall of the tympanum. Ossification proceeds in curved linear directions to form the *tympanic ring*, which is incomplete superiorly, and fuses with the petrous part medially. After birth it extends medially, laterally and downwards to form the tympanic plate.

Structure and Variations.—The temporal bone is remarkable for the hardness and density of its petrous part, which contains the osseous labyrinth, wherein are lodged the delicate organs of hearing and equilibration. The weakest part of the bone corresponds to a line that connects the two meatuses; for they are separated only by the cochlea and tympanum. It is usually in this position that fracture of the bone occurs.

The line of the petro-squamous suture is occasionally grooved for the lodgment of a sinus (petro-squamous); sometimes the posterior end of the groove is continuous with a canal that traverses the upper border of the bone and opens into the transverse groove. Anteriorly the groove may pass into a canal that traverses the root of the zygoma and appears externally above the lateral end of the squamo-tympanic fissure. They are the remains of channels through which the blood passed in the fœtal condition. Single cases have been recorded in which:—(1) the

squamous part was pneumatic, the sinus reaching as high as the parietal bone; (2) the squamous part was separate from the rest of the bone in an adult; (3) the squamous part was divided into two by a transverse suture; (4) the zygoma was separated from the rest of the bone by a suture close to its root; (5) the zygoma was almost completely absent; (6) the carotid canal was rudimentary; (7) there was absence of the internal auditory meatus and the stylo-mastoid foramen and also of the jugular fossa, associated with a large mastoid foramen and partial absence of the transverse groove. In idiots and imbeciles a more pronounced form of post-glenoid tubercle has been noted and associated with regressive changes in the development of the temporal bone. Occasionally the temporal articulates with the frontal, as happens normally in the anthropoid apes.

Sphenoid Bone

The **sphenoid bone** lies in front of the basilar part of the occipital bone and the two temporal bones. It enters into the formation of the cranial, orbital, and nasal cavities, and also the temporal, infratemporal, and pterygo-palatine fossæ. It has a body and three pairs of processes—the greater and lesser wings and the pterygoid processes.

The **body** is more or less cubical, and it is hollow, for it contains the **sphenoidal air-sinuses.** The sinuses are a right and left, separated by a partition. Each sinus communicates by a round aperture with the spheno-ethmoidal recess of the nose (see p. 195). In the adult the **posterior surface** of the body is a sawn surface because it is fused with the basi-occipital. The **superior surface** resembles an oriental saddle (**sella turcica**). The seat is a depression, called the **hypophysial fossa**, that lodges the hypophysis of the brain. The fossa is overhung posteriorly by a sloping plate called the **dorsum sellæ**, the posterior surface of which is continuous with the clivus of the skull. The upper angles of the dorsum sellæ are prominent tubercles called the **posterior clinoid processes.** In front of the hypophysial fossa there is a transverse elevation called the **tuberculum sellæ**, behind the lateral ends of which there are sometimes little spurs of bone called the **middle clinoid processes.** In front of the tuberculum sellæ there is the **optic groove**, which passes laterally into the optic foramina. The flat area in front of the optic groove is called the *jugum sphenoidale*; it is on the same plane as the upper surfaces of the lesser wings, and terminates anteriorly in a ragged edge that articulates with the cribriform plates of the ethmoid.

The lower part of each **side** of the body is fused with the greater wing, and in part also with the root of the pterygoid process. Curving along the side of the body, above its attachment to the greater wing, there is an ʃ-shaped groove, called the **carotid groove**, in which the internal carotid artery lies. Posteriorly, the hinder margin of that groove, formed by the salient lateral edge of the posterior surface of the body, articulates with the apex of the petrous portion of the temporal bone.

The **anterior surface** of the body displays a median ridge, the **crest of the sphenoid**, whose lower, more prominent part is the **rostrum**. The crest articulates with the perpendicular plate of the ethmoid. On each side of the median plane there is a triangular area which forms part of the roof of the nose; in that area there is the opening that leads out of the sphenoidal sinus. The lateral part of the anterior surface, on each side, articulates with the labyrinth of the ethmoid and the orbital process of the palatine bone. The **sphenoidal rostrum** is continued backwards for some distance along the **inferior surface** of the body, where it forms a prominent keel that fits into the recess between the alæ of the vomer. Posteriorly, the inferior surface of the body is rougher, and is covered with the muco-periosteum of the pharynx.

The **sphenoidal conchæ** are a pair of thin bones that are fused with the sphenoid, ethmoid, and palatine bones, and usually are partially destroyed when the skull is disarticulated. They form the anterior surface of the body of the sphenoid and the anterior part of its lower surface, except its crest and rostrum. Each resembles an inverted triangle, and is curved. Its smaller, apical part lies in the floor of the sphenoidal sinus and separates the sinus from the most posterior part of the roof of the nose, and its infero-lateral edge forms the upper margin of the spheno-palatine foramen. The remainder of the triangular plate lies in the anterior wall of the sinus and is divisible into two parts. The lateral part forms the posterior wall of the posterior ethmoidal sinuses and articulates inferiorly with the orbital process of the palatine bone. The medial part is free in the roof of the nose, and in it there is the opening of the sphenoidal sinus.

The sphenoidal conchæ are formed, before birth, around the most posterior part of the cavity of the cartilaginous nasal capsule. That part of each half of the nasal cavity is a recess shut off from the rest of the cavity by membrane inferiorly, but anteriorly it communicates with the cavity by an aperture. In the fifth month, or later, ossification begins in the cartilaginous and membranous boundaries of the recess and converts them into the bony walls of a sphenoidal concha. In the infant, each concha is a hollow, three-sided pyramid. Its cavity is the rudiment of the **sphenoidal sinus**, but it was originally part of the cavity of the nose. It remains in communication with the nose; for the original aperture of communication is in the *base* of the pyramid, which partly is free in the roof of the nose, and partly fits on to the posterior surface of the ethmoid labyrinth and also articulates with the orbital process of the palatine bone. The *apex* articulates with the vaginal process of the medial pterygoid plate. The *infero-lateral wall* forms part of the roof of the nose and the upper boundary of the spheno-palatine foramen. The *superior wall* and the *medial wall* are applied to the antero-inferior aspect of the body of the sphenoid. In the fourth year, the concha fuses with the ethmoid and palatine bones, and its

superior and medial walls are absorbed. But the extension of the rudimentary sinus into the body of the sphenoid, by absorption of its spongy bone, does not begin till the seventh or eighth

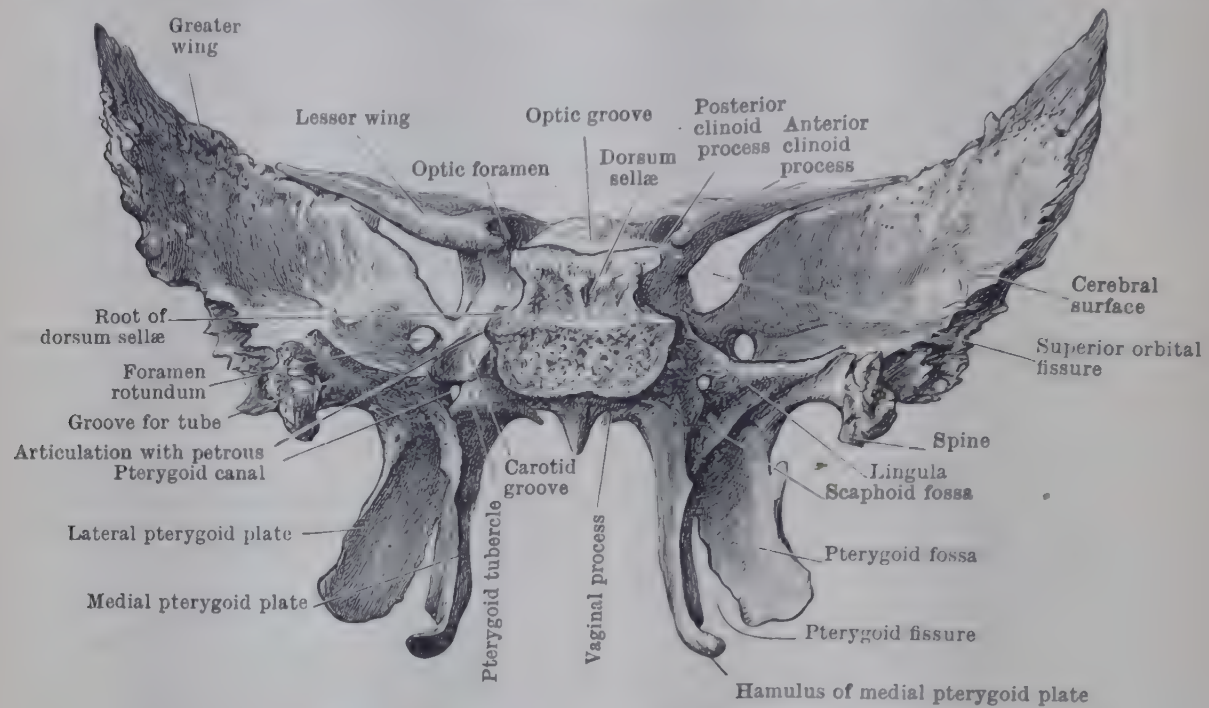


FIG. 189.—SPHENOID BONE SEEN FROM BEHIND.

year; and fusion of the concha with the sphenoid does not take place till between the ninth and twelfth years.

The **lesser wings** are a pair of flattened, triangular plates that project laterally from the anterior and upper part of the body of the bone; each wing is united to the body by two roots—an anterior and a posterior—separated by the **optic foramen.** The posterior root springs from the body just wide of the tuberculum sellæ, separating the carotid groove behind from the optic foramen in front; laterally this root is confluent with the recurved posterior angle of the lesser wing, which projects backwards and is known as the **anterior clinoid process.** The anterior root, broad and compressed, joins the anterior part of the upper surface of the body.

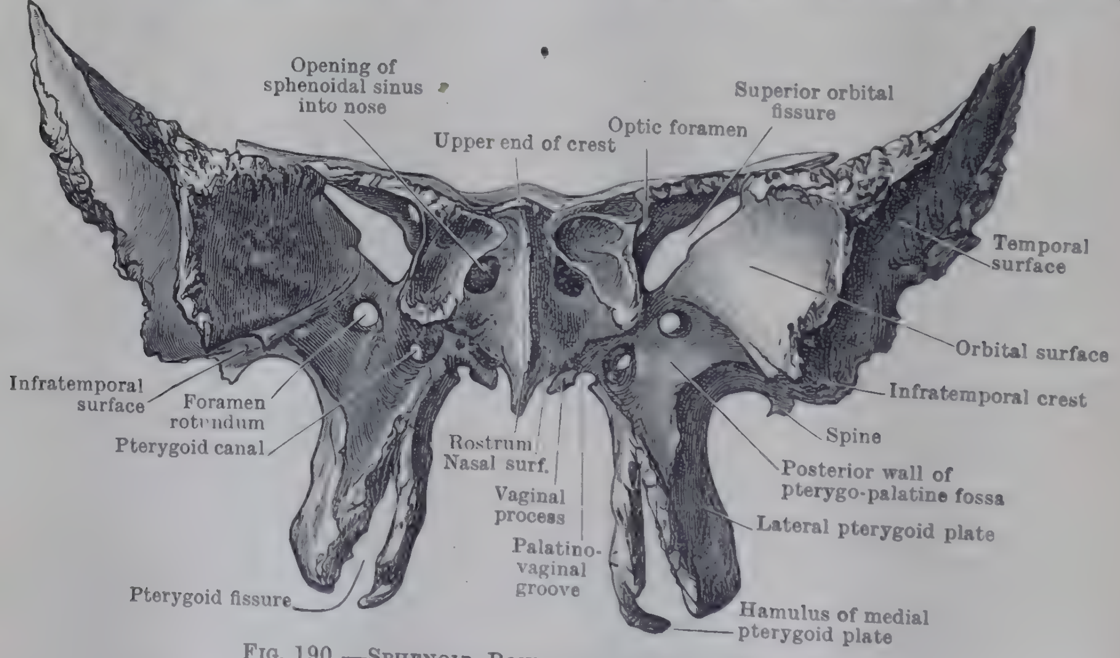


FIG. 190.—SPHENOID BONE SEEN FROM IN FRONT.

Laterally, the pointed end of the wing reaches the region of the pterion and articulates there with the frontal, and may come in contact with the greater wing. The upper surface is smooth and forms part of the floor of the anterior cranial fossa. The lower surface is the most posterior portion of the roof of the orbit, and it is also the upper boundary of the **superior orbital fissure,** which separates the lesser wing from the greater wing. The anterior edge is ragged and articulates with the orbital plate of the frontal bone. The posterior margin, sharp and sickle-shaped, separates the anterior from the middle cranial fossa and ends medially in **the anterior clinoid process.**

Each **greater wing** spreads out from the side of the body of the sphenoid in the floor of the middle cranial fossa and turns upward into the side-wall of the skull. It has three surfaces —an internal or *cerebral*, an *orbital*, and an external, which is divided into a *temporal surface* and an *infratemporal surface.*

The **cerebral surface** is concave and is marked by impressions for cerebral gyri and by grooves for meningeal vessels. Three foramina are seen in it and sometimes four. The **foramen rotundum** is a short horizontal canal that passes forwards below the medial part of the superior orbital fissure. The **foramen ovale** is situated about 10 or 12 mm. behind and lateral to the foramen rotundum. The **foramen spinosum** is the smaller aperture immediately behind and lateral to the foramen ovale. The fourth foramen, which is not always present, is a small hole, called the **sphenoidal emissary foramen,** situated medial to the foramen ovale. The *borders* of the cerebral surface are upper or anterior, medial, and posterior. The *medial border* is fused with the side of the body of the sphenoid. The *posterior border* is divided into two distinct parts that meet together posteriorly in a sharp projecting angle. The medial part is a short distance behind the foramina ovale and spinosum and is oblique in direction; laterally it articulates with the petrous temporal; medially it forms the anterior boundary of the foramen lacerum. There projects backwards from it a spur of bone of variable size, called the **lingula,** which forms the anterior or lateral margin of the commencement of the carotid groove; when the lingula is long enough it forms also the lateral margin of the foramen lacerum. The lateral part of the posterior border is a long, concave, serrated edge that articulates with the squamous temporal. The *upper border* also is divided into parts. The medial part, thin and sharp, forms the lower boundary of the superior orbital fissure; the next part articulates with the frontal bone; and the third part is the extreme upper part of the wing and articulates with the antero-inferior angle of the parietal bone.

The **orbital surface** is smooth, nearly flat, more or less quadrilateral, and forms a great part of the lateral wall of the orbit. Its *posterior border* is the medial part of the upper border of the cerebral surface and forms the lower margin of the superior orbital fissure. The *lower border* is smooth and forms the upper or lateral boundary of a cleft called the inferior orbital fissure; immediately below that border there is an oblique, horizontal groove that forms part of the posterior wall of the pterygo-palatine fossa. The *anterior border* articulates with the zygomatic bone; and the *upper border* articulates with the frontal bone.

The **temporal surface** is separated *posteriorly* from the cerebral surface by the border that articulates with the squamous temporal. *Anteriorly* it is separated from the orbital surface by the sharp crest that articulates with the zygomatic bone and sometimes also with the zygomatic process of the maxilla. *Superiorly* the uppermost part of the surface is separated from the cerebral surface by the short border that articulates with the parietal bone; in front of that it articulates with the frontal bone. The articulation of the greater wing with the frontal bone is by a rough triangular area bounded by the upper margins of the three surfaces of the wing. *Inferiorly* the temporal surface is limited by a rough, horizontal ridge called the **infratemporal crest.**

The **infratemporal surface** is almost at right angles to the temporal surface. The **foramen ovale** and **foramen spinosum** are seen in it near its posterior border, and the occasional *sphenoidal emissary foramen* medial to the foramen ovale. The *posterior border* articulates with the petrous temporal and is grooved lengthwise for the cartilage of the pharyngo-tympanic tube, which lies along the junction of the two bones. *Medially* the surface is fused with the pterygoid process. *Anteriorly* it is bounded by a sharp margin behind the inferior orbital fissure. *Laterally* it is bounded by the infratemporal crest, and behind that it is separated from the cerebral surface by the part of the posterior border that articulates with the lower part of the squamous temporal. That boundary and the posterior border which articulates with the petrous temporal meet at the angle which fits into the angular interval between the squamous and petrous temporal. From the angle a projection called the **spine** of the sphenoid juts downwards.

Each **pterygoid process** springs from the lower part of the side of the body and from the root of the greater wing and passes vertically downwards. Its *lateral* and *medial* plates enclose the **pterygoid fossa** between them; the upper parts of their anterior borders are fused together.

The **lateral pterygoid plate,** thin and expanded, is directed obliquely backwards and laterally—its lower part being often slightly everted. Its posterior edge is sharp, and often has projecting from it one or two spines, one of which (*pterygo-spinous process*) gives attachment to the pterygo-spinous ligament, which stretches to the spine of the sphenoid.

The **medial pterygoid plate** is narrower and rather thicker. It is placed between the pterygoid fossa and the posterior part of the nasal cavity. Its posterior margin is sharp, and ends below as a slender, curved process, called the **pterygoid hamulus,** which, reaching a lower level than the lateral plate, curves backwards and laterally, and has a groove on its lower surface in which the tendon of the tensor palati muscle glides; superiorly, the posterior margin bifurcates to enclose the **scaphoid fossa,** a small, shallow, oval concavity. Below the fossa is a small projection from the posterior margin to support the cartilage of the pharyngo-tympanic tube. At the extreme upper end of the posterior margin of the plate, there is a small, blunt projection called the **pterygoid tubercle.** The **vaginal process** is a thin lamina which passes medially from the upper end of the plate. Near the plate this process is fused with the lower surface of the body of the sphenoid. More medially it is free and is separated from the rostrum by a groove in which the edge of the ala of the vomer fits in the articulated skull, and it articulates with the ala. On the lower surface of the vaginal process, near the medial pterygoid plate, there is a groove which, in an articulated skull, leads forwards into the palatino-vaginal canal.

Above the pterygoid tubercle, and below the lingula, there is a small aperture that leads into

the **pterygoid canal**, which passes forwards through the root of the pterygoid process. In front, at its root, the pterygoid process displays a broad, smooth surface which is confluent above with the root of the greater wing around the foramen rotundum, and forms the posterior wall of the **pterygo-palatine fossa**. Medial to the foramen rotundum, and below it, the anterior opening of the **pterygoid canal** is seen. The lower parts of the pterygoid plates are separated by an angular cleft called the **pterygoid fissure**; this fissure lodges the tubercle of the palatine bone; the edges of the fissure are serrated, and they articulate with the margins of the tubercle.

Ossification.—The sphenoid is ossified partly in cartilage and partly in membrane (p. 213). The body is at first in two parts—pre-sphenoid and post-sphenoid. The **pre-sphenoid** is the part in front of the tuberculum sellæ and is connected with the lesser wings. The **post-sphenoid** is the rest of the body and is connected with the pterygoid processes and the greater wings.

The ossific centres are in pairs, and appear as follows:—

One, at the eighth week, between the foramen ovale and foramen rotundum, for the **greater wing** and the **lateral pterygoid plate**.

One, at the eighth week, in the hypophysial fossa at the side of the cranio-pharyngeal canal, for the main part of the **post-sphenoid**.

One, at the ninth week or later, near the carotid groove, for the side of the post-sphenoid and the **lingula**.

One, at the ninth week, in the **medial pterygoid plate**, for that plate and its hamulus.

One, at the ninth week, immediately lateral to the optic foramen, for the **lesser wing** and its roots and the jugum sphenoidale.

One, at the tenth week, medial to the optic foramen, for the main part of the **pre-sphenoid** (*i.e.*, pre-sphenoid *minus* the jugum and the conchæ).

One (which may be quadruple), in the fifth month or later, for the **sphenoidal concha**.

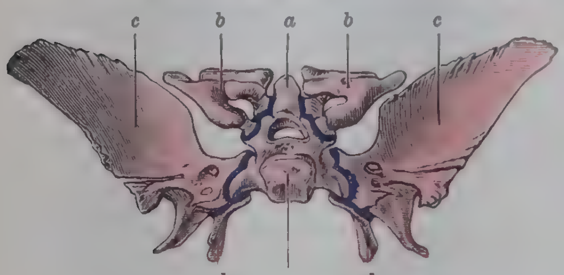


Fig. 191.—Ossification of Sphenoid.

a, Pre-sphenoid; *b*, Lesser wings; *c*, Greater wings; *d*, Medial pterygoid plates; *e*, Post-sphenoid.

The medial pterygoid plate is the first part to be completely ossified; its hamulus is chondrified during the third month immediately before ossification spreads into it. The two pairs of centres for the post-sphenoid are fused by the sixth month; and the post-sphenoid unites with the pre-sphenoid in the seventh month. **At birth** the bone is in three pieces—the greater wing with the pterygoid process on each side, and the body with the lesser wings. They have fused by the end of the first year. During that year ossification spreads medially from the lesser wings to form the jugum sphenoidale. Occasionally two median foramina are seen in young skulls—one on the tuberculum sellæ and one farther forward—due to delayed fusion between the post-sphenoid and the jugum and between the halves of the jugum.

Variations.—The foramen spinosum and the foramen ovale are sometimes incomplete posteriorly. The superior orbital fissure, in rare cases, communicates with the foramen rotundum or with the optic foramen. The optic foramen has been found double—the optic nerve passing through one canal and the ophthalmic artery through the other. Ossification of fibrous bands leads to the formation of anomalous foramina, *e.g.*, the *carotico-clinoid foramen*, between the anterior and middle clinoid processes; the *pterygo-spinous foramen*, enclosed by ossification of the band between the spine and the lateral pterygoid plate; the *porus crotaphitico-buccinatorius*, enclosed by ossification of a ligament below and lateral to the foramen ovale. The lesser superficial petrosal nerve sometimes passes through a minute, unnamed hole near the posterior border of the greater wing. The sphenoidal sinus varies in size; may be absent; and is occasionally multilocular.

Ethmoid Bone

The **ethmoid bone** lies in front of the sphenoid, between the orbits and the orbital plates of the frontal bone; it enters into the formation of the anterior cranial fossa, the orbits, and the nasal cavities. It is extremely light, and consists of a pair of cellular parts called the **ethmoidal labyrinths**, united superiorly to a median **perpendicular plate** by a pair of thin horizontal laminæ which, from their perforated condition, are called the **cribriform plates**.

The study of the ethmoid bone will be easier if one cribriform plate is cut through.

The **perpendicular plate** forms the upper part of the nasal septum and has an irregular pentagonal outline. Its **superior border** projects above the level of the cribriform plates into the cranial cavity to form a crest called the **crista galli**. The crest is thicker than the rest of the plate, and contains either spongy bone or an air-cell. It is highest in front, and its lower part divides anteriorly into a pair of **alæ** which project forwards to articulate with the frontal bone and enclose the **foramen cæcum**. The **posterior border** of the perpendicular plate articulates with the crest of the sphenoid. The **posterior inferior border** in the adult articulates with the vomer, and fuses with it after the fortieth year. The **anterior inferior border** is usually thicker than the others, and unites with the cartilaginous nasal septum. The **anterior superior border** articulates with the nasal spine of the frontal bone and with the median crest of the two

nasal bones. The *surfaces* are fairly smooth, except superiorly, where there are short and shallow grooves that lead to the foramina in the cribriform plate.

Each **cribriform plate** occupies the interval between the orbital plate of the frontal bone and the crista galli; it lies in the roof of the nose and in the floor of the anterior cranial fossa, and it articulates posteriorly with the sphenoid.

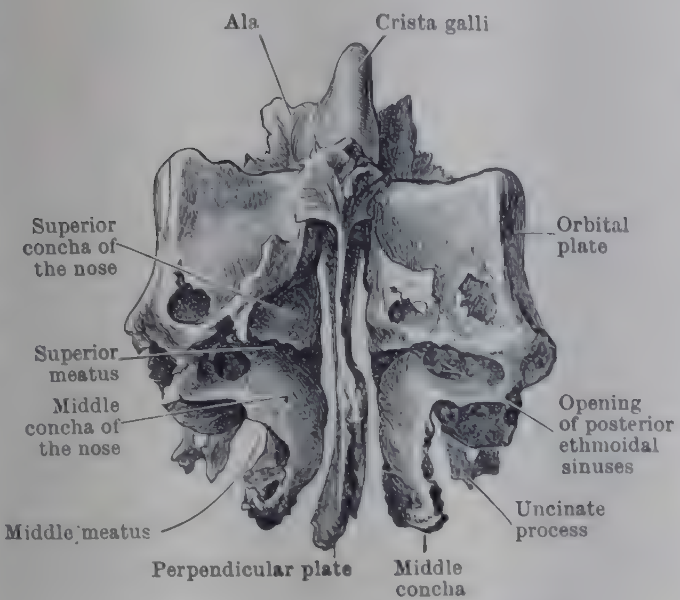


Fig. 192.—Ethmoid seen from Behind.

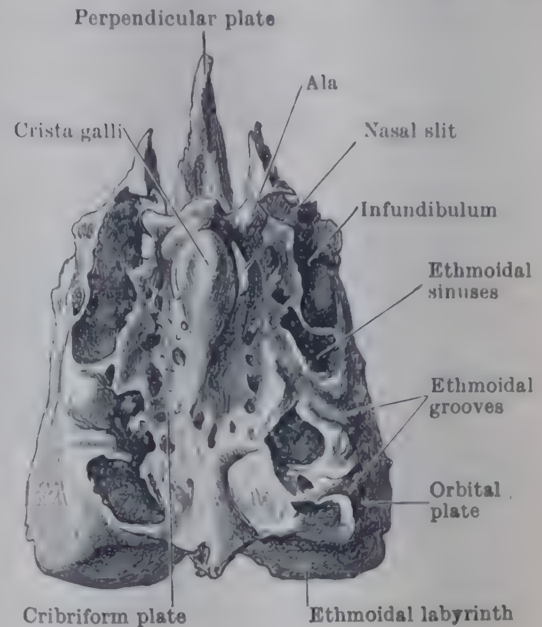


Fig. 193.—Ethmoid seen from Above.

The **ethmoidal labyrinth** is composed of exceedingly thin bone which encloses a large number of air-sinuses; the sinuses are arranged in three groups—an anterior, a middle, and a posterior—the walls of which have been broken in the process of disarticulation.

The *posterior surface* of the labyrinth articulates with the front of the body of the sphenoid and the orbital process of the palatine bone, which close in the posterior sinuses. The *anterior surface* is oblique and is covered by the lacrimal bone and the upper part of the frontal process of the maxilla, which close the anterior sinuses. The *upper surface* is covered by the orbital plate of the frontal bone, which completes the sinuses superiorly; and it is crossed by two grooves which are converted into the **anterior** and **posterior ethmoidal canals** when the orbital plate is in position. *Laterally* the cells are closed in by a thin, oblong lamina, the **orbital plate** of the ethmoid, which forms a part of the medial wall of the orbit. The plate articulates *above* with the orbital plate of the frontal bone; *in front* with the lacrimal bone; *below* with the orbital surface of the maxilla; *behind* with the sphenoid; and at its posterior inferior angle for a variable distance, with the orbital process of the palatine bone.

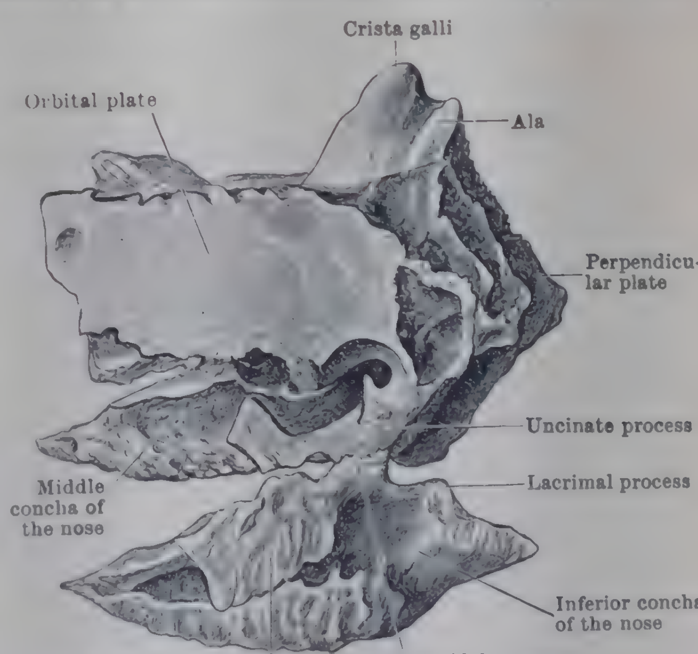


Fig. 194.—Lateral Surface of Ethmoid and Inferior Concha.

On the *medial surface* of the labyrinth the sinuses are closed in by thin, rough bone, but they open into the nose by small apertures on this surface, which is free in the lateral wall of the nasal cavity. The surface is very uneven, and from it two thin, rough, curled plates of bone, called the superior and middle nasal conchæ, project medially into the cavity of the nose and then curve downwards.

The **superior concha** is small and may be a mere ridge. It projects from the posterior half of the surface, less than half an inch below the cribriform plate. The bone above the concha closes in the posterior ethmoidal sinuses, and is finely grooved for olfactory nerves; the grooves begin on the concha and run upwards and forwards to the lateral foramina of the cribriform plate. The space lateral to the concha, and between it and the middle concha, is the **superior meatus** of the nose, and the posterior ethmoidal sinuses open into it. The bone in front of the superior meatus and superior concha closes in middle and anterior ethmoidal sinuses.

The **middle concha** is much deeper than the superior, and is as long as the labyrinth. Its anterior end articulates with the ethmoidal crest of the maxilla, and its posterior end with the ethmoidal crest of the palatine bone. The space lateral to it is the upper part of the **middle meatus** of the nose. The lower members of the middle ethmoidal sinuses bulge into the meatus, forming the **ethmoidal bulla**, a rounded elevation on which the middle sinuses open. The bulla is bounded below and in front by a curved groove or a slit, the **hiatus semilunaris**, into which the anterior sinuses open. The upper or anterior end of the hiatus is continuous with a canal, called the **ethmoidal infundibulum**, which runs upwards and forwards through the anterior part of the labyrinth to open into the frontal sinus. The hiatus is bounded in front and below by a thin bar of bone called the **uncinate process**. The uncinate process springs from the anterior part of the roof of the middle meatus; it curves downwards, backwards and a little laterally, bridging across the opening of the maxillary sinus, to articulate with the ethmoidal process of the inferior concha.

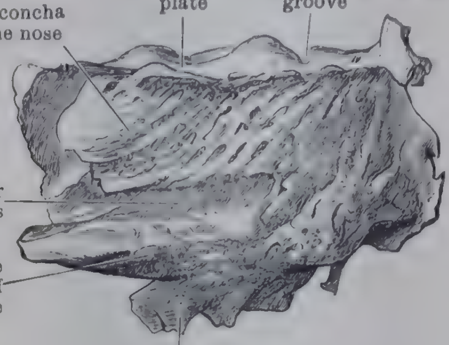


Fig. 195.—Section showing the Nasal Side of Left Labyrinth of Ethmoid.

Ossification takes place in the cartilage of the nasal capsule. In the fourth or fifth month one centre appears, near the orbital plate, for each **labyrinth** (including its conchæ), which is completely ossified at birth; the sinuses appear before birth. At the end of the first year, a pair of centres appear at the root of the crista galli for the **perpendicular plate**, whose ossification is not completed till the fifth or sixth year. The **cribriform plate** is ossified during the second year by extension from the labyrinth and the perpendicular plate; and it fuses with the sphenoid after twenty-five.

Variations.—The orbital plate varies in size and shape. It is narrower from above downwards in the lower races than in the higher—in this respect resembling the condition in the anthropoids. And, as in the gorilla and chimpanzee, it may fail to articulate with the lacrimal, owing to a downgrowth of the frontal which articulates with the orbital surface of the maxilla (orbito-maxillary-frontal suture). It is sometimes divided by a vertical suture into an anterior and a posterior part. The number of the conchæ may be increased from two to four, or may be reduced to one.

Inferior Nasal Conchæ

Each **inferior concha** is an elongated, shell-like lamina of bone that lies along the lower part of the lateral wall of the nasal cavity. It has two surfaces and two borders.

The **superior** or **attached border** is thin and unevenly convex. It is sharp in front and behind, where it articulates with the conchal crests of the maxilla and the palatine bone. Between those two articulations the central part of the upper border rises in the form of a sharp crest; the anterior part of the crest stands up as the **lacrimal process**, which articulates above with the descending process of the lacrimal bone, and also with the edges of the lacrimal groove of the maxilla, thus completing the wall of the naso-lacrimal canal. The posterior end of the crest is raised to form the **ethmoidal process**, an irregular projection which unites with the uncinate process of the ethmoid bone (see Fig. 194). From the middle of the upper border, on its lateral side, a thin irregular plate, the **maxillary process**, spreads downwards and conceals part of the lateral surface. This process unites with the medial surface of the maxilla, partly helping to close the gap that leads into the maxillary sinus and partly hanging down in the sinus between its mucous lining and medial wall. The **inferior** or **free border** is gently curved from before backwards and turned slightly laterally, is rounded and full, is deeply pitted, and is of a slightly cellular character. The **anterior** and **posterior ends** of the bone are thin and sharp.

Fig. 196.—Medial Surface of Right Inferior Concha.

The **medial surface** is uneven and convex and bulges into the nasal cavity; it is rough and pitted, and is marked by some fine, scattered, and longitudinally directed vascular grooves. The **lateral surface** is concave and forms the medial boundary of the inferior meatus of the nose. It is smooth in front, where it corresponds to the opening of the naso-lacrimal canal; posteriorly and towards its inferior border it is irregular and pitted.

A case in which the inferior conchæ were absent has been recorded.

Ossification.—The inferior concha is ossified in the cartilage of the lateral wall of the nasal capsule from one centre which appears about the fifth month of intra-uterine life.

Lacrimal Bones

The **lacrimal bone**—a thin scale of bone about the size of a finger-nail—forms part of the medial orbital wall behind the frontal process of the maxilla. It is irregularly quadrangular, and has two surfaces—a medial and a lateral—and four borders.

The posterior part of the **medial surface** is uneven and cellular; it closes in some anterior ethmoidal sinuses and the ethmoidal infundibulum. The anterior part is smaller and smoother, and is separated from the posterior part by a shallow groove; it forms a small part of the lateral wall of the nose behind the frontal process of the maxilla and above the inferior concha. The **lateral surface** looks into the orbit, and is divided by a vertical ridge opposite the groove on the medial surface. This **crest** ends inferiorly as a hook-like process called the **lacrimal hamulus.** The hamulus curves forwards round the postero-lateral edge of the naso-lacrimal notch of the maxilla, and thus forms the postero-lateral boundary of the opening into the naso-lacrimal canal. The area behind the crest is nearly flat, and forms the part of the medial wall of the orbit in front of the orbital plate of the ethmoid. The area in front of the crest is narrower and is concave, forming the floor of the **lacrimal groove**, which combines with the lacrimal groove on the frontal process of the maxilla to form the fossa for the lacrimal sac. The floor of the lacrimal groove is prolonged downwards beyond the main part of the bone as the **descending process**, which forms the medial boundary of the opening of the naso-lacrimal canal.

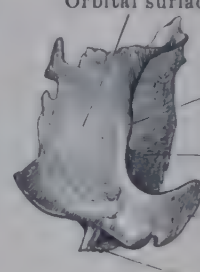


FIG. 197.—RIGHT LACRIMAL BONE (Orbital Surface).

The **inferior border** articulates with the orbital surface of the maxilla, and, anteriorly, by the descending process, with the lacrimal process of the inferior concha. The **anterior border** articulates with the frontal process of the maxilla; the **superior border** with the frontal bone; the **posterior border** with the orbital plate of the ethmoid.

Ossification.—The lacrimal is ossified from one centre which appears in the third month of intra-uterine life in the membrane that covers the cartilaginous nasal capsule.

Variations.—The lacrimal bone is occasionally absent. In some skulls it is divided into two or more parts. The hamulus may be small; but in rare cases it extends forwards to the orbital margin, and shares in the formation of the face, as in lemurs.

Vomer

The **vomer** is placed in the posterior part of the nasal septum. It has four borders and two surfaces. The **superior border** is easily recognized, because it is split into a pair of everted lips or **alæ**. It articulates with the inferior surface of the body of the sphenoid, whose rostrum fits in between the alæ. Each **ala** is wedged in between the sphenoidal process of the palatine bone and the vaginal process of the medial pterygoid plate. The **posterior border** is a free, sharp, slightly curved edge, and forms the posterior margin of the nasal septum. The **inferior border** articulates with the nasal crest formed by the maxillæ and the palatine bones. The **anterior edge** is the longest; it slopes obliquely from above downwards and forwards. Its upper half articulates with the perpendicular plate of the ethmoid and is fused with it after middle age; its lower half is grooved to receive the septal cartilage of the nose. The **anterior end** of the bone is a truncated angle which articulates with the posterior border of the prominent, anterior part of the nasal crest of the maxillæ, and sends downwards a pointed process which passes between the incisive canals. The **surfaces** of the bone are smooth, except for a few vascular grooves; one groove, usually more distinct than the others, runs obliquely downwards and forwards and lodges the long spheno-palatine nerve.

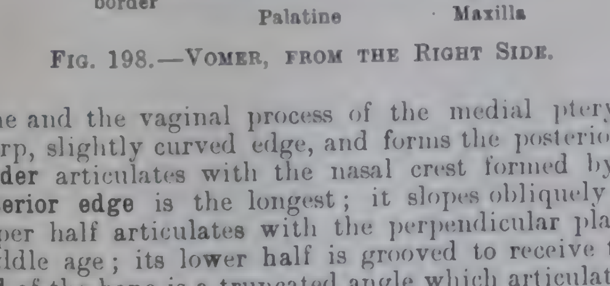


FIG. 198.—VOMER, FROM THE RIGHT SIDE.

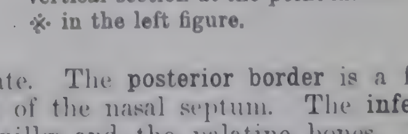


FIG. 199.

VOMER AT BIRTH, consisting of two Osseous Laminæ united inferiorly. The figure to the right represents a vertical section at the point marked * in the left figure.

Ossification.—The vomer begins to ossify at the eighth week of intra-uterine life from a pair of centres that appear in the membrane on the postero-inferior part of the cartilaginous septum of the nose. They form a pair of plates of bone separated by cartilage. During the third month the plates unite along their lower edges, and their fusion is not much further advanced at birth. As growth goes on, the cartilage is absorbed, and fusion of the laminæ takes place from below

upwards and is almost complete at puberty; but, even in the adult, the bilaminar origin is indicated by the alæ and by the groove on the anterior border. The anterior end is partly ossified in cartilage by extension of the ossifying process into the paraseptal cartilages (p. 213).

Structure and Variations.—The bone is composed of two compact layers fused together, except at the grooves for the rostrum of the sphenoid and the septal cartilage, and also along a line where a canal runs horizontally from behind forwards in the substance of the bone. The canal is named the **spheno-vomerine canal**; it transmits the nutrient vessels, which enter the bone through a minute aperture at the posterior end of the groove between the alæ.

Owing to imperfect ossification there may be a deficiency in the bone—filled up during life with cartilage. The depth of the groove along the anterior border varies considerably; sometimes the two lamellæ are separated by a considerable cavity; and occasionally the sphenoidal sinus sends a small extension forwards between the lamellæ.

Nasal Bones

The **nasal bones** lie between the frontal processes of the maxillæ in the bridge of the nose. Each bone is elongated and quadrangular and is slightly constricted above its middle. The **outer surface** is convex from side to side, and slightly concavo-convex from above downwards. Near its centre there is usually the opening of a vascular canal. The **inner surface** or mucous surface forms part of the roof and side-wall of the cavity of the external nose. It is smooth and concave, and it is triangular in outline. On its posterior part the anterior ethmoidal nerve makes a narrow, nearly vertical groove. The **medial border** articulates with its fellow of the other side. Inferiorly it is thin. Superiorly it widens out into a triangular area. The posterior edges of these triangular areas of the right and left bones are raised to form a narrow median **nasal crest**, which forms a small part of the nasal septum and articulates, from above downwards, with the nasal spine of the frontal bone, the perpendicular ethmoidal plate, and the septal cartilage. The **lateral border**, usually the longest, is serrated and bevelled, and articulates with the anterior edge of the frontal process of the maxilla. The **superior border** is a toothed surface which articulates with the frontal bone at the nasal notch. It rests, posteriorly, on the root of the nasal spine. The **inferior border** is thin and sharp; it is connected with the lateral cartilage of the nose, and is often deeply notched near its medial extremity.

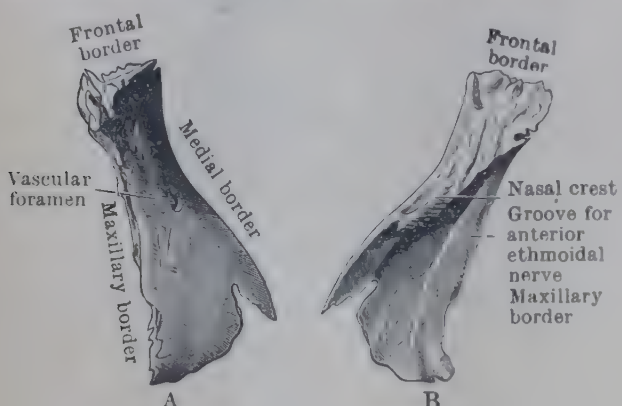


FIG. 200.—RIGHT NASAL BONE.
A, Outer aspect; B, Inner aspect.

Ossification.—The nasal bones are each developed from a single centre which appears about the end of the second month in the membrane that covers the cartilaginous nasal capsule.

Structure and Variations.—The nasal bone is made of dense compact tissue, and it is strengthened by the formation of the nasal crest.

The nasal bones vary greatly in different people as well as in different races. As a rule they are large and prominent in the White races, and are small, flat, and depressed in Mongolians and Negroes. Absence has been recorded; and division into two or more parts; and one case of unusual extension downwards. Obliteration of the internasal suture is uncommon; it is stated to occur more frequently in negroes, and it is the usual condition in adult apes.

Maxillæ

The two **maxillæ** form the upper jaw. Each has a **body** and four **processes**—**zygomatic, frontal, alveolar,** and **palatine.**

The **body** is pyramidal, and contains the **maxillary sinus** (p. 197). It has four surfaces—anterior, posterior, orbital, and nasal.

The **anterior surface** is concavo-convex. *Superiorly* it is limited, from behind forwards (or latero-medially), by the root of the zygomatic process, the **infra-orbital margin**, and the root of the frontal process. *Anteriorly* it is limited by a sharp, curved edge that bounds the wide concavity of the nasal notch, and ends below in a pointed process. This process unites with the similar projection of the other maxilla to form the **anterior nasal spine**, a sharp spur situated at the upper end of the intermaxillary suture. *Inferiorly* the surface is confluent with the alveolar process, which is ridged by the sockets of the teeth. The largest ridge is the canine eminence produced by the socket of the canine tooth. The shallow depression medial to the eminence overlies the upper parts of the incisor sockets. The wide depression that extends from the eminence to the zygomatic process is called the **canine fossa**; immediately above it, near the infra-orbital margin, is the **infra-orbital foramen**. *Posteriorly* the surface is limited by

the zygomatic process and a blunt ridge that descends from the process and fades away at the first or the second molar socket.

The **posterior surface** is rounded and full. It forms the anterior walls of the infratemporal and pterygo-palatine fossæ. *Laterally* it is separated from the anterior surface by the zygomatic process and the ridge. *Medially* it is separated from the nasal surface by an uneven, vertical margin. *Inferiorly* it ends as the **maxillary tuberosity**, which is a rough, low prominence behind the last molar socket; above the tuberosity there are the openings of the two **posterior dental canals**, which convey the vessels and nerves downwards and forwards to the molar and premolar teeth. *Superiorly* the surface is limited by a rounded border that forms the anterior boundary of the inferior orbital fissure in the articulated skull.

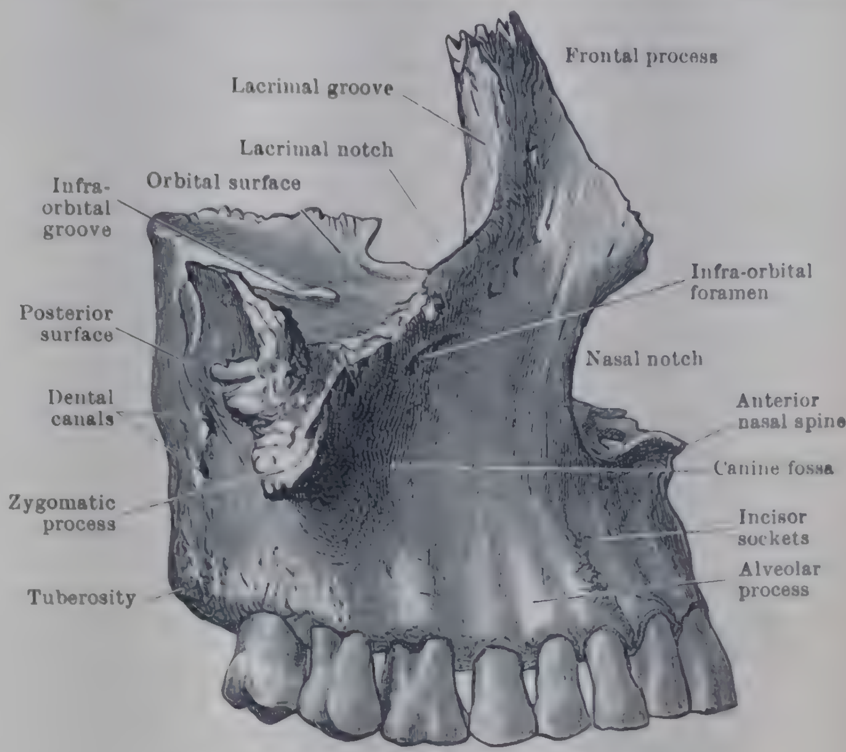


FIG. 201.—RIGHT MAXILLA (Lateral View).

The **orbital surface** is smooth and flat, and is triangular in outline. It forms the greater part of the floor of the orbit. From behind forwards, the surface is traversed by the **infra-orbital groove** and **canal**. The canal ends as the infra-orbital foramen; and, if it is laid open, a small aperture is seen leading into the **anterior dental canal**, which conveys the vessels and nerve to the canine and incisor teeth. The surface is limited *posteriorly* by the margin of the inferior orbital fissure, and *anteriorly* by the root of the zygomatic process and the infra-orbital margin. *Medially* it is limited by a sharp margin whose anterior part bounds the **naso-lacrimal notch**, while the rest articulates, from before backwards, with the lacrimal bone, the orbital plate of the ethmoid, and the orbital process of the palatine bone.

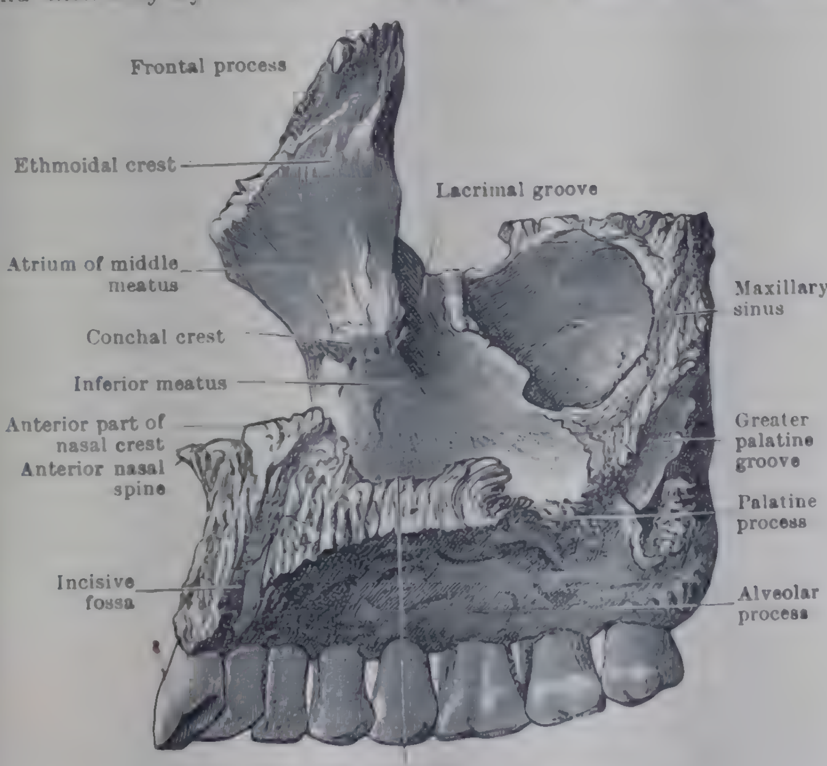


FIG. 202.—RIGHT MAXILLA (Medial Aspect).

The **nasal surface** forms part of the lateral wall of the cavity of the nose. It is limited *superiorly* by the medial margin of the orbital surface and the root of the frontal process, *posteriorly* by the medial margin of the posterior surface, *anteriorly* by the margin of the nasal notch, and *inferiorly* by the attachment of the palatine process. Above that attachment, there is a wide smooth area that forms the anterior and larger part of the lateral wall of the inferior meatus of the nose. Above and behind that area there is the large opening into the maxillary sinus; in the articulated skull the opening is to a large extent closed by the lacrimal, the ethmoid, the inferior concha, and the palatine bone. Behind the opening and also below it, there is a rough area for articulation with the perpendicular plate of the palatine bone; that area is traversed from above downwards and forwards by an oblique groove which, when the palatine bone is in place, is converted into the greater palatine canal. In front of the opening there is a wide, vertical lacrimal groove, which is converted into the naso-lacrimal canal when the lacrimal and inferior

concha are in place. In front of the groove, at the junction of the body and the frontal process, there is a low, horizontal **conchal crest**, which articulates with the inferior concha.

The **frontal process** is a long, wide, thin plate that stands up from the junction of the nasal, facial, and orbital surfaces. It lies in the side-wall of the cavity of the nose and forms a great part of the skeleton of the external nose. Its *upper end* is serrated and articulates with the maxillary process of the frontal bone. The upper part of the *anterior border* is rough or grooved for articulation with the nasal bone; the lower part is sharp and bounds the upper part of the nasal notch. The *posterior border* is a thin edge that articulates with the lacrimal. The *lateral surface* is divided lengthwise into two parts by a smooth ridge, the **lacrimal crest**, which forms the medial margin of the orbital opening and is continuous with the infra-orbital margin. The part of the surface in front of the crest lies in the side of the external nose and is confluent inferiorly with the anterior surface of the body; one or two vascular foramina may be seen on it. The part behind the crest is narrower, and it forms the most anterior part of the medial wall of the orbit; it is the floor of a vertical groove which is continuous with the lacrimal groove of the body, and, combined with the groove of the lacrimal bone, it forms the **fossa for the lacrimal sac.** The uppermost part of the *medial surface* is rough for articulation with the front of the ethmoid labyrinth, and it closes in some of the anterior ethmoidal sinuses. Below the rough area there is an ill-defined, nearly horizontal **ethmoidal crest**. The posterior part of that crest articulates with the anterior end of the middle concha; in the unmacerated head its anterior part produces a slight elevation called the **agger nasi**. The rest of the surface is the wide, smooth area between the ethmoidal and conchal crests, and forms the side-wall of the atrium of the middle meatus.

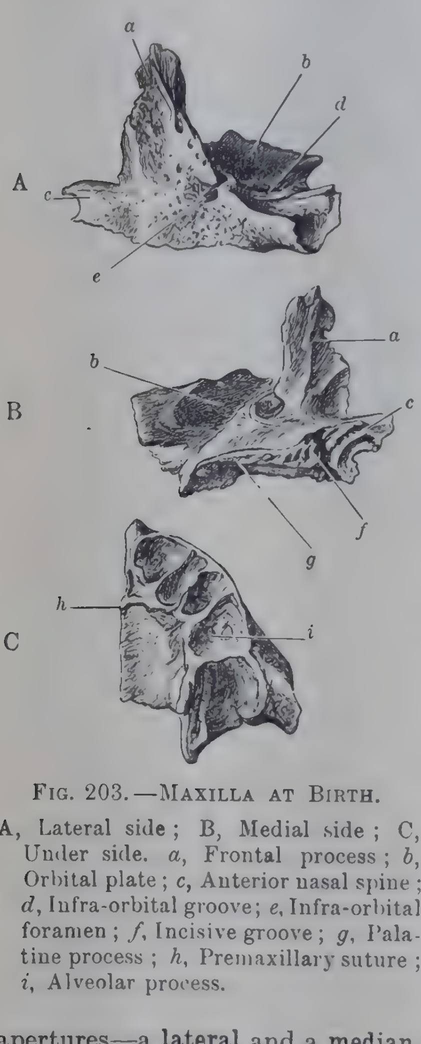


Fig. 203.—Maxilla at Birth.

A, Lateral side; B, Medial side; C, Under side. *a*, Frontal process; *b*, Orbital plate; *c*, Anterior nasal spine; *d*, Infra-orbital groove; *e*, Infra-orbital foramen; *f*, Incisive groove; *g*, Palatine process; *h*, Premaxillary suture; *i*, Alveolar process.

The **palatine process** is a horizontal plate attached to the medial side of the bone, at the junction of the body and alveolar process, from the incisor sockets to the second molar socket. It is much thinner behind than in front and has two surfaces and three borders. The *upper surface* is smooth and is slightly concave from side to side; it forms the anterior two-thirds of the floor of the nasal cavity. The *lower surface* is in the roof of the mouth, forming the anterior two-thirds of its own half of the bony palate (Fig. 156); it is rough, and is pitted for the palatine mucous glands; near its lateral margin there is an ill-defined groove (or maybe two) for the greater palatine vessels and nerve. The *lateral border* is the attached border and is curved. The *posterior border* is a notched, sharp, nearly horizontal edge that articulates with the horizontal plate of the palatine bone. The *medial border* is rough and articulates with its fellow in the median line of the palate. It is raised up as a lip which, with its fellow, forms the **nasal crest** The lower edge of the vomer fits in between the two lips of the posterior part of the crest. The anterior part is raised still higher; it articulates with the subvomerine cartilages superiorly, and with the anterior end of the vomer posteriorly, while anteriorly it is continuous with the anterior nasal spine. Inferiorly, behind the incisor sockets, the articulating margins of the two palatine processes are grooved to form the sides of a small funnel-shaped pit called the **incisive fossa** The **incisive canal**, one on each side, begins in the floor of the nose at the side of the nasal crest and divides to open into the fossa by two small apertures—a **lateral** and a **median incisive foramen**.

The **alveolar process** is thick and curved. It projects downwards from the body. With its fellow of the opposite side it forms the *alveolar arch*, in which the roots of the teeth are embedded; when the adult dentition is complete, each alveolar process has sockets for eight teeth. Two small vascular foramina are usually visible on the lingual surface behind the incisor sockets. When any or all of the teeth are shed the walls of the sockets are absorbed, and the alveolar process may be reduced to the level of the plane of the palatine process. Posteriorly the alveolar process ends in the **maxillary tuberosity**.

The **zygomatic process** is short and thick. It projects from the junction of the anterior, posterior, and orbital surfaces. Its *anterior* and *posterior surfaces* are separated from each other by a rounded, concave ridge that fades away at the socket of either the first or the second molar tooth. The *upper surface* is oblique and rough, and articulates with the zygomatic bone.

The **premaxillæ**, in most vertebrates, are a pair of independent bones that lie in front of the maxillæ. In Man and Apes they are the parts of the maxillæ that lie in front of the incisive fossa and carry the incisor teeth. But the premaxillary part is ossified separately, and, though the greater part of it fuses in intra-uterine life with the rest of the maxilla, yet, up to middle age, their independent origin is indicated by a faint suture that extends sinuously from the hinder part of the incisive fossa to the interval between the canine and lateral incisor sockets.

Ossification.—The **maxilla proper** is ossified in membrane in the wall of the oral cavity

from one centre which appears in the sixth week above the germ of the canine tooth. Ossification spreads rapidly in different directions to form the body of the bone and its processes. The infra-orbital nerve is at first placed considerably above the orbital surface of the maxilla, and comes in contact with it only in the second month, when a groove is formed on the bone; the groove is converted into the infra-orbital canal and foramen by the uprising and folding medialwards of its lateral boundary. In the early stages the alveolar part lies close below the infra-orbital groove; later, they are separated by the maxillary sinus, which first makes its appearance as a shallow fossa on the medial side of the bone about the fourth month of intra-uterine life.

The **premaxilla** is ossified from at least two centres. The first appears above the incisor tooth germs in the sixth week; from it, most of the premaxilla is ossified and also the anterior part of the frontal process; the bone formed from it fuses with the maxilla proper, beginning at the alveolar part almost at once. The second centre appears at the twelfth week and soon fuses with the rest; it forms the medial wall of the incisive canal. It may be that there are two main centres and that they fuse almost at once, but sometimes never fuse. For in some cases of lateral cleft palate the line of cleavage does not pass between the germs of the canine tooth and lateral incisor tooth (*i.e.*, the cleft is not between the maxilla proper and the premaxilla), but passes between the germs of the two incisors, or even through the germ of the lateral incisor—accounting for the extra incisor sometimes found on the lateral side of the cleft.

Variations.—There may be a vertical suture in the infra-orbital margin above the infra-orbital foramen. The infra-orbital canal may be an open groove. A spine that projects upwards from the lower part of the nasal notch has been recorded. A case has been described in which the premaxillæ and the incisor teeth were absent. A *torus palatinus* is not uncommon—*i.e.*, a ridge along the median suture of the hard palate. The lacrimal groove may be constricted towards its centre. A part of the maxillary sinus may be constricted off anteriorly and, owing to its relation to the naso-lacrimal canal, is called the *lacrimal recess.* Almost complete septa in the maxillary sinus have been recorded.

Palatine Bones

Each **palatine bone** is ∟-shaped with two main parts—a **horizontal** and a **perpendicular plate.** At their junction posteriorly there is an irregular projection called the **tubercle.** Two irregular projections, named the **sphenoidal** and **orbital processes**, stand up from the upper edge of the perpendicular plate and are separated by an interval called the **spheno-palatine notch.**

The **horizontal plate** is thin and square, having two surfaces and four borders. Its *upper surface* is smooth, is slightly concave from side to side, and forms the floor of the posterior part of the nasal cavity. Its *lower surface* is rougher, and forms the posterior third of the bony

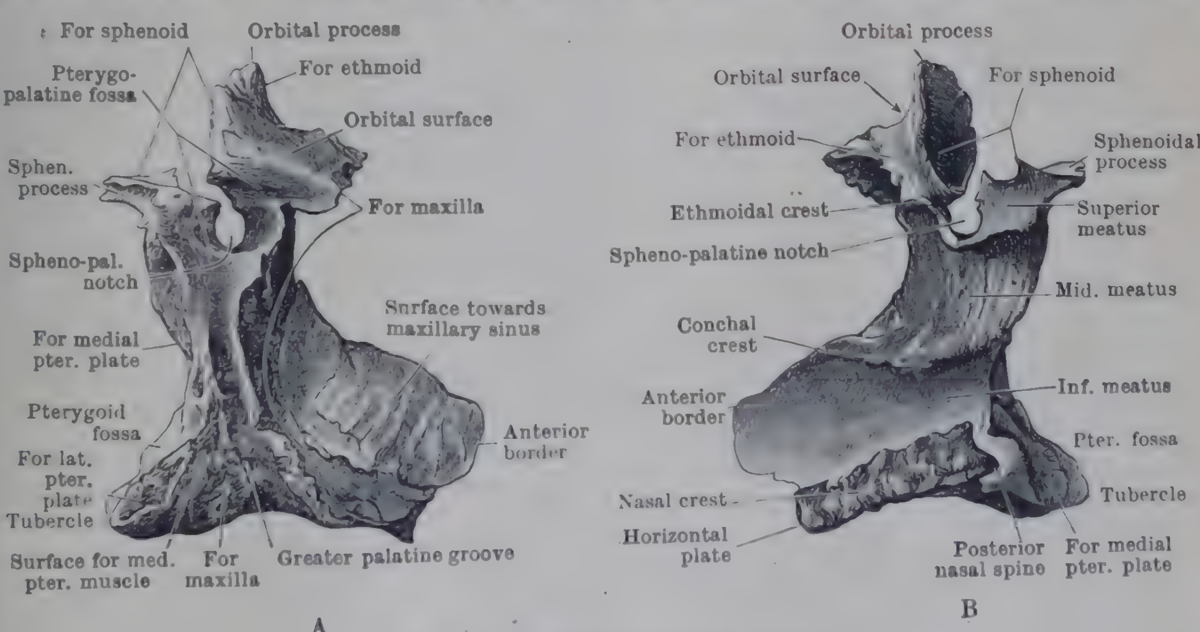


FIG. 204.—RIGHT PALATINE BONE.

A: As seen from the Lateral Side. B: As seen from the Medial Side.

palate; near its posterior edge there is a sharp, transverse ridge called the **palatine crest.** The *anterior border* is rough, and articulates with the palatine process of the maxilla. The *posterior margin* is free and concave; at the median plane it meets its fellow, and the two together send backwards a pointed **posterior nasal spine.** The *medial border* is thick and rough, and articulates with its fellow; the two margins send up a median ridge called the **nasal crest**; it is continuous in front with the nasal crest of the maxilla, and the posterior part of the inferior border of the vomer fits in between its two lips. The *lateral border* joins the perpendicular plate at a right angle, and is grooved to form the medial margin of the **greater palatine foramen.**

The **perpendicular plate** also is thin and has two surfaces and four borders. It is longer than the horizontal part and is much wider inferiorly. Its *medial surface* is crossed horizontally, about its middle, by the **conchal crest**, which articulates with the posterior part of the inferior concha; above and below the crest, the surface forms part of the lateral wall of the middle and inferior meatuses of the nose. Near the upper end of the surface there is another horizontal ridge, called the **ethmoidal crest**, which articulates with the posterior part of the middle concha. The *lateral surface*, for the most part, is applied to the medial side of the maxilla and helps to close the opening into the maxillary sinus; but the upper, posterior part—below the sphenoidal process and the spheno-palatine notch—is free, and forms the medial wall of the pterygo-palatine fossa. From that free area, the **greater palatine groove** runs downwards and forwards to the lower end of the plate. When the bone is in place, the groove, with the corresponding groove on the maxilla, forms the greater palatine canal, which leads from the pterygo-palatine fossa to the greater palatine foramen. The *anterior border* is a thin edge, of irregular outline, which articulates above with the ethmoid, with the posterior edge of the maxillary process of the inferior conchal bone about its middle, and below with the maxilla. The *posterior border* is thin above, where it articulates with the anterior part of the medial pterygoid plate, but expands below into the tubercle. The *lower border* is fused with the lateral edge of the horizontal plate. The *upper border* supports the **orbital** and **sphenoidal processes**; the notch between them is converted into the **spheno-palatine foramen** by the articulation of the palatine bone with the body of the sphenoid.

The **tubercle** is directed backwards and laterally from the junction between the perpendicular and horizontal plates. Its *posterior surface* presents a smooth, vertical groove bounded by two rough furrows that unite above in a ⋀-shaped manner. The furrows articulate with the anterior parts of the lower portions of the two pterygoid plates, and the groove fits into the pterygoid fissure to form the floor of the lower part of the pterygoid fossa. The *lateral surface* of the tubercle is confluent with the lateral surface of the perpendicular plate; its anterior part is rough for articulation with the maxilla; its posterior part is a smooth, narrow triangle that fits into the interval between the tuberosity of the maxilla and the lateral pterygoid plate in the medial wall of the infratemporal fossa. The **lesser palatine canals** descend through the tubercle to open on its lower surface as the **lesser palatine foramina**.

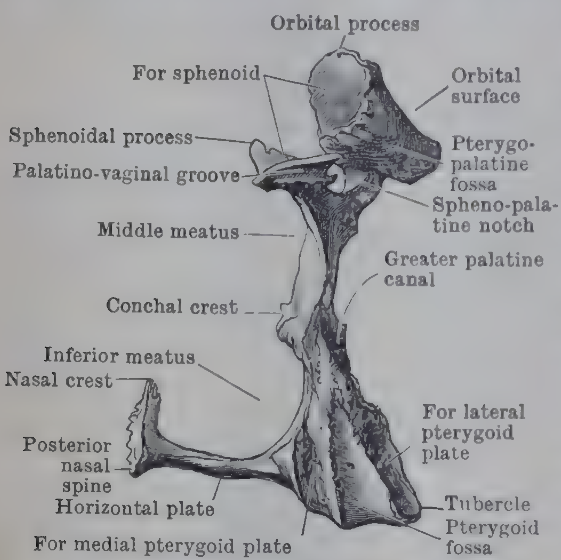


Fig. 205.—Right Palatine Bone.
As seen from behind.

The **orbital process**, shaped like a hollow cube, surmounts the anterior part of the perpendicular plate The mouth of the cube is applied to the body of the sphenoid and usually opens into its cavity; the anterior part of the cube articulates with the medial end of the border between the orbital and posterior surfaces of the maxilla. Of the remaining four surfaces, one, directed forwards and medially, articulates with the ethmoid. The others are non-articular: the *superior* forms the posterior part of the floor of the orbit; the *lateral* is directed towards the pterygo-palatine fossa; whilst the *inferior*, which is confluent with the medial surface of the perpendicular plate, is of variable width, and overhangs the superior meatus of the nose.

The **sphenoidal process**, much smaller than the orbital, curves upwards, medially, and backwards from the posterior part of the summit of the perpendicular plate. Its *upper surface*, which is grooved, articulates with the anterior part of the lower surface of the body of the sphenoid and the root of the medial pterygoid plate, thereby converting the groove into the **palatino-vaginal canal.** Its *lateral surface* forms part of the medial wall of the pterygo-palatine fossa. Its *medial surface* is in the side-wall of the superior meatus of the nose; its medial edge is in contact with the ala of the vomer.

Ossification.—The palatine bone ossifies from one centre which appears during the eighth week in the membrane in the side-wall of the nasal cavity. The orbital process may be ossified from an independent centre. Until the third year the antero-posterior width is greater than the vertical height, which increases as the maxillary sinus enlarges.

Structure and Variations.—The greater part of the palatine bone is composed of two thin plates of compact substance, which may be separated, in the horizontal plate, by an extension of the maxillary sinus. The lower part of the greater palatine canal may be completely bounded by the palatine bone. The orbital process varies greatly in size, and is not always pneumatic; occasionally it unites with the sphenoidal process and converts the spheno-palatine notch into a foramen, which may be divided into two by a bridge of bone.

Zygomatic Bones

Each **zygomatic bone** lies below and lateral to the orbit in the most prominent part of the cheek, and hence it is often called the *cheek-bone*. It forms the lateral border of the orbit and helps to separate it from the temporal fossa and the upper part of the infratemporal fossa; below, it rests upon and is united to the maxilla; behind, it enters into the formation of the zygomatic arch. The zygomatic bone is described as having three *surfaces*, named the *lateral*, the *orbital*, and the *temporal*, two processes, named the *frontal* and the *temporal*, and a *marginal tubercle*.

The **lateral surface** is the largest surface; it is slightly convex and rather uneven; above its most elevated part there is a small aperture called the **zygomatico-facial foramen**, which is often double. The lower border of the surface is free and rough, and is continuous with the lower edge of the zygomatic process of the maxilla. The upper border is smooth and

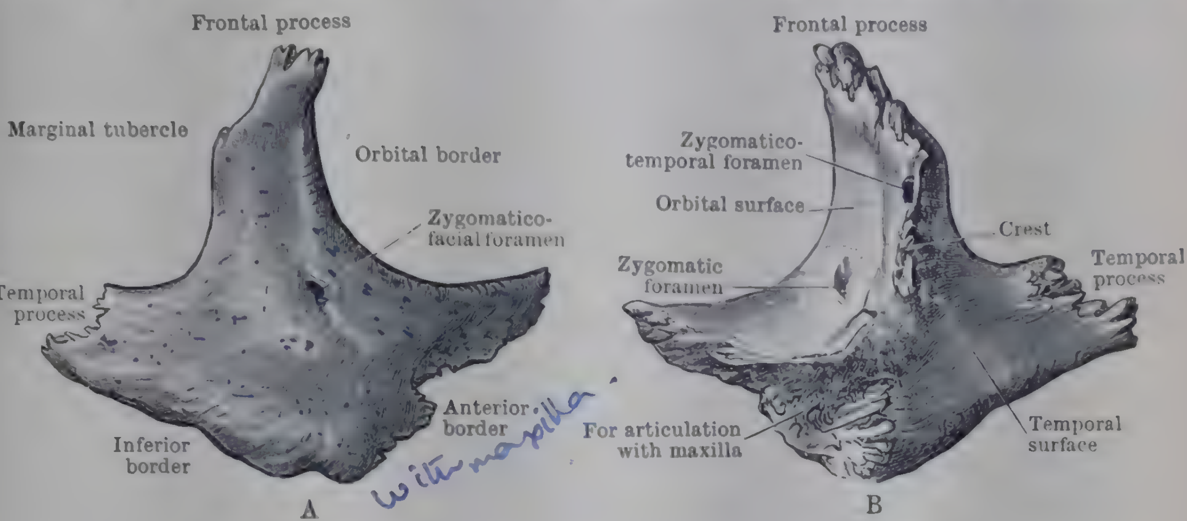


FIG. 206.—RIGHT ZYGOMATIC BONE. A, Lateral Side; B, Medial Side.

forms a great part of the infra-orbital margin. The anterior border is oblique and is united to the zygomatic process of the maxilla. The posterior border is continuous with the two processes. The **temporal process** projects backwards and articulates by an oblique, serrated extremity with the zygomatic process of the temporal bone. The **frontal process** is a large process that projects upwards; its medial margin is smooth and forms the greater part of the lateral border of the orbit; its lateral or posterior margin meets the upper border of the temporal process almost at a right angle. About half-way up that margin there is usually a prominence ~~called~~ the **marginal tubercle**. The upper end of the frontal process articulates with the zygomatic process of the frontal bone; and from its deep surface a wide, thin crest projects backwards in the lateral wall of the orbit, between the orbit and the temporal fossa, and articulates by its sharp, posterior edge with the greater wing of the sphenoid. That crest is continuous inferiorly with a small shelf of bone which projects backwards from the infra-orbital margin into the floor of the orbit and articulates with the maxilla. The crest and the shelf form the **orbital surface** of the bone; their free margins may be separated by a small, smooth notch that forms the anterior end of the inferior orbital fissure; at a varying point on the orbital surface there is an aperture, called the **zygomatic foramen**, which may be double.

The **temporal surface** is a large, concave surface which looks towards the temporal and infratemporal fossæ and includes the deep aspects of the temporal and frontal processes. On that part formed by the frontal process there is a small hole called the **zygomatico-temporal foramen**.

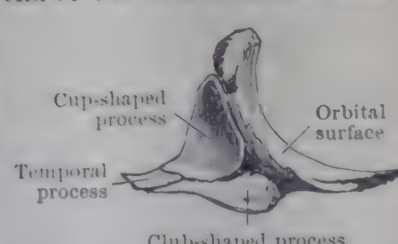


FIG. 207.—MEDIAL SURFACE OF ZYGOMATIC BONE AT BIRTH.

Besides the named surfaces there is a wide, rough, triangular area which articulates with the zygomatic process of the maxilla.

Ossification.—The zygomatic bone ossifies in membrane from one centre which appears between the eighth and the tenth week. There may be more than one centre, for the bone is sometimes divided in the adult. At birth there are narrow grooves or fissures on the temporal surface, produced by the overlapping edges of a cup-shaped and a club-shaped thickening of the bone; in some cases these grooves persist in the adult.

Structure and Variations.—In structure the zygomatic bone is compact, with little spongy tissue. Together with the zygomatic process of the temporal bone it forms the buttress which supports the maxilla and the lateral wall of the orbit. Additional strength is imparted to the bone by the angular mode of union of its orbital and facial parts.

The zygomatic bone is sometimes divided by a horizontal or a vertical suture. Partial separation of the upper and lower parts by a process from the maxilla has been recorded; and in one case an extension of the maxilla completely separated the two parts and articulated with the

zygoma. Cases have been noted where, owing to deficiency in the zygomatic bone, the zygomatic arch has been incomplete; and a case of absence of the zygomatic arch has been recorded.

Sutural Bones

Sutural bones are isolated bones of variable size and shape occasionally met with in the sutures and at the fontanelles. They were once called Wormian bones after the Danish anatomist *Ole Worm*. They are ossified from independent centres and usually include the whole thickness of the cranial wall, but they may involve only the outer or the inner table. They are most frequent at the lambda and in the lambdoid suture (Fig. 153). They are common at the pterion where they are called *epipteric bones*, and by their fusion with one or other of the adjacent bones they may lead to the occurrence of a fronto-squamosal suture. They have been seen in the sagittal suture, and sometimes in the interfrontal suture of metopic skulls. They are occasionally met with at the asterion and more rarely at the obelion. They are infrequent in the face, but they have been noted around the lacrimal bone, and also at the lateral end of the inferior orbital fissure, where one may form an independent nodule wedged in between the greater wing of the sphenoid, the zygomatic bone, and the maxilla.

The **mandible** and the **hyoid bone** are described on pp. 200, 206

BONES OF THE UPPER LIMB

The parts of the **upper limb** are the shoulder, the upper arm, the forearm, and the hand (see Fig. 129, p. 119).

The **shoulder** is not a sharply defined region; it includes not only the familiar prominence at the proximal end of the arm, but also (1) the *scapular region* (the parts around the shoulder-blade); (2) the *pectoral region* (the parts which overlie the upper part of the front of the chest); and (3) the *axilla* or armpit. The bones of the shoulder are the **scapula** or shoulder-blade and the **clavicle** or collar-bone. These two constitute what is called the *shoulder-girdle*: they articulate with each other at the *acromio-clavicular joint*. The clavicle articulates with the upper end of the sternum or breastbone, forming with it the *sterno-clavicular joint*; the scapula does not articulate with any part of the axial skeleton, being connected with it only by muscles.

The **upper arm** (brachium) extends from the shoulder to the elbow. The bone of the upper arm is the **humerus**; it articulates with the scapula to form the *shoulder joint*.

The **forearm** (ante-brachium) is continuous with the upper arm at the *elbow* (cubitus); there the humerus articulates with the two bones of the forearm to form the *elbow joint*. The bones of the forearm are the **radius** and the **ulna**; they articulate with each other at their proximal and distal ends, forming *radio-ulnar joints*.

The **hand** (manus) has three parts: (1) the wrist; (2) the hand proper, one surface of which is the palm and the other surface is the "back of the hand"; (3) the five digits.

The bones of the **wrist** (carpus) are eight small bones named collectively the **carpal bones**, and each has its own name besides. They are arranged in two rows—a proximal and a distal—four bones in each row. Three of the bones of the proximal row articulate with the radius and with a fibro-cartilaginous *articular disc* to form the *radio-carpal joint* or *wrist joint*, where the hand joins the forearm. Each carpal bone articulates with the adjoining carpal bones, forming *intercarpal joints*. Note that the "wrist" of every-day speech is the distal part of the forearm; the anatomical *wrist* is lower, and it is not marked off from the rest of the hand on the surface.

The bones of the **hand proper** (metacarpus) are the five **metacarpal bones**—one to each digit. They are named **first** metacarpal, **second** metacarpal, etc., beginning with the one that corresponds to the thumb. The metacarpal bones articulate with the distal row of carpal bones, forming *carpo-metacarpal joints*; and they articulate with one another at their proximal ends, forming *intermetacarpal joints*; their distal ends are the rounded prominences known as the first row of *knuckles*.

Each of the **digits** is named: the thumb or *pollex*; the forefinger or *index*; the middle finger or *digitus medius*; the ring-finger or *digitus annularis*; the little finger or *digitus minimus*. The bones of the digits are called **phalanges.** The thumb has two phalanges, named the **proximal** phalanx and the **distal** phalanx. Each finger has three phalanges: **proximal, middle,** and **distal.** The distal phalanx is sometimes called the *ungual phalanx*, because the *nail* (unguis) is associated with it. The proximal phalanx of each digit articulates with the distal end of its metacarpal bone to form a *metacarpo-phalangeal joint.* The ends of the middle phalanx articulate with the other two, forming *interphalangeal joints.*

Scapula

The **scapula** is a thin, wide, triangular bone [σκαπάνη (scapanē) = a digging tool] that lies obliquely in the upper part of the back and in the posterior wall of the axilla, opposite the second to the seventh ribs. It is classed as a 'flat' bone and has a main part or **body** and three processes,[1] named the **spine**, the **acromion**, and the **coracoid process**. At one of its angles the body is greatly thickened and is coated with articular cartilage. The thickened angle is the **head**, and the part contiguous to the head is the **neck**. The spine is the large triangular plate attached to the posterior surface of the body; the acromion is the flattened piece of bone which is continuous with the spine at the angle between its two unattached borders; and the coracoid process is the thick, bent piece of bone that projects from the upper part of the head and neck.

The **body** is the blade proper; it is thin and even translucent in places, and is triangular in outline—having two surfaces, three borders, and three angles.

The **borders** of the scapula are named *superior*, *medial*, and *lateral*.

The **superior border** is the shortest of the three. At its lateral end, close to the root of the coracoid process, there is a notch called the *suprascapular notch* which may be wide and shallow, or narrow and deep; it is bridged across by a fibrous band called the *suprascapular ligament*. In some scapulæ the ligament is ossified, and the notch is thus converted into a foramen.

The **medial border** is the longest of the three, and it looks medially and backwards towards the spines of the vertebræ. When the shoulder is at rest the border lies two or three finger-breadths from these spines and can be both felt and seen in a thin person. It is divided into three parts:—a small part opposite the spine of the scapula, a part above that and a part below, the lowest part being by far the longest.

The **lateral border** looks in a lateral direction and forwards, and lies in the posterior wall of the axilla, where it may be indistinctly felt. The part of it immediately below the head is thick and rough and is called the *infraglenoid tubercle*; the rest of it is thin, though rough.

The **angles** of the scapula are named *superior*, *inferior*, and *lateral*.

The **superior angle** is the one between the superior and medial borders; it is so thickly covered with muscles that it can scarcely be felt.

The medial and lateral borders meet at the **inferior angle**, the lowest part of the scapula. It is covered thinly with muscle, is easily felt and is used as a landmark for spines of vertebræ. When the arm is hanging at rest, it is at the level of the spine of the *seventh* thoracic vertebra.

The **lateral angle** is between the lateral and superior borders. It is only nominally an angle, for it is truncated and thickened to form the **head**. The lateral surface of the head is slightly hollowed to form what is called the **glenoid cavity**; it is smooth, articular, and pear-shaped in outline; it is directed forwards and slightly upwards as well as laterally, and it articulates with the head of the humerus to form the shoulder joint [γλήνη (glēnē) = a socket]. The small rough area at the upper margin of the glenoid cavity is called the *supraglenoid tubercle.*

The **surfaces** of the scapula are named *costal* and *dorsal*.

The **costal surface** looks towards the ribs and the greater part of it is concave;

[1] Definitions of terms are given on pp. 3 and 111.

the concavity is known as the **subscapular fossa**, and is deepest opposite the spine. At the medial and lower angles there are usually flat, triangular areas marked off by ridges from the rest of the surface, and these two areas are connected by a narrow, raised strip alongside the medial border; the areas and the strip are for the insertion of a large muscle, the *serratus anterior*. All the rest of the costal surface (except a small part near the neck, Fig. 211) gives origin to the *subscapularis* muscle and low ridges that run from the medial margin towards the neck give attachment to tendinous fibres in the substance of the subscapularis. A wide, blunt, smooth ridge begins at the neck, runs downwards near the lateral margin and fades away near the inferior angle. If the scapula is held up against the light, this will be seen to be the thickest part of the blade; and it is the bar-like lever on which the serratus anterior acts when it moves the scapula.

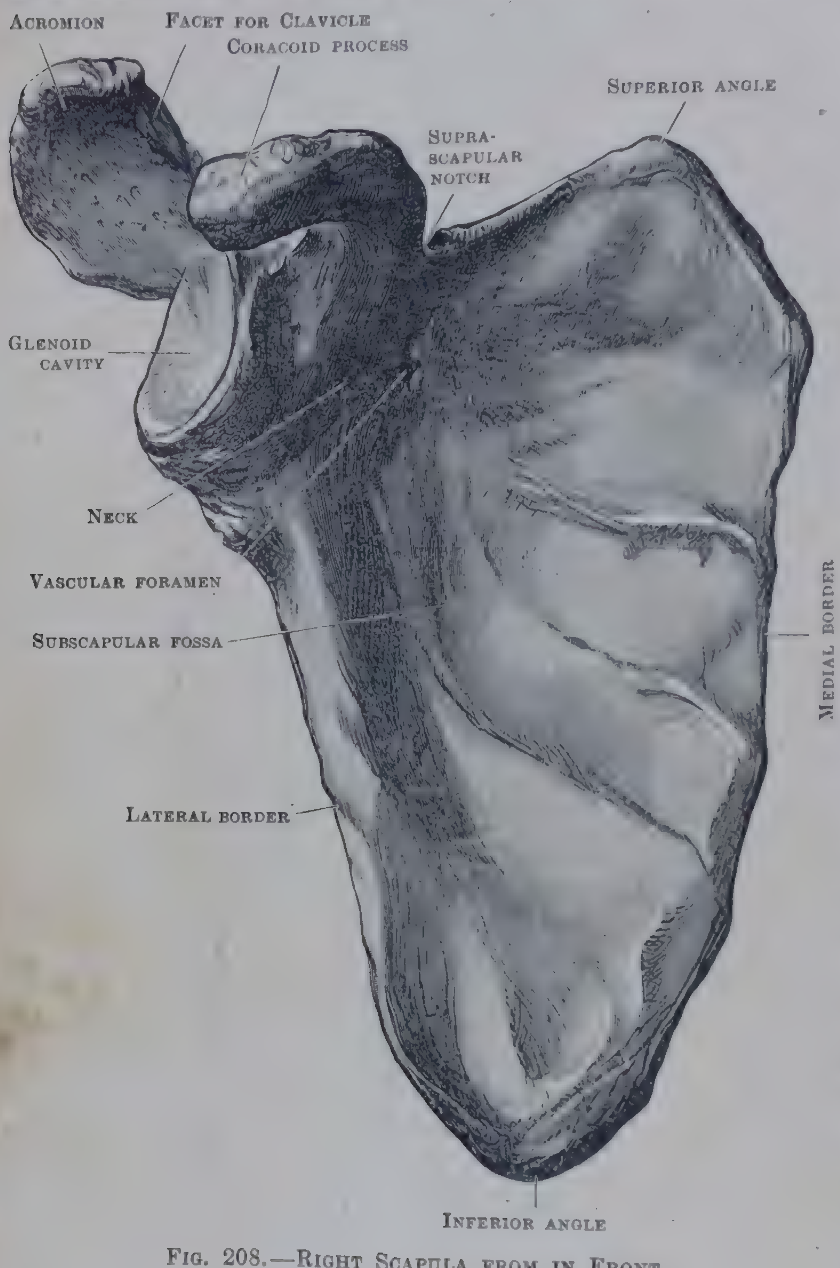


Fig. 208.—Right Scapula from in Front.

The **dorsal surface** is divided into two unequal parts by the spine; the two parts are not in the same plane, for the scapula is bent at the attachment of the spine. The smaller, supraspinous part and the upper surface of the spine form the boundaries of the **supraspinous fossa.** On the larger, infraspinous part there is a raised oval area alongside the lower part of the lateral margin; this area gives origin to the *teres major* muscle. Above that area there is a raised narrow strip that reaches up to the head of the bone; the *teres minor* muscle arises from the strip; and, crossing it, there is a narrow, shallow groove produced by the circumflex scapular artery; occasionally there are two grooves, and they correspond to branches of the artery. The remainder of the lower part of the dorsal surface forms one wall of the **infraspinous fossa**, while the the lower surface of the spine is the other wall.

The **spine of the scapula** is a triangular plate of bone attached by one of its borders to the dorsum of the scapula. Another border of the spine looks in a lateral direction towards the shoulder joint; it is smooth and rounded, and the wide notch that separates it from the neck and head of the scapula is the **spino-glenoid notch**. The notch is bridged by a weak fibrous band called the *spino-glenoid ligament.* The third border is the **crest of the spine.** It is subcutaneous and can be felt easily in all its length in the living person. It has fairly sharp *upper* and *lower lips* or edges; and the lower lip shows a low, wide *tubercle* or enlargement towards

PLATE IX

PLATE IX.—RADIOGRAPH OF SHOULDER REGION OF MAN AGED 29.

For alterations in the relative positions of the Humerus and the Scapula during movements of the Upper Limb, see Plate XXXII, p. 347.

PLATE X

PLATE X.—RADIOGRAPH OF SHOULDER REGION OF YOUTH AGED 18 TO SHOW THE RELATION OF THE DIAPHYSIS OF THE HUMERUS TO THE CAP-LIKE EPIPHYSIS OF THE HEAD AND TUBEROSITIES.

Note also the acromial epiphysis and the scale-epiphysis on the coracoid process.

[Facing p.

its medial end. At the medial margin of the blade the lips of the crest spread apart to enclose a small, smooth, triangular area which one can easily feel in the living person by pressing the finger along the crest; it is at the level of the spine of the *third* thoracic vertebra, and is used as a landmark.

The **acromion** is broad and flattened; it is continuous with the spine at the angle where the crest and the lateral border of the spine meet; it extends in a lateral direction and forwards and overhangs the shoulder joint above and behind. It is easily felt at the top of the shoulder, its upper surface being subcutaneous and continuous with the crest of the spine [ἄκρον (acron) = highest point; ὦμος (ōmos) = shoulder (with upper arm)]. Its lateral border is long and is sharply bent to become continuous with the lower lip of the crest. The bend, called the **acromial angle**, is easily found in the living person, and is used as a point from which measurements may be taken and as a guide to the back of the shoulder joint which lies directly below and in front of it. The medial border of the acromion is short and is continuous with the upper lip of the crest. Its anterior and larger part is occupied by an oval facet, facing slightly upwards as well as medially, for articulation with the lateral end of the clavicle at the *acromio-clavicular joint*.

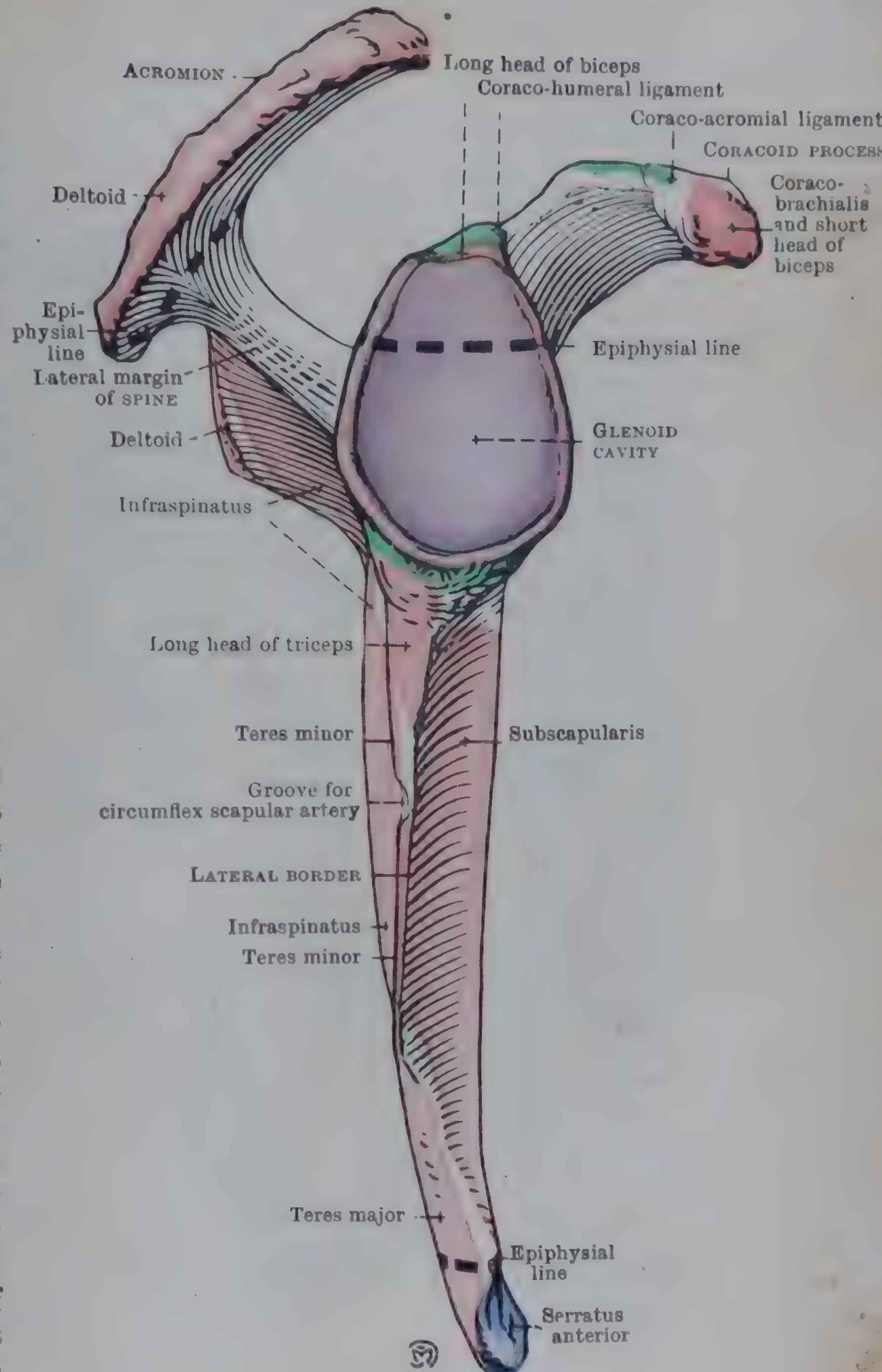


FIG. 209.—LATERAL VIEW OF RIGHT SCAPULA.

The **coracoid process** is the stout, blunt process that projects from the upper margin of the neck and head of the scapula. In shape it has some resemblance to the bill of a bird [κόραξ (corax) = a raven or crow], and it is divisible into a root and a coracoid process proper.

The **root** projects upwards and forwards from the neck and head and is flattened from before backwards—its anterior and posterior surfaces being continuous with the front and the back of the neck. Its medial border is the lateral margin of the suprascapular notch, and its lateral border is immediately above the glenoid cavity.

The **coracoid process proper** is fused with the top of the root and is almost horizontal. When the scapula is in its right position in the skeleton, with its

glenoid cavity looking forwards as well as sidewards, the coracoid process extends forwards and only slightly in a lateral direction. It overhangs the shoulder joint above and in front. Its **borders** are *lateral* and *medial*. The lateral border is connected with the tip of the acromion by the strong, flat, triangular *coraco-acromial ligament*; the two processes and this ligament form a wide **coraco-acromial arch**, which overhangs the shoulder joint and protects it. The **surfaces** of the coracoid

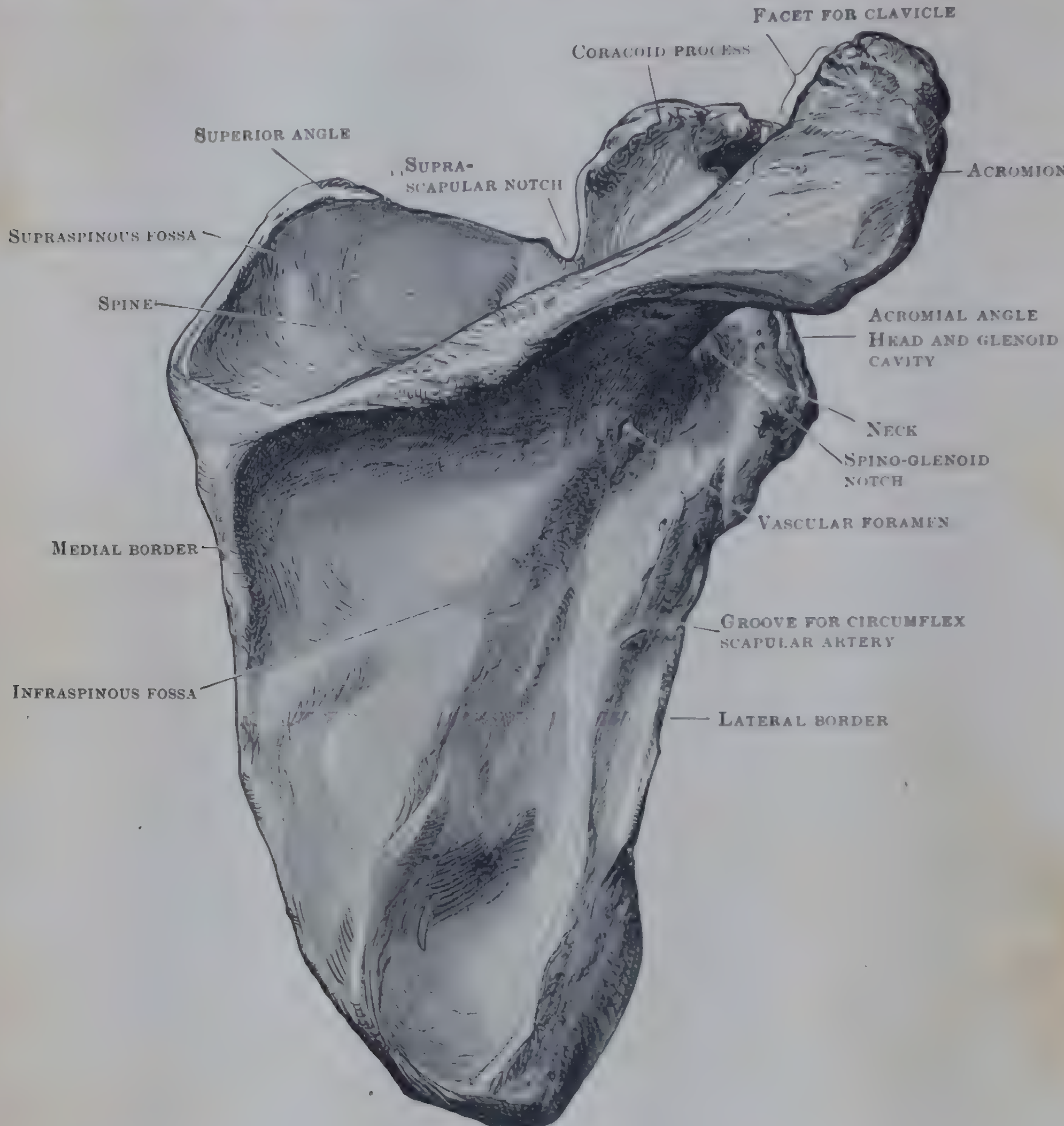


Fig. 210.—Dorsal Surface of Right Scapula.

process are *upper* and *lower*. The posterior part of the upper surface is roughened for the attachment of a thick, strong *coraco-clavicular ligament*, which binds it to the clavicle. The **tip of the coracoid process** is a landmark in the root of the upper limb. It is felt, rather indistinctly, as a hard, resisting object in the hollow on the front of the shoulder about an inch below the clavicle.

Nutrient foramina, by which arteries enter the bone and veins leave it, are scattered here and there, and are largest near the attached margin of the spine.

Attachments.—The **upper margin** of the scapula gives attachment to only one small muscle, namely, the inferior belly of the omo-hyoid, which arises from the suprascapular ligament and the adjoining part of the upper margin. The **medial border** gives insertion to three muscles: (1) the levator scapulæ, opposite the supraspinous fossa; (2) the rhomboideus minor, opposite the spine; and (3) the rhomboideus major, opposite the infraspinous fossa.

The **costal surface** gives attachment to (1) the serratus anterior, which is inserted into the small areas at the upper and lower angles and into the narrow strip along the medial border,

and (2) the subscapularis, which arises from the whole costal surface except the parts for the insertion of the serratus anterior and a part near the neck; a *bursa* protrudes from the capsule of the shoulder joint and separates the subscapularis from the neck and from the root of the coracoid process, and these parts of the bone are smooth.

The **glenoid cavity** gives attachment by its circumference to a fibrous ring called the labrum glenoidale. The capsular ligament of the shoulder is attached to the rim of the cavity outside

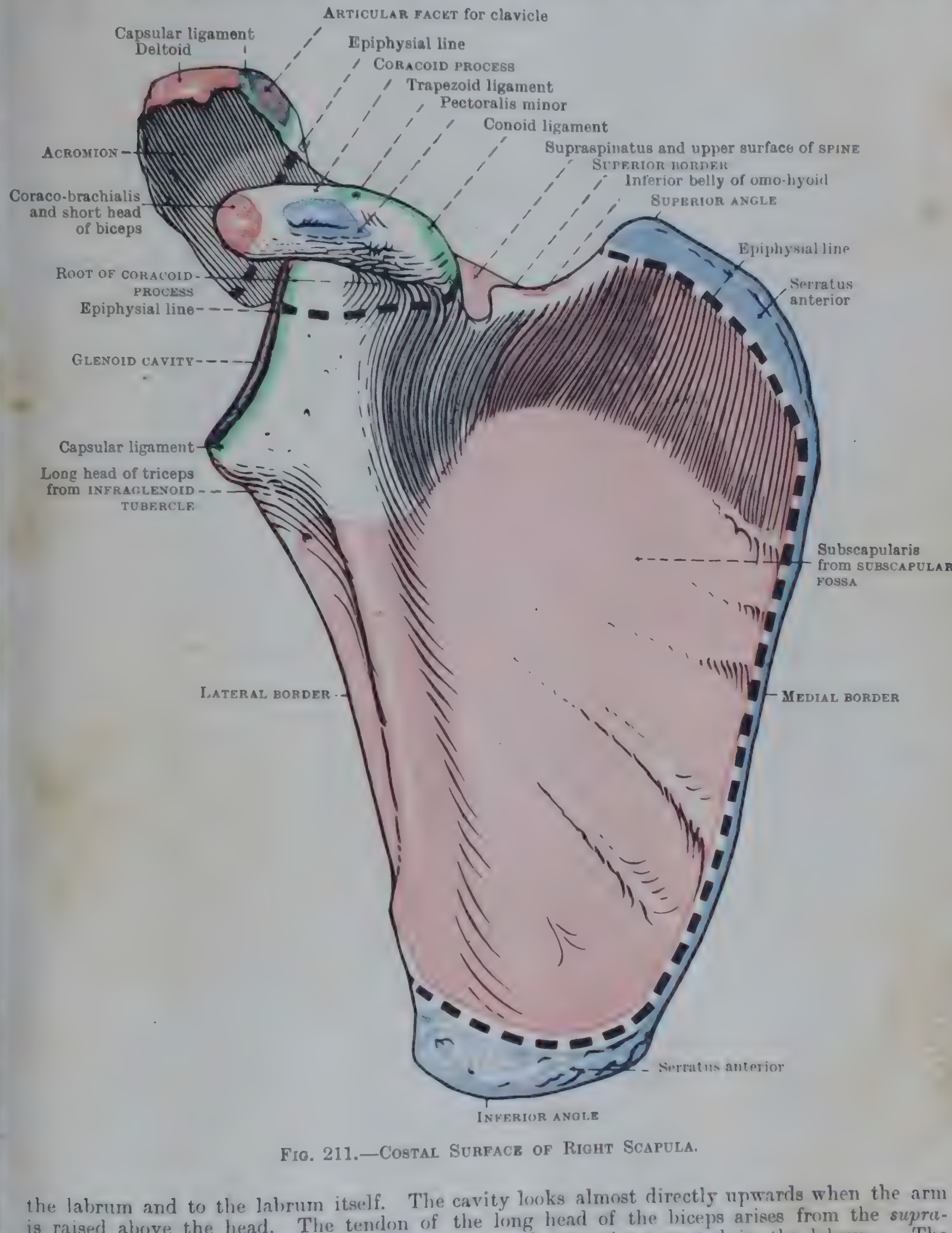


FIG. 211.—COSTAL SURFACE OF RIGHT SCAPULA.

the labrum and to the labrum itself. The cavity looks almost directly upwards when the arm is raised above the head. The tendon of the long head of the biceps arises from the *supraglenoid tubercle*, and some of the fibres of the tendon are incorporated in the labrum. The tendon of the long head of the triceps arises from the *infraglenoid tubercle*, and that is the only muscle attached to the **lateral border**.

On the **dorsal surface** the teres major muscle arises from the oval or *triangular elevated area* near the inferior angle, and the latissimus dorsi muscle receives a small slip of origin from the lowest part of that area; the teres minor arises from the *elongated elevated area* that extends upwards to the head; the infraspinatus muscle arises from the walls of the **infraspinous fossa**, except near the neck. The supraspinatus arises from the walls of the **supraspinous fossa**, except a part near the neck; as it passes over the shoulder joint towards its insertion into

the humerus it is separated from the smooth, lower surface of the acromion by the *subacromial bursa.*

The *upper* and *lower surfaces* of the **spine** help to bound the supra- and infraspinous fossæ and give origin to some fibres of the supraspinatus and infraspinatus. The spino-glenoid ligament stretches from the *lateral margin* of the spine to the back of the **neck** of the scapula. The whole of the *lower lip* of the **crest** and the *lateral margin* of the **acromion** give origin to fibres of the deltoid muscle. The circumference of the *facet* on the medial margin of the acromion

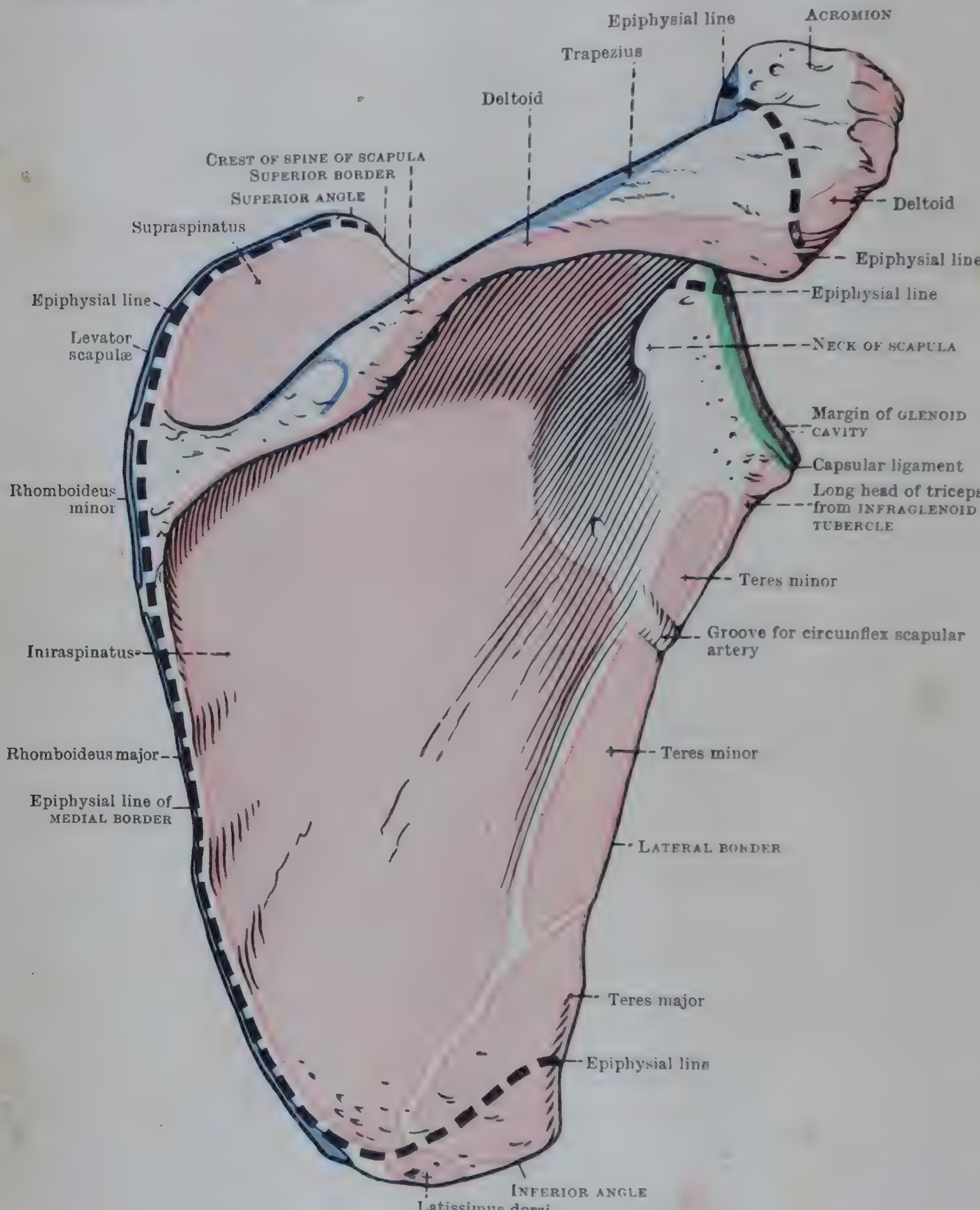


Fig. 212.—Dorsal Surface of Right Scapula.

gives attachment to the capsule of the acromio-clavicular joint. The coraco-acromial ligament is attached to the *tip* of the acromion in front of the facet. Fibres of the trapezius muscle are inserted into the small part of the *medial margin* behind the facet, and into nearly the whole length of the *upper lip* of the **crest** and the **tubercle** on the *lower lip* of the crest; and a tendinous part of the trapezius, before reaching its insertion, plays over the smooth area where the spine joins the medial border, and it is separated from that area by a small *bursa.*

The **coracoid process** gives attachment to numerous structures. The coraco-humeral ligament is attached to the *lateral margin* of its **root**, and the suprascapular ligament to the *medial margin.* The coraco-brachialis muscle and the tendon of the short head of the biceps muscle arise conjointly from the *tip* of the **process proper**; the coraco-acromial ligament is attached

to its *lateral margin*; the clavi-pectoral fascia to the posterior part of the *medial margin*; the pectoralis minor muscle is inserted into the anterior part of the *medial margin* and the adjoining part of the *upper surface*, and its attachment is sometimes marked by a ridge or a tubercle. The coraco-clavicular ligament is attached to the posterior part of the *upper surface*. The *lower surface* does not give attachment to any structure; it is smooth and is in relation with the subscapular *bursa* and muscle.

Ossification.—The **primary** centre appears at the eighth week of intra-uterine life. At birth the acromion, the coracoid process, the glenoid cavity, the inferior angle, and the medial border are still cartilaginous.

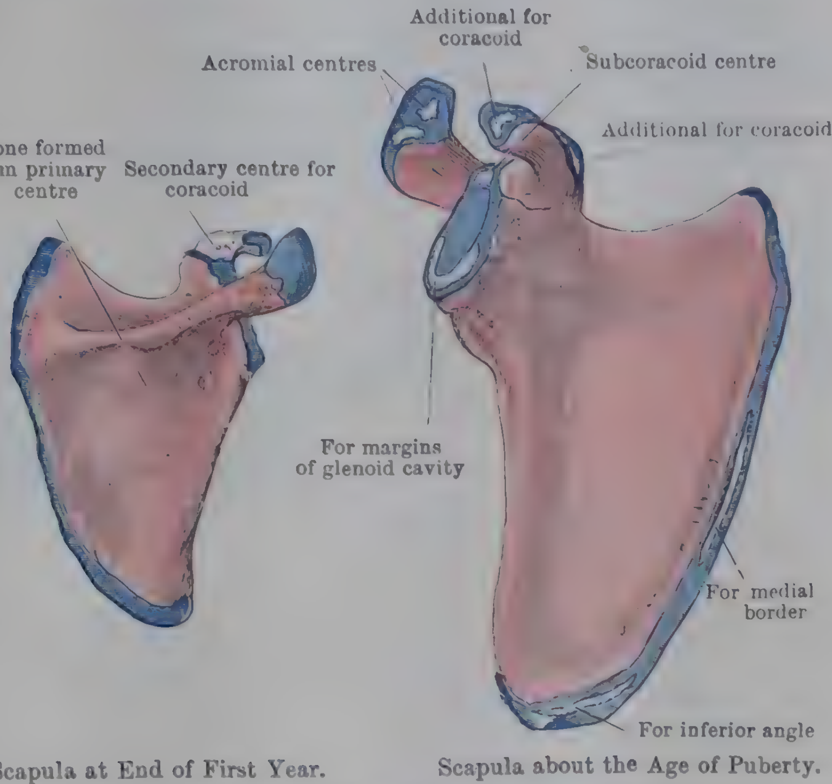


Fig. 213.—Ossification of Scapula.

Occasionally the epiphysis formed from the two acromial centres fails to fuse with the rest of the bone, and the greater part of *the acromion is* **throughout life a separable bone** united to the rest of the bone by a cartilaginous or a synovial joint; the joint appears like a line of fracture

Secondary Centre.	Appears at	Epiphysis fuses at	Relation of Epiphysial line to Capsule of Neighbouring Joint.
For coracoid process (proper)	1st year	Puberty	None.
Subcoracoid, for lateral part of root of coracoid and upper third of glenoid cavity . .	10th year	Puberty	Partly outside, partly inside.
For margins of glenoid cavity	Puberty	20-25	Inside.
For inferior angle . .	Puberty	20-25	None.
For medial border . .	Puberty	20-25	None.
Two for acromion . .	Puberty	20-25	Outside.

in a radiograph; the condition is usually alike on the two sides. The centre for the coracoid process may be regarded morphologically as a primary centre and is sometimes present at birth; sometimes one or two additional centres appear on its surface after puberty and form small scaly epiphyses which join about the twentieth year.

Structure and Variations.—Two plates of compact bone separated by spongy tissue in the thicker parts and fused together in the thinner parts. In old people the bone may be absorbed in parts, but the periosteum remains. The coracoid process may be separate, but much more seldom than the acromion. In an infant the scapula is relatively wide.

Clavicle

The **clavicle** is an elongated, curved bone [*clavicula*, diminutive of *clavis* = a key, or of *clavus* = nail or bolt]. It lies nearly horizontally in front of the upper part of the thorax at the root of the neck, stretching from the upper end of the sternum or breastbone to the acromion of the scapula and bracing the upper limb back so that the arm can swing to and fro clear of the trunk; it can be felt through the skin from end to end. It is a long bone and has a **shaft** and two slightly expanded **ends**. The **lateral third** of the bone is flattened from above downwards, and the lateral end can therefore be distinguished from the medial end at once; the lower surface of the lateral third is rougher than the upper surface, and therefore one can determine at a glance which is the *upper surface* and which is the *lower*. The bone

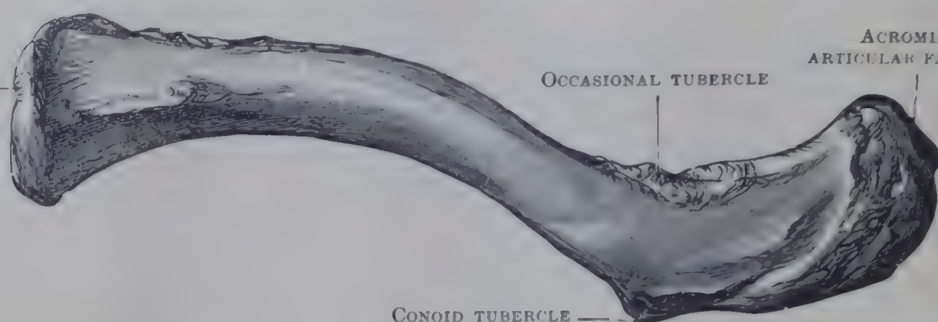


FIG. 214.—RIGHT CLAVICLE SEEN FROM ABOVE.

as a whole has a double curve like the *italic* letter *f*: the **medial half or two-thirds** of the bone is convex forwards, as may be felt and seen in the living person, and the lateral half or third is concave forwards; the *anterior* and *posterior surfaces* of the bone are therefore easily identified.

The **acromial end** of the clavicle articulates with the medial margin of the acromion and is occupied by an oval *articular facet*. The margins of the facet are often raised or 'lipped', and the ridge at the upper margin may assist one in finding the acromio-clavicular joint in the living person. Its articulation with the acromion is not direct, for an *articular disc* of fibro-cartilage intervenes between the two bones. The articular surface is oblique, looking downwards as well as laterally; when the bones are dislocated the clavicle therefore overrides the acromion, and it is difficult to keep it in place once dislocated.

The **sternal end** is thick. It articulates with the clavicular notch on the upper

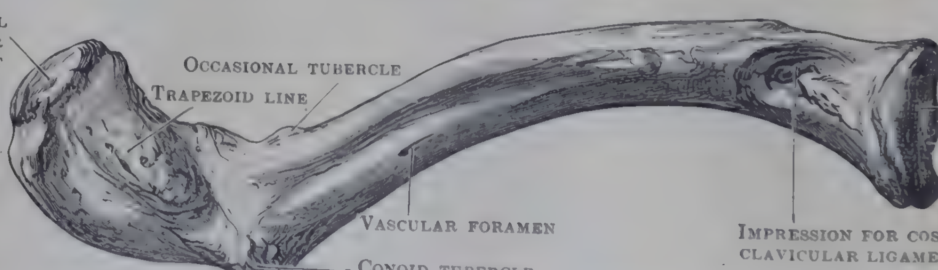


FIG. 215.—RIGHT CLAVICLE SEEN FROM BELOW.

end of the sternum and with the cartilage of the first rib at the side of the sternum, and the joint is called the *sterno-clavicular joint*. The end of the clavicle is larger than the clavicular notch on the sternum and its upper part can be felt above the level of the sternum; the *articular facet* occupies the lower three-fourths of the end of the clavicle and curves also on to the inferior surface for articulation with the first costal cartilage. In some clavicles the facet has been destroyed during maceration. An *articular disc* separates the clavicle from actual contact with the sternum, though not from the first costal cartilage.

The **shaft** of the clavicle is divided, for descriptive purposes, into a lateral third and a medial two-thirds.

The **lateral third** has two surfaces, *upper* and *lower*, and two borders, *anterior* and *posterior*. The **anterior border** is rough and concave; the **posterior border** is smooth and convex. The **superior surface** is subcutaneous and is usually smooth, but it may be rough near the borders, because the muscles attached to the borders sometimes extend their attachments on to the surface. The **inferior surface** is rough. At the posterior border there is a blunt, rounded **conoid tubercle**; a broad, rough ridge, the **trapezoid ridge**, extends from the tubercle towards the lateral end of the clavicle. The lateral third of the clavicle lies above the coracoid process of the scapula and is attached to it by a strong, *coraco-clavicular ligament*. The ligament is in two parts named from their shape *conoid* and *trapezoid*, and they give the names to the tubercle and the ridge to which they are attached.

The **medial two-thirds** of the clavicle has four surfaces—anterior, posterior, superior, and inferior—separated by borders for which names are not necessary.

The **anterior surface** is the convex surface; laterally it narrows down to become continuous with the anterior border of the lateral third. Nearly all of it is occupied by an impression for the origin of part of the *pectoralis major* muscle. The **posterior surface** is the concave surface; it is smooth and is continuous with

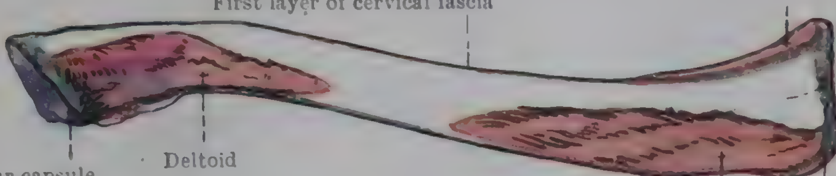


FIG. 216.—ANTERIOR ASPECT OF RIGHT CLAVICLE.

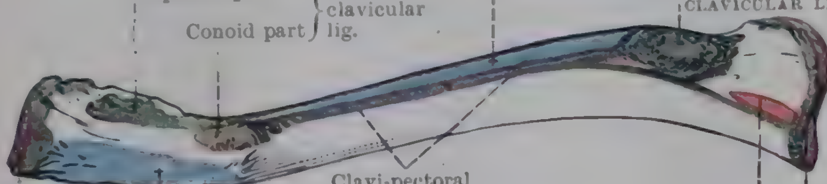


FIG. 217.—POSTERIOR ASPECT OF RIGHT CLAVICLE.

the posterior border of the lateral third. The **upper surface** is continuous with the upper surface of the lateral third, and is usually smooth and flat; it may be so narrow that it is a mere ridge, or it may seem to be part of the anterior surface.

Close to the medial end of the **lower surface** there is a rough impression of variable size and character which may be an elevation or a depression. It gives attachment to the *costo-clavicular ligament*, a strong fibrous band which binds the clavicle to the first rib. The lateral part of the lower surface of the medial two-thirds is occupied by a shallow groove which extends as far as the conoid tubercle and gives insertion to a small muscle called the *subclavius*. The rest of the surface may be of appreciable width, but it is often narrowed to a mere border.

The **nutrient foramen** is on the posterior surface near the junction of the lateral third with the medial two-thirds, and it is directed towards the lateral end.

The clavicle varies a great deal in different people, and a poorly developed bone may have ill-defined surfaces in its medial two-thirds.

The clavicle is horizontal or nearly so when the body is in the upright position. But it slants upwards from medial to lateral end when the body is recumbent; for, in that position, the shoulder-blades are moved upwards, and the lateral ends of the clavicles move with them. In a radiograph of a recumbent person the shadow of the clavicle is therefore very oblique. It is oblique also in radiographs taken when

the arm is held away from the side; for, in the movement of raising the arm, the scapula rotates, and the acromion, with the lateral end of the clavicle, is raised.

Attachments.—The capsule of the acromio-clavicular joint is attached to the margins of the *facet* on the **lateral extremity**. Part of the trapezius is inserted into the *posterior border* of the **lateral third**; part of the deltoid arises from the *anterior border*, on which there is occasionally a small, rough tubercle; the conoid and trapezoid ligaments are attached to the **conoid tubercle** and the **trapezoid ridge**.

The capsular ligament of the sterno-clavicular joint is attached to the margins of the *facet* at

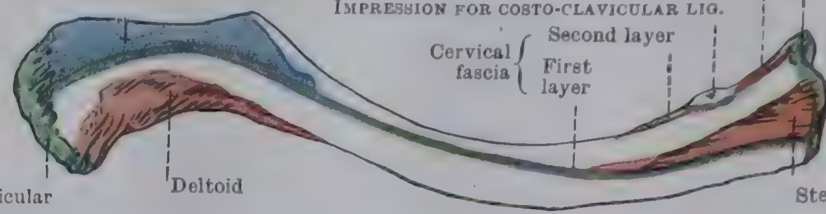


FIG. 218.—SUPERIOR ASPECT OF RIGHT CLAVICLE.

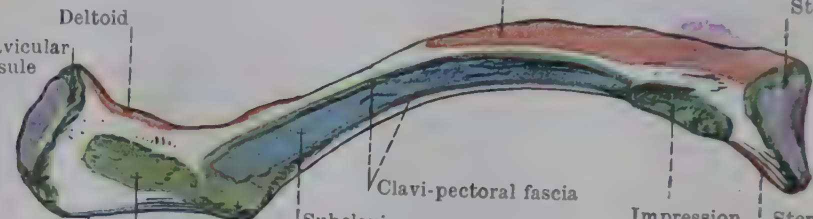


FIG. 219.—INFERIOR ASPECT OF RIGHT CLAVICLE.

the **medial end**; the capsular ligament, the articular disc and the interclavicular ligament are attached to the rough *area above the facet*. The costo-clavicular ligament is attached to the impression on the lower surface. The subclavius muscle is inserted into the floor of the *elongated groove* on the lower surface of the shaft; the clavi-pectoral fascia, which splits to enclose the subclavius, is attached to the *margins of the groove*. Part of the pectoralis major muscle arises from the *anterior surface* of the **medial two-thirds**. Part of the sterno-mastoid muscle arises from the *upper surface* of the medial third. Fibres of the sterno-hyoid muscle (and sometimes sterno-thyroid) arise from the *posterior surface* near the medial end.

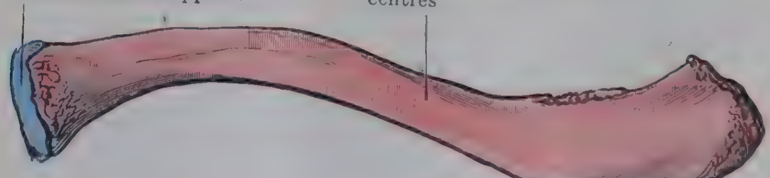


FIG. 220.—OSSIFICATION OF CLAVICLE.

Ossification.—The clavicle is the first bone in the body to begin to ossify, and it is peculiar in its mode of ossification. Two **primary** centres appear in the fifth week of intra-uterine life in two separate portions of mesodermal tissue which are at the pro-cartilage stage. When the tissue between those two portions also becomes pro-cartilage, the two centres coalesce to form one; ossification spreads from this centre into the cartilage that appears at the ends of the bone-rudiment, and almost the whole bone is ossified from it.

Secondary Centre.	Appears at	Epiphysis fuses at	Epiphysial Line is inside
For medial end	20th year	25	Capsule of sterno-clavicular joint.

Structure and Variations.—The clavicle, though a long bone, has no medullary cavity. It consists of spongy tissue surrounded by a shell of compact bone which is thickest in the middle. The nutrient artery is a branch of the suprascapular. There may be two nutrient foramina,

and one of them may be on the lower surface. The right clavicle is often longer, stronger, and more curved than the left.

The clavicle in women is shorter, smoother, and more slender than in men, and the curvatures are less marked; its acromial end is at a lower level than the sternal end, while in men the ends are at the same level or the acromial end is the higher. Occasionally the clavicle is perforated by one of the supraclavicular nerves. In rare cases the clavicle is incompletely developed or is absent. A freely movable medial end and a bifurcated lateral part have been recorded. A small epiphysis may appear at the acromial end about 20, and it unites rapidly.

Humerus

The **humerus** is the bone of the upper arm; its length is about one-fifth of the height of the person; though nearly all thickly covered with muscles it can be felt by deep palpation in all its length. It is a long bone with a **shaft** and **two ends**.

It is necessary first to distinguish the ends and ascertain the general direction of its surfaces. The **upper** end is the thick, rounded end, while the lower end is compressed from before backwards; there is a wide, deep hollow on the **back** of the lower end; the smooth, hemispherical part of the upper end looks in a **medial** direction.

The **upper end** includes the head, the anatomical neck, the greater and lesser tuberosities, and part of the bicipital groove.

The **head** is the large, convex, smooth articular part. It looks in a medial direction and also upwards, and, when the arm is hanging naturally by the side, it looks backwards as well. It articulates with the glenoid cavity of the scapula and may be indistinctly felt by the fingers pushed well up into the axilla.

The **lesser tuberosity** is the well-marked prominence on the front of the upper end; the part of it nearest the head has an impression, usually smooth, for the insertion of the tendon of the subscapularis. The lesser tuberosity can be felt in the front of the shoulder immediately lateral to the coracoid process (and may be mistaken for it) when the arm is hanging comfortably by the side, but at a

FIG. 221.—FRONT OF RIGHT HUMERUS.

little distance from that process when the limb is rotated so that the palm of the hand looks forwards.

The **greater tuberosity** is the prominence on the lateral side of the upper end. Though larger than the lesser tuberosity it is not so clearly defined, for its lateral surface shades off into the lateral side of the shaft. Its upper surface and its posterior surface have smooth impressions for the insertion of muscles. The greater tuberosity forms the "point of the shoulder", *i.e.*, its most projecting lateral part, and it may be felt there a little below the lateral margin of the acromion.

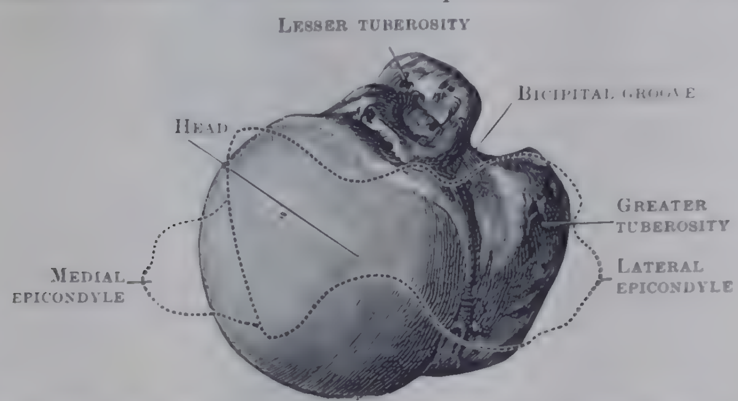


Fig. 222.—Proximal Aspect of Right Humerus (with the outline of lower end in relation to it in dotted line).

The **bicipital groove** is the clean-cut groove between the two tuberosities, and it is prolonged slightly spirally (Fig. 221) for two inches or more on to the shaft, where it is not so sharply defined. The tendon of the long head of the biceps, after it emerges from the shoulder joint, lies in the groove.

The **anatomical neck** is the narrow strip that encircles the margins of the head; its upper part is the narrow and shallow depression that separates the head from the tuberosities.

The **surgical neck** is the region immediately below the head and tuberosities—where the upper end joins the shaft. It does not have sharp limits, and may be reckoned as about a finger's breadth in extent all round the bone. The name is given because the bone is often fractured there.

The **lower end** includes the capitulum, the trochlea, the radial, coronoid and olecranon fossæ, and the lateral and medial epicondyles.

The **capitulum** is the smooth, rounded knob placed near the lateral part of the lower end. It is situated partly on the front and partly below, but not at all on the back. It articulates with the head of the radius.

The **radial fossa** is the shallow depression on the front of the bone immediately above the capitulum; the margin of the head of the radius comes into close relation with it when the forearm is fully bent.

The **trochlea** is the wide, smooth, pulley-shaped surface at the medial side of the capitulum [τροχιλία (trochilia) = the sheave of a pulley]. It is situated on both the front and back and distal aspect. It winds slightly spirally from front to back, and its medial lip stands out as a prominent rim. It articulates with the ulna at the trochlear notch, *i.e.*, the wide concavity on the front of the upper end of the ulna. The axis of rotation of the joint is set slightly obliquely, so that the forearm is not quite in line with the upper arm when the limb is held with the palm facing forwards.

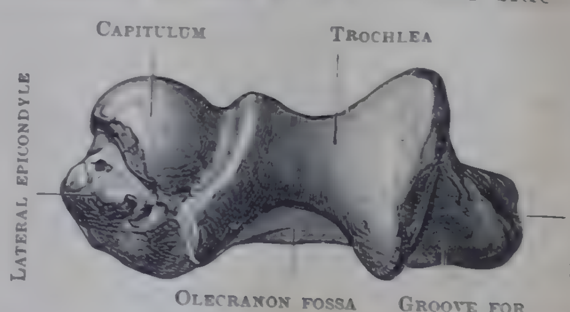


Fig. 223.—Distal Aspect of Right Humerus.

The **coronoid fossa** is the depression on the front, immediately above the trochlea. It is related to the coronoid process of the ulna when the forearm is fully flexed.

The **olecranon fossa** is the large depression in a corresponding position on the back; the olecranon of the ulna fits into it when the forearm is straightened out. The bony substance between the coronoid and olecranon fossæ is very thin.

The **medial epicondyle** is the prominent projection on the medial side of the lower end. It is easily felt at the medial side of the elbow and can be gripped between finger and thumb. Its anterior surface has impressions for the origin

of muscles; its posterior surface is smooth and has a shallow groove which lodges the *ulnar nerve* as it passes from the upper arm into the forearm; the nerve can be felt and rolled between the finger and the bone.

The line or ridge (often poorly marked) that extends from the epicondyle on to the shaft for two or three inches is called the **medial supracondylar ridge**.

The **lateral epicondyle** is the projection on the lateral side of the lower end; it is not nearly so prominent as the medial epicondyle. Its anterior surface is small and is occupied by an impression for the origin of muscles. Its posterior surface is broad and smooth and subcutaneous; it can be felt on the back of the arm immediately above the lateral part of the elbow joint—that part of the joint being recognizable as a transverse depression.

The strong ridge which extends on to the shaft from the lateral epicondyle is the **lateral supracondylar ridge**; it is easily felt when the elbow joint is in the bent position and the muscles are relaxed.

When the upper limb is placed so that the palm looks forwards, the various parts of the humerus are in the position indicated in the description given; but when the limb hangs comfortably by the side with the palm looking towards the thigh, the directions in which the parts look are altered—for example, the lateral epicondyle is felt on the antero-lateral aspect of the limb, and the medial epicondyle on the postero-medial aspect.

The **shaft** is more or less cylindrical in its upper half, but is rather compressed from before backwards in its lower part; it is described as having three borders and three surfaces. The **borders** are anterior, medial, and lateral; the **surfaces** are posterior, antero-lateral, and antero-medial.

The **anterior border** begins at the anterior margin of the greater tuberosity, runs along the front of the bone, and ends near the radial and coronoid fossæ; its upper third is the lateral lip of the bicipital groove.

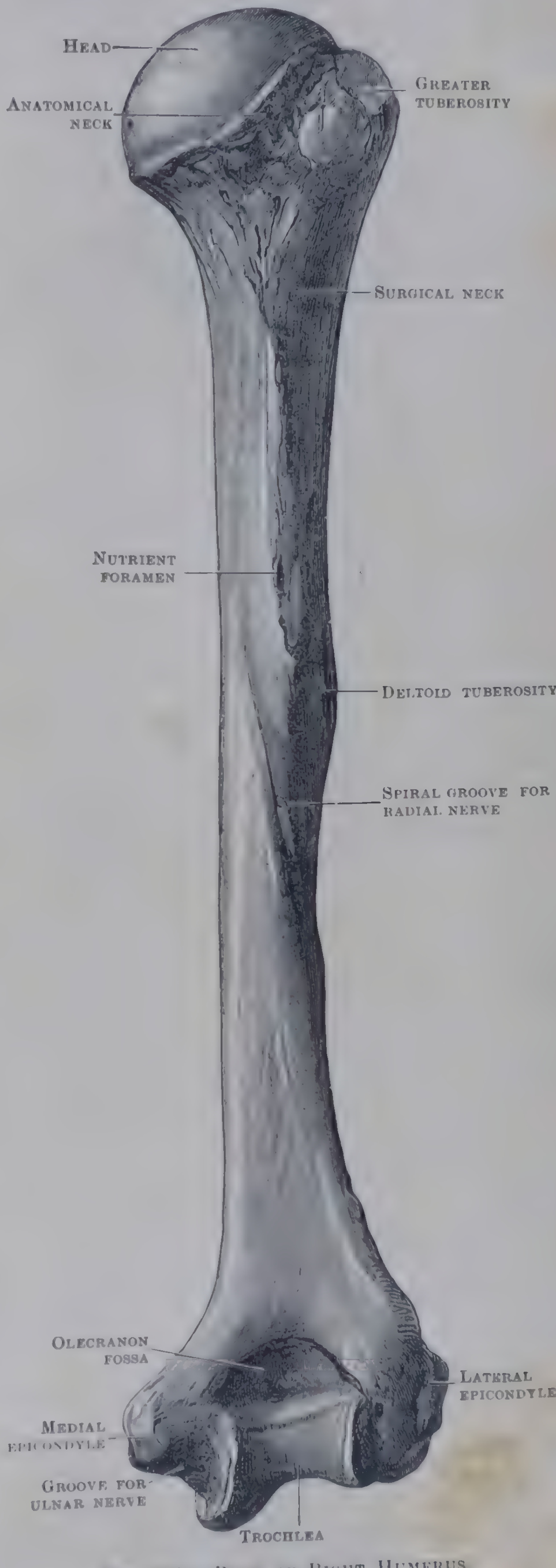


FIG. 224.—BACK OF RIGHT HUMERUS.

The **medial border** begins at the lesser tuberosity and ends at the medial epicondyle. It is not nearly so well marked as the anterior border. Its upper

third is the medial lip of the bicipital groove; its lower third is the medial supracondylar ridge; in bones in which muscular markings are well seen its middle part is roughened for the insertion of the coraco-brachialis muscle.

The **lateral border** begins at the posterior surface of the greater tuberosity and ends at the lateral epicondyle. Its lower third is the lateral supracondylar ridge;

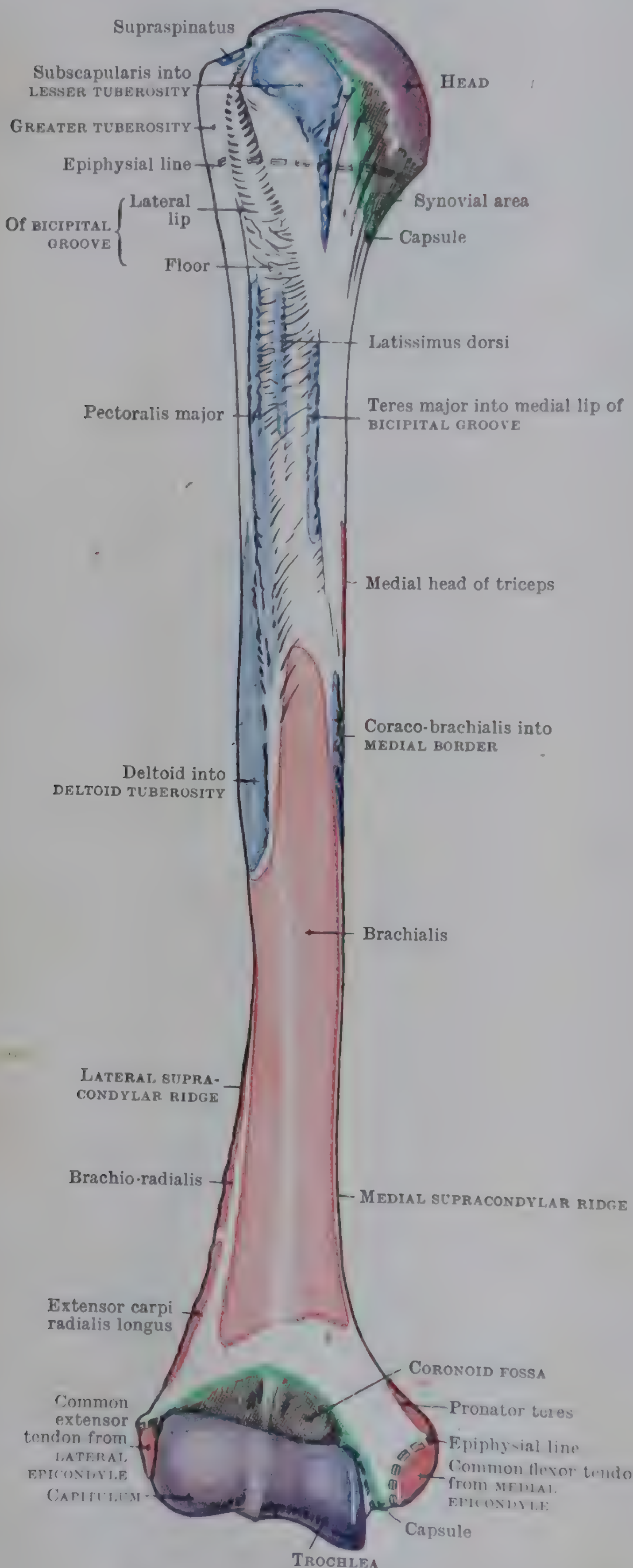


FIG. 225.—FRONT OF RIGHT HUMERUS.

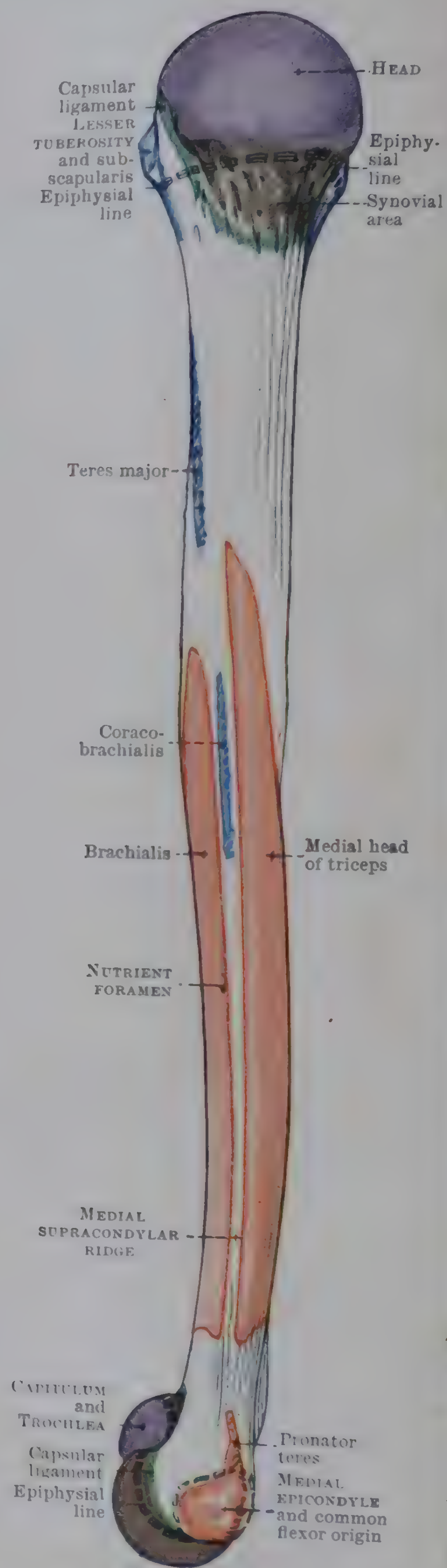


FIG. 226.—MEDIAL ASPECT OF RIGHT HUMERUS.

its upper third is an indistinct ridge that descends from the back of the greater tuberosity; it is interrupted in its middle third by a broad, shallow groove which extends obliquely across it. The groove is named the **spiral groove**; it begins on the back of the bone and is directed downwards and forwards on to the front;

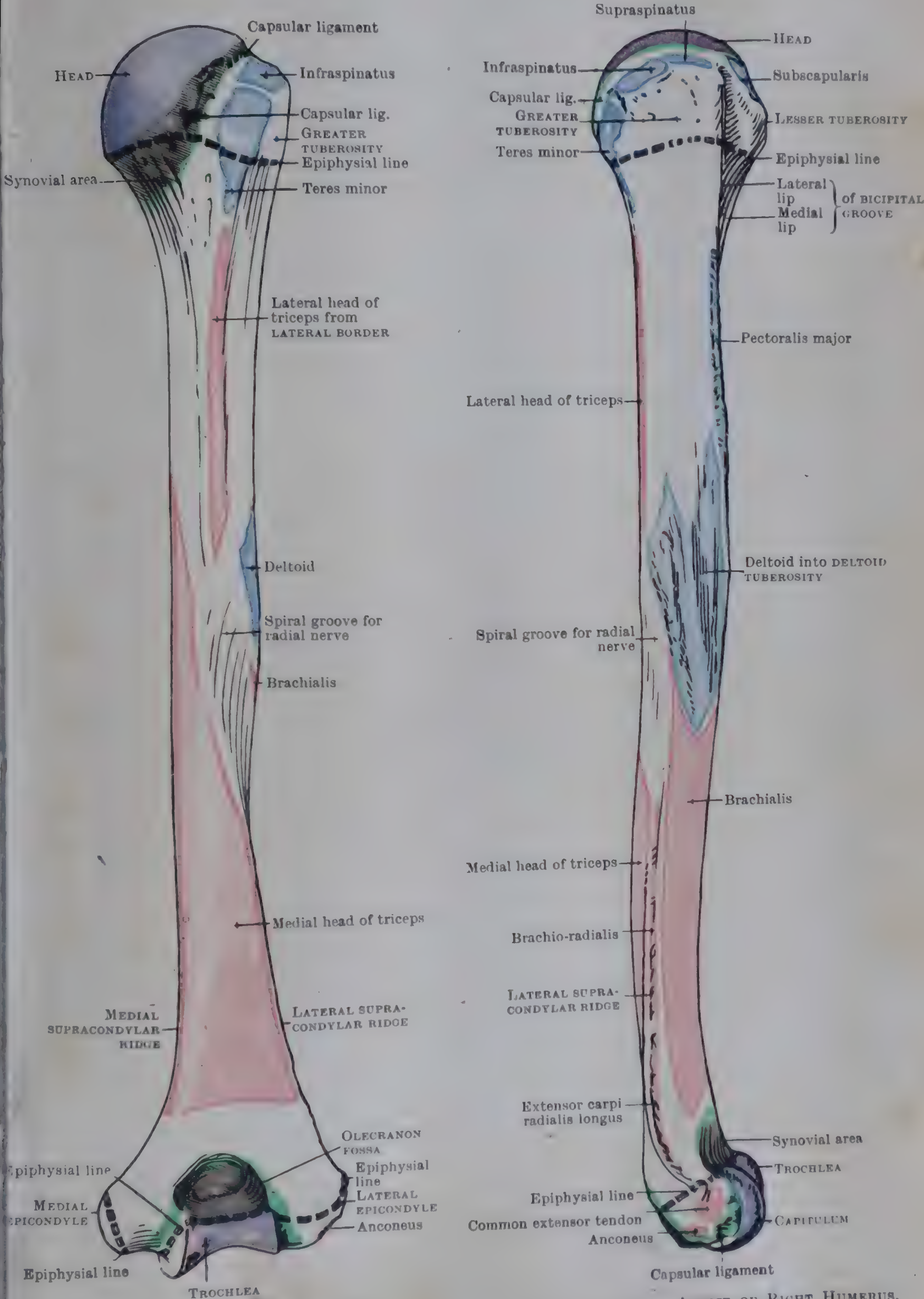


FIG. 227.—BACK OF RIGHT HUMERUS.

FIG. 228.—LATERAL ASPECT OF RIGHT HUMERUS.

the radial nerve, winding round the humerus, lies in it along its posterior or lower margin.

The **posterior surface** is the area between the lateral and medial borders.

The **antero-lateral surface** is the area between the anterior and lateral borders. Its proximal part is continuous with the lateral surface of the greater tuberosity. About its middle it is occupied by a rough, V-shaped **deltoid tuberosity**—so named because the deltoid muscle is inserted into it. The anterior margin of the V is part of the anterior border of the humerus, and its posterior margin is one of the boundaries of the spiral groove, for that groove is immediately behind and below the tuberosity. The tuberosity can usually be made out in the living person by deep pressure on the middle of the lateral side of the upper arm.

The **antero-medial surface** is the area between the anterior and medial borders. Its upper part is narrow, for it is merely the floor of that part of the bicipital groove which extends on to the shaft.

The lower halves of the antero-lateral and antero-medial surfaces are often spoken of together as the lower half of the anterior aspect of the humerus, in order to simplify the description of the brachialis muscle, which arises from the whole of that region.

The principal **nutrient foramen** is almost always situated immediately in front of the medial border—not far from its middle—and is directed towards the lower end. Sometimes it is in the upper part of the spiral groove; and there may be a foramen in both places.

Attachments.—The capsular ligament of the shoulder joint is attached to the **anatomical neck** above and in front and behind, but is attached to the bone nearly a finger's breadth below the head on the medial side, and the part of the medial side of the bone immediately below the head is therefore covered with synovial membrane; the coraco-humeral ligament is attached to the anatomical neck at the anterior and upper part of the greater tuberosity. The supraspinatus is inserted into the anterior impression on the top of the **greater tuberosity**, the infra-spinatus into the impression behind that, the teres minor into the impression on the back and into a strip below that for half an inch; the subscapularis into the **lesser tuberosity** and into the surface below for half an inch. The transverse ligament of the humerus is attached to *both tubercles*, and bridges across the upper end of the **bicipital groove**, holding the tendon of the long head of the biceps in place; farther down—on the shaft—the pectoralis major is inserted into the *lateral lip* of the groove, the teres major into the *medial lip*, and the latissimus dorsi into *its floor*; the tendon of the long head of the biceps lies in the groove, ensheathed in synovial membrane which is prolonged from the synovial lining of the shoulder joint and envelops the tendon and lines the groove; deep to that sheath a little artery, a branch of the anterior circumflex, runs upwards in the groove to the joint.

The common extensor tendon (*i.e.*, the combined tendons of origin of the extensores carpi radialis brevis, digitorum, digiti minimi and carpi ulnaris) arises from the *front* of the **lateral epicondyle**; the lateral ligament of the elbow is attached to its *distal margin*; and the tendon of the anconeus arises immediately behind the attachment of the ligament, leaving the posterior surface smooth. The common flexor tendon (the combined tendons of origin of the flexores carpi radialis, palmaris longus, digitorum sublimis and carpi ulnaris) arises from the impressions on the lower part of the *front* of the **medial epicondyle**, the pronator teres from the flatter, upper part and the adjoining lower end of the supracondylar ridge; the medial ligament of the elbow is attached to the *distal margin* of the epicondyle. The anterior ligament of the elbow is attached to the *upper margins* of the **radial** and **coronoid fossæ** and to the front of the epicondyles near the capitulum and trochlea. The posterior ligament is attached to the *floor* of the **olecranon fossa**, to its margins on each side, and to the backs of the epicondyles close to the margins of the trochlea.

The deltoid is inserted into the **deltoid tuberosity**; the coraco-brachialis into the middle of **the medial border**. The medial intermuscular septum is attached to the *edge* of the **medial supracondylar ridge**; the lateral intermuscular septum to the *edge* of the **lateral supracondylar ridge**; the brachio-radialis arises from the upper two-thirds of the *anterior aspect* of the lateral ridge, and the extensor carpi radialis longus from its lower third. The lateral head of the triceps arises from the *upper third* of the **lateral border**; the medial head from the *whole width* of the **posterior surface** below the spiral groove; the brachialis from the distal half or two-thirds of the **anterior aspect** of the shaft.

Ossification (Pls. XIII, XIV, XV, pp. 260, 261, 268).—The **primary** centre appears at the eighth week of intra-uterine life. At birth only the ends are cartilaginous.

The centres for the head and the tuberosities coalesce in the sixth year to form **one** epiphysis, which fits like a cap on the end of the diaphysis. Radiographs show a separate centre for the greater tuberosity in only 50 per cent of cases (Paterson, 1929), and **seldom show one for the** lesser tuberosity; and though the overlap of shadows may account for their apparent absence in some cases, yet it may be that the tuberosities are often ossified by extensions from the head. The centres for the capitulum and the trochlea coalesce to form **one** epiphysis at 15 in boys and 13

in girls. The lateral epicondyle usually joins the shaft independently (Paterson), but it may fuse with the capitulum before doing so; and in 30 per cent of cases it appears to have no separate centre but to be ossified by extension from the capitulum.

Secondary Centre	Appears at	Epiphysis fuses at	Relation of Epiphysial Line to Capsule of Neighbouring Joint.
For head	Birth, or soon after	Male 21 Female 18	Medial part inside, remainder outside.
For greater tuberosity	3 years (F. 2)		
For lesser tuberosity	5 "		
For capitulum and lateral part of trochlea	1-1½ "	M. 19 F. 14–15	Lateral extremity outside, remainder inside.
For medial part of trochlea	10 "		
For lateral epicondyle	14 "	M. 17–18. F. 14–15	
For medial epicondyle	M. 8–9 F. 5 6	M. 18–21. F. 14–15	Outside.

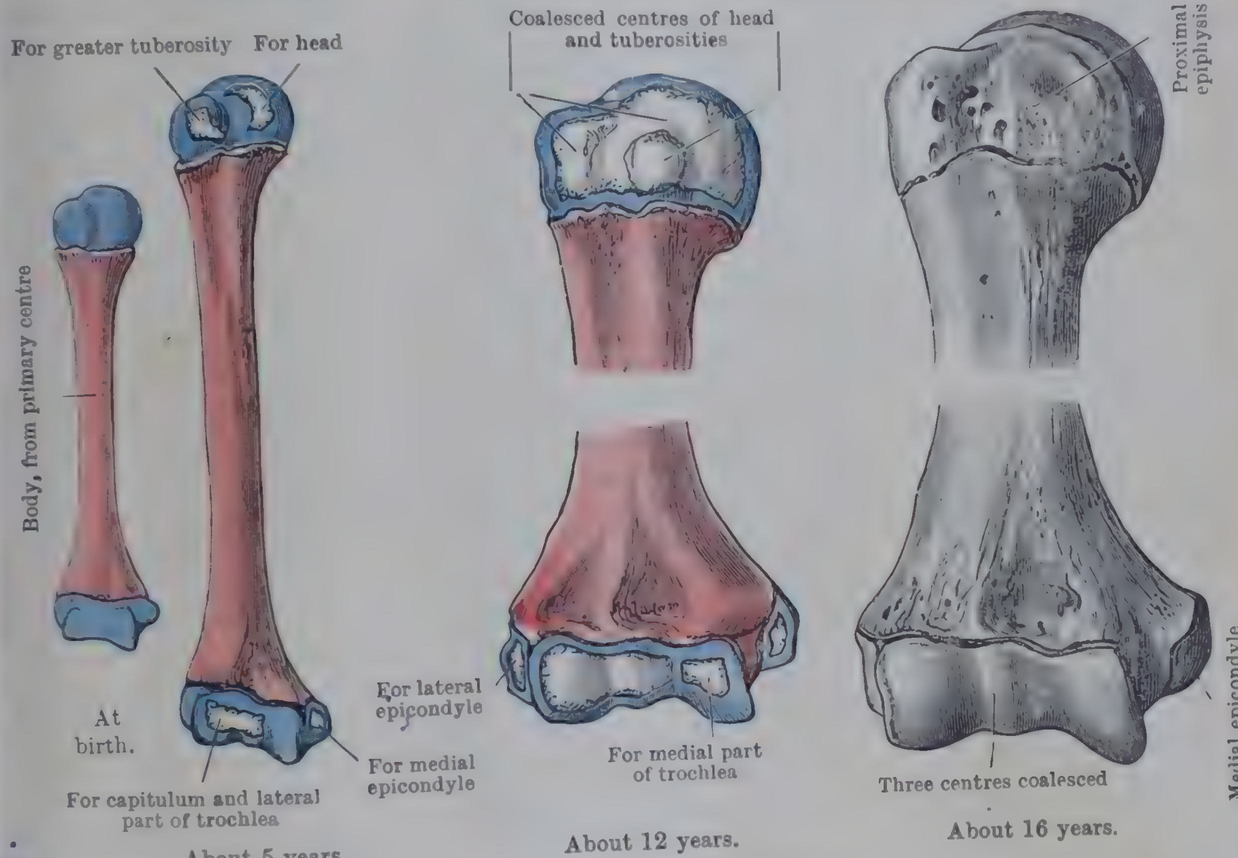


Fig. 229.—Ossification of Humerus.

Structure and Variations.—The structure is that of a typical long bone; the walls of the medullary cavity are thickest immediately below the middle of the bone. *Vascular foramina* are most numerous at the upper end—where most of the growth takes place. The chief nutrient canal runs a course of over two inches before it reaches the medullary cavity.

In women the head is relatively smaller than in men. Occasionally—more often in lower races—the bone above the trochlea is perforated. In rare cases a small projection (*supracondylar process*) is found about two inches above the medial epicondyle, with which it is connected by a fibrous band; the median nerve and brachial vessels—taking an unusual course—pass under cover of the band. The humerus normally appears twisted, so that while the articular surface at the upper end looks mainly in a medial direction, the articular surfaces at the lower end look backwards and forwards; the twist is more marked in adults than in children and fœtuses, in men than in women, and in modern Europeans than in more primitive races or in prehistoric Europeans.

Ligament of Struthers.

Ulna

The **ulna** is the medial and longer bone of the forearm [from ὠλένη (ōlenē) = forearm or elbow]. It is easily felt on the back of the forearm in its whole length.

It is a long bone, about one-sixth of the body-length, and it has a **shaft** and **two ends.**

The **upper** end is the larger end, and it has two large projections that give it a resemblance to a spanner. The wide, deep concavity between these two projections is directed **forwards.** The lateral side can be distinguished from the medial because the **lateral** border of the shaft is the sharpest and most outstanding of the three borders.

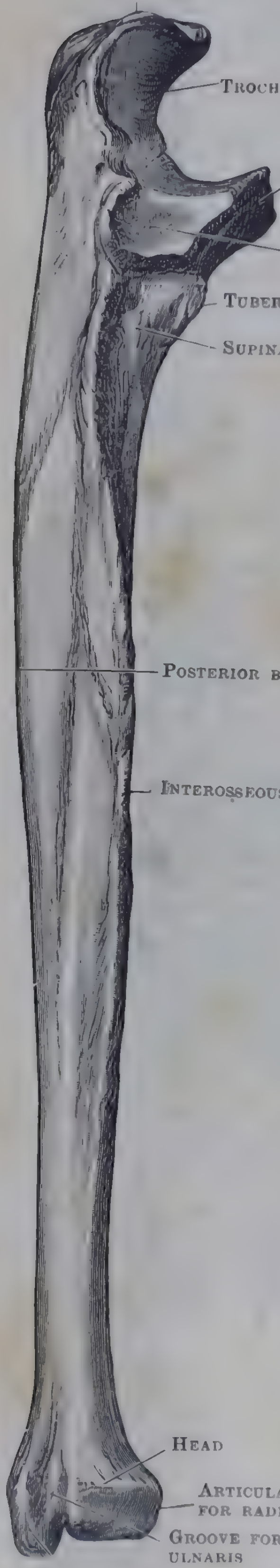


FIG. 230.—LATERAL SIDE OF RIGHT ULNA.

The **upper end** includes the olecranon, the coronoid process, the trochlear notch, the radial notch, and the tuberosity of the ulna.

The **olecranon** is the larger of the two projections and is the uppermost part of the ulna [*ὠλένη*—see p. 255; *κρανίον* (cranion) = head]; it is the prominence felt at the back of the elbow and is the part which rests on the table when one leans on the elbow. It is in line with the shaft, and, though stout and strong, it is sometimes broken off. It has superior, anterior, and posterior surfaces, and lateral and medial borders or surfaces. The **posterior** surface is smooth and subcutaneous and is nearly triangular in outline, with the apex pointing downwards. The **anterior** surface is smooth and coated with articular cartilage. The **superior surface** is the very end of the bone, and the tendon of the triceps muscle is inserted into its posterior part. The **lateral** and **medial** borders are thick and are rough for the attachment of ligaments and muscles.

The **coronoid process** is the projection that juts forward from the upper part of the shaft and has a fancied resemblance to the beak of a bird [*κορώνη* (corōnē) = a sea-crow]. Its *upper* surface is smooth and coated with articular cartilage; its *anterior* surface is rough for the insertion of the brachialis muscle; on its *medial* side there is a rounded tubercle for the attachment of part of the medial ligament of the elbow joint; the tubercle can be felt about a thumb's breadth below the medial epicondyle of the humerus, and the ulnar nerve, as it passes into the forearm, can be felt and rolled over the tubercle by the finger.

The **radial notch** is the shallow, smooth hollow on the lateral surface of the coronoid process; its floor is coated with articular cartilage and articulates with the side of the head of the radius. Immediately below the notch—on the shaft—there is a rough, shallow, triangular hollow with its base at the notch; it is named the *supinator fossa*, and its posterior margin, which is often a strong ridge, is named the *supinator crest*, for the supinator muscle arises from both the crest and the floor of the fossa.

PLATE XI

PLATE XI.—POSTERIOR RADIOGRAPH OF ELBOW OF YOUNG WOMAN AGED 19.

For lateral radiographs of the same elbow, see Plate XII. Cf. also Plate XIII, p. 260 and Plate XIV, Fig. 1.

PLATE XII

FIG. 1.—LATERAL RADIOGRAPH OF THE SAME ELBOW AS IN PLATE XI (YOUNG WOMAN AGED 19), FULLY EXTENDED.

Note the tip of the Olecranon in the olecranon fossa of the Humerus.

FIG. 2.—LATERAL RADIOGRAPH OF THE SAME ELBOW, SEMI-FLEXED.

Compare with Fig. 1, and note the relative positions of Epicondyle and Olecranon.

Cf. also Plate XIV, Fig. 2, p. 261.

The **trochlear notch** is the wide concavity between the coronoid process and the olecranon. The trochlea of the humerus fits into it and articulates with both olecranon and coronoid process. The articular surfaces are the reverse of a pulley, being elevated in the middle and sloping to the sides—the medial slope is more pronounced. If the humerus and the ulna are placed together properly, the olecranon fits into the olecranon fossa when the bones are in line, *i.e.*, when the forearm is extended. The coronoid process comes into relation with the coronoid fossa when the two bones make an acute angle, *i.e.*, when the forearm is fully flexed. Where the olecranon and the coronoid process join each other the trochlear notch has little rough patches at its sides; these patches may meet, forming a rough strip across the floor of the notch, separating the front of the olecranon from the upper surface of the coronoid process.

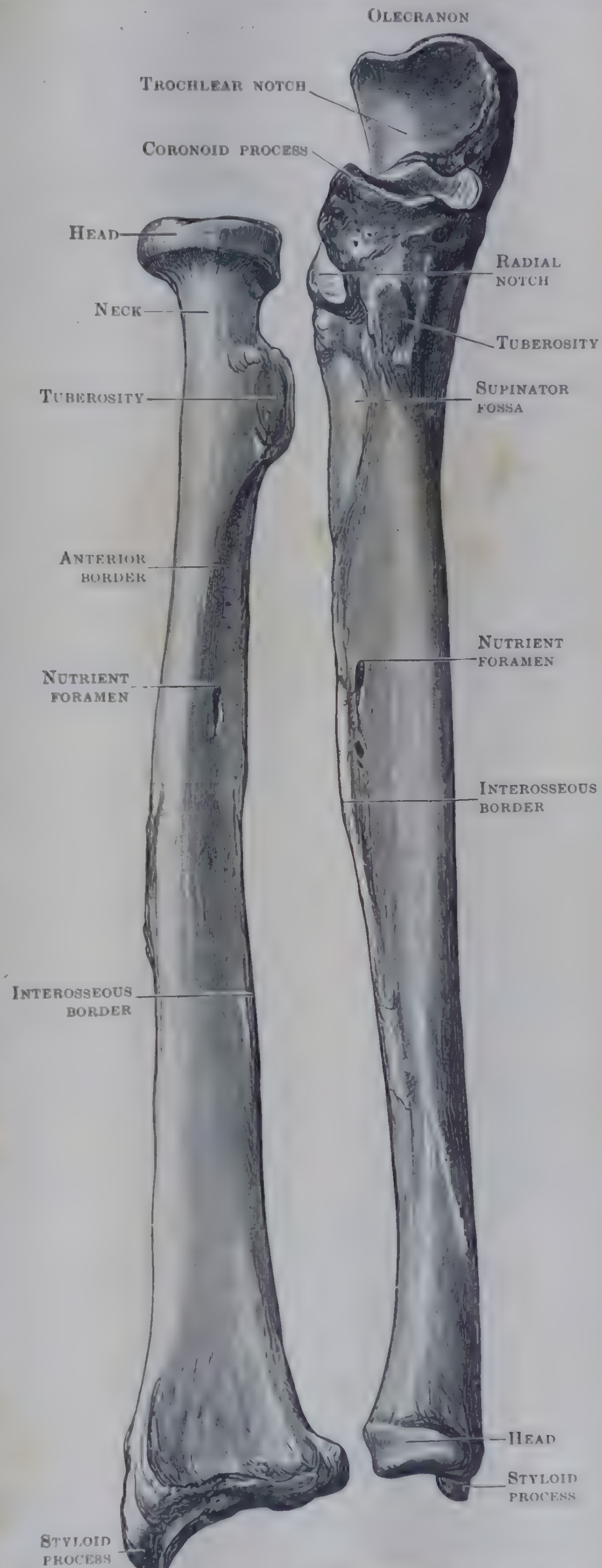


Fig. 231.—Front of Right Radius and Ulna.

The **tuberosity** of the ulna is a rough mark at the distal end of the anterior surface of the coronoid process and is continuous with that surface; but it is on the shaft rather than on the upper end.

The **lower end** of the ulna is small, and it includes the head and the styloid process.

The **head** is the larger, rounded part. Note that in the ulna the part called the *head* is at the *lower* end. When the hand is held with the palm looking downwards, the head of the ulna can be seen as a knob on the back of the forearm immediately above the wrist on the ulnar side (in line with the little finger). The *front* and *lateral side* of the head are smooth and convex, and articulate with the lower end of the radius—the radius articulating with the lateral side when the limb is in *supination* (the thumb pointing away from the body) and with the front in *pronation* (when the thumb points medially) — see p. 264. The *lower surface* also is smooth; it articulates not with a bone but with a triangular plate of fibro-cartilage, called the *articular disc*, which separates the head from the bones of the wrist.

The **styloid process** is the small, conical projection that juts downwards towards

the wrist from the postero-medial part of the lower end. Between the base of the styloid process and the lower surface of the head there is a small, rough patch to which the apex of the articular disc is attached. On the *back of the bone*, between the styloid process and the head, there is a well-marked **groove** which lodges the tendon of the *extensor carpi ulnaris* muscle.

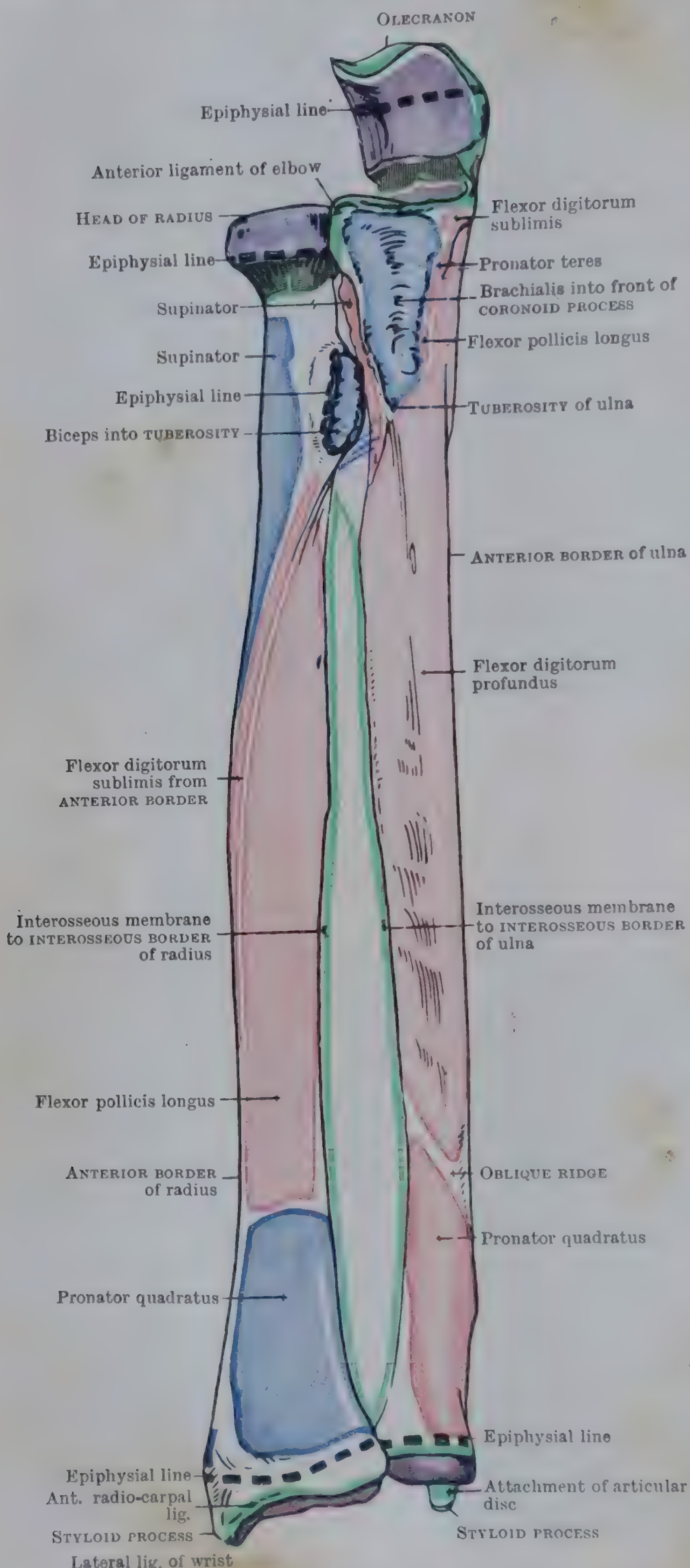


FIG. 232.—FRONT OF RIGHT RADIUS AND ULNA.

When the hand is in the position in which the palm looks towards the shoulder (the elbow being bent), the styloid process, along with the tendon of the extensor carpi ulnaris, can be felt as a ridge on the ulnar border of the back of the forearm, but the head of the ulna is scarcely palpable. When the hand is held palm downwards, the head of the ulna appears as a round knob at the ulnar border of the back of the forearm, and the styloid process is then felt on the ulnar surface of the limb. The apparent differences in position are not due to movements of the ulna, but to movements of the lower end of the radius round the head of the ulna (see p. 264).

The **shaft** of the ulna diminishes in thickness from above downwards. It has three **borders**, named anterior, posterior, and interosseous, and three **surfaces**, named posterior, anterior, and medial.

The **anterior border** is smooth and rounded. It begins at the tuberosity and ends at or near the root of the styloid process. The **posterior border** begins at the lower angle of the back of the olecranon, extends sinuously along the shaft, and fades away near the distal end. It is felt as a sharp, subcutaneous ridge on the back of the forearm. The **interosseous border** is a sharp, salient ridge on the lateral side. It is so named because a strong,

wide fibrous sheet, the *interosseous membrane*, stretches across from it to the radius. It begins at the lower angle of the supinator fossa, becomes very prominent in the middle of the bone, and fades away near the lower end.

The **anterior surface** is between the anterior and interosseous borders; and the tuberosity of the ulna is situated at its upper end. It is usually hollowed out longitudinally in its upper two-thirds or more, and the lower end of the hollow is limited by an oblique ridge from which a part of the pronator quadratus muscle arises. The ridge begins about two inches above the lower end and winds spirally towards the root of the styloid process. The **posterior surface** is between the posterior and interosseous borders. In a well-marked bone an oblique ridge runs from the back of the radial notch to a point on the posterior border about an inch below the lower end of the back of the olecranon. The anconeus muscle is inserted into the area above the ridge. Below the ridge a vertical line maps off a long, flat strip between itself and the posterior border. The strip gives no attachment to any muscle, but the extensor carpi ulnaris lies on it; nearly all the rest of the posterior surface is mapped out by faint oblique ridges into areas for the origin of muscles. The **medial surface** is the smooth, slightly convex surface between the anterior and posterior borders. Its upper part is covered with muscle, but its lower third is subcutaneous and therefore easily felt.

The **nutrient foramen** is on the anterior surface about the junction of the upper and middle thirds, and it is directed towards the upper end.

Attachments.—The tendon of the triceps is inserted into the posterior part of the *superior surface* of the **olecranon**; the posterior ligament of the elbow joint is attached to the anterior edge of the surface; and a small *bursa* lies between them on the intervening part. The posterior ligament is attached also to the *lateral surface*, and the anconeus is inserted into that surface behind the ligament; the posterior band of the medial ligament of the elbow joint is attached to the *medial surface*, and fibres of the flexor carpi ulnaris and of the flexor digitorum profundus arise from it behind the ligament.

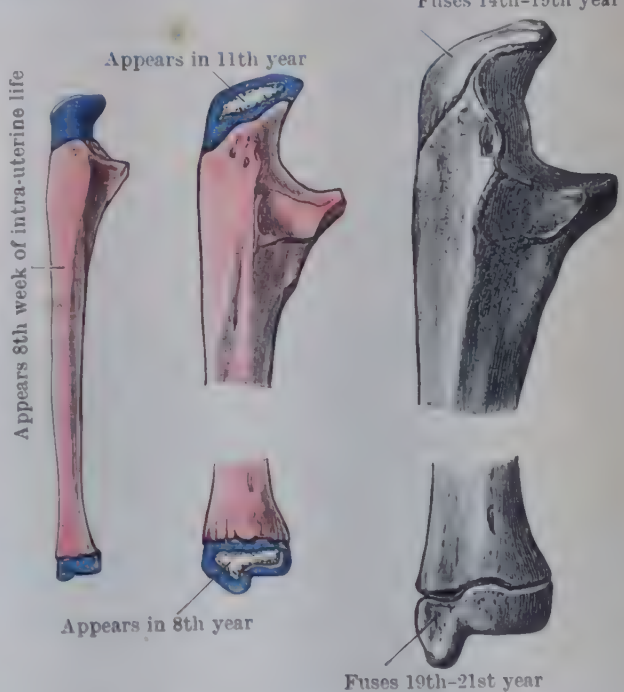


Fig. 233. Ossification of Ulna.

The anterior band of the medial ligament is attached to the *tubercle* on the *medial border* of the **coronoid process**; some fibres of the flexor digitorum sublimis arise from it; slips of the pronator teres and flexor pollicis longus arise from the ridge which descends from the tubercle, and fibres of the flexor profundus from the hollow behind that ridge; the anterior ligament of the elbow joint is attached to the *anterior margin* of the process, and the brachialis is inserted into the *anterior surface* and also into the **tuberosity** immediately below. The annular ligament which surrounds the head of the radius is attached to the *anterior* and *posterior margins* of the **radial notch**, and the quadrate ligament to its *lower margin*.

The capsule of the inferior radio-ulnar joint is attached to the *front* and *back* of the **head**: a septum of the extensor retinaculum to the radial border of the **groove** on the back; the medial ligament of the wrist joint to the tip of the **styloid process**, and the apex of the articular disc to the small, rough mark between its root and the head.

On the **shaft**, the oblique cord, as well as part of the brachialis, is attached to the **tuberosity**. The supinator arises from the **supinator crest** and **fossa**. The interosseous membrane is attached to the **interosseous border**. The flexor carpi ulnaris arises by a wide aponeurosis from the upper three-fourths of the *posterior border*, besides having a small origin from the ~~lateral~~ med surface of the olecranon. By means of the same aponeurosis part of the extensor carpi ulnaris arises from the middle third of the posterior border. The anconeus is inserted into the upper part of the *posterior surface*; parts of the abductor pollicis longus, extensor pollicis longus, and extensor indicis arise from the lateral part of the posterior surface—in that order from above downwards. The pronator quadratus arises from the lower fourth of the *anterior surface* (including the ridge above that fourth); the flexor digitorum profundus arises from the upper two-thirds or three-fourths of the *anterior* and *medial surfaces*—extending up to the medial surfaces of the coronoid process and olecranon.

Ossification (Pls. XIII, XIV; XV, p. 268; XVIII, p. 273).—The **primary centre** appears at the eighth week of intra-uterine life, and from it the shaft, the coronoid process, and nearly the whole of the olecranon are ossified, though at birth a great part of the olecranon—as well as the lower end—is cartilaginous.

Secondary Centre.	Appears at	Epiphysis joins at	Relation of Epiphysial Line to Capsule of Neighbouring Joint.
For lower end	8th year	**M.** 21. **F.** 19-20	Outside.
For top of olecranon	11th ,,	{ **M.** 18-19 / **F.** 14-15	Outside; anterior part sometimes inside (Fig. 232).

The olecranon may have an additional centre, or more than one, in its body; and its epiphysis varies in size.—See Figs. 232, 233.

Structure and Variations.—The structure resembles that of the humerus and other long bones. The medullary canal extends from the root of the coronoid process to the distal fifth of the bone, and its posterior wall is the thicker. The weakest parts are at the junction of the olecranon and the coronoid process, and the junction of the middle and lower thirds of the shaft.

In rare cases the ulna is incompletely developed or is absent. In one recorded case the olecranon was a separate bone.

Radius

The **radius** resembles the spoke of a wheel—hence its name. It is the lateral and shorter bone of the forearm, and can be felt in all its length, though deep pressure is necessary at its middle. It is a long bone with a **shaft** and **two ends.**

The **upper** end is the smaller end. The lower end is slightly bent forwards, and its **anterior** surface is broad, slightly concave, and fairly smooth; from the **lateral side** of the lower end a short, pointed process projects downwards.

The **upper end** includes the head, the neck, and the tuberosity.

The **head** is a circular disc, cupped on its upper surface, and that surface is smooth and articulates with the capitulum of the humerus. The circumference of the head is smooth; it articulates with the radial notch of the ulna and with the inner surface of a fibrous band, called the *annular ligament* of the radius, which encircles five-sixths of the head of the radius and is attached by its ends to the anterior and posterior margins of the radial notch of the ulna; the ligament and the notch, together, make a complete ring within which the head of the radius rotates during the movements of supination and pronation (p. 264). The head of the radius can be felt, through the ligament, on the back of the limb towards the lateral side, immediately below the lateral epicondyle of the humerus.

The **neck** is the cylindrical, slightly constricted part that supports the head.

The **tuberosity** of the radius is the broad, low prominence on the medial side immediately below the neck. The tendon of the biceps is inserted into it.

When the humerus and radius are fitted together properly the upper surface of the head of the radius articulates with the capitulum at its lower part when the elbow is extended (straightened), with its anterior part when the elbow is flexed to a right angle. Its edge comes into relation with the radial fossa of the humerus in extreme flexion. The trochlear notch of the ulna partially encircles and hinges on the trochlea; the ulna is therefore the more important constituent of the elbow joint, and the stability of the joint depends on it—the radius offering no bar to dislocation. The grip of the ulna is least secure when the forearm is extended in line with the arm; the ulna can then slip backwards off the humerus. But the olecranon is a positive bar to forward dislocation until the forearm is becoming acutely flexed.

The **lower end** of the radius has five surfaces and a styloid process. The surfaces are anterior, posterior, medial, lateral, and distal or carpal.

FIG. 1.—POSTERIOR RADIOGRAPH OF ELBOW OF BOY AGED 7.
(Dr. J. Duncan White.)

Note that the centre for the capitulum of the Humerus forms part of the trochlea, and that the other trochlear centre and the lateral epicondyle centre have not yet appeared. For further development of the epiphyses, see Fig. 2.

FIG. 2.—POSTERIOR RADIOGRAPH OF ELBOW OF BOY AGED 12, SHOWING ALL EPIPHYSIAL CENTRES.

The three centres for (1) capitulum and lateral part of trochlea, (2) medial part of trochlea, and (3) lateral epicondyle, unite to form a single epiphysis.
Note the olecranon epiphysis above the part of the olecranon that overlaps the Humerus. For earlier stage of development of the epiphyses, see Fig. 1.

[Facing p. 260

PLATE XIV

Fig. 1.—Posterior Radiograph of Elbow of Girl aged 12, showing Epiphyses of Medial Epicondyle of Humerus and Head of Radius not yet united.

Fig. 2.—Lateral Radiograph of the same Elbow (Girl aged 12), slightly flexed.
Note the uniting Epiphyses of Head of Radius and Olecranon of Ulna.

[Facing p

The **anterior surface** is broad and slightly concave; at its lower margin there is a broad, rough ridge that can be felt on the front of the forearm about an inch above the ball of the thumb; it indicates the position of the distal epiphysial line, and it is also a guide to the position of the wrist joint, which is immediately distal to it.

The **posterior surface** is more uneven, being occupied by grooves and ridges. The most prominent ridge is about the middle of the surface; it is called the **dorsal tubercle** and can usually be felt in the living limb. On the lateral side of the tubercle there is a shallow groove, more than half an inch wide, on which two thick tendons lie; they are the tendons of the extensor carpi radialis longus and brevis muscles, and when the closed fist is bent slightly backwards they can be seen as they pass off the radius on to the back of the wrist. On the medial side of the tubercle there is a narrow, oblique, clean-cut groove for the tendon of the extensor pollicis longus, which can be seen reaching almost to the thumb-nail when the thumb is outstretched. The rest of the surface—the part medial to the narrow groove—is a wide, shallow groove that lodges the tendons of the extensor digitorum and extensor indicis (Fig. 234).

The **lateral surface** is less than half an inch wide; it is occupied by a shallow groove for the tendons of the abductor pollicis longus and extensor pollicis brevis, and it is separated from the anterior surface by a sharp ridge that is easily felt in the living limb.

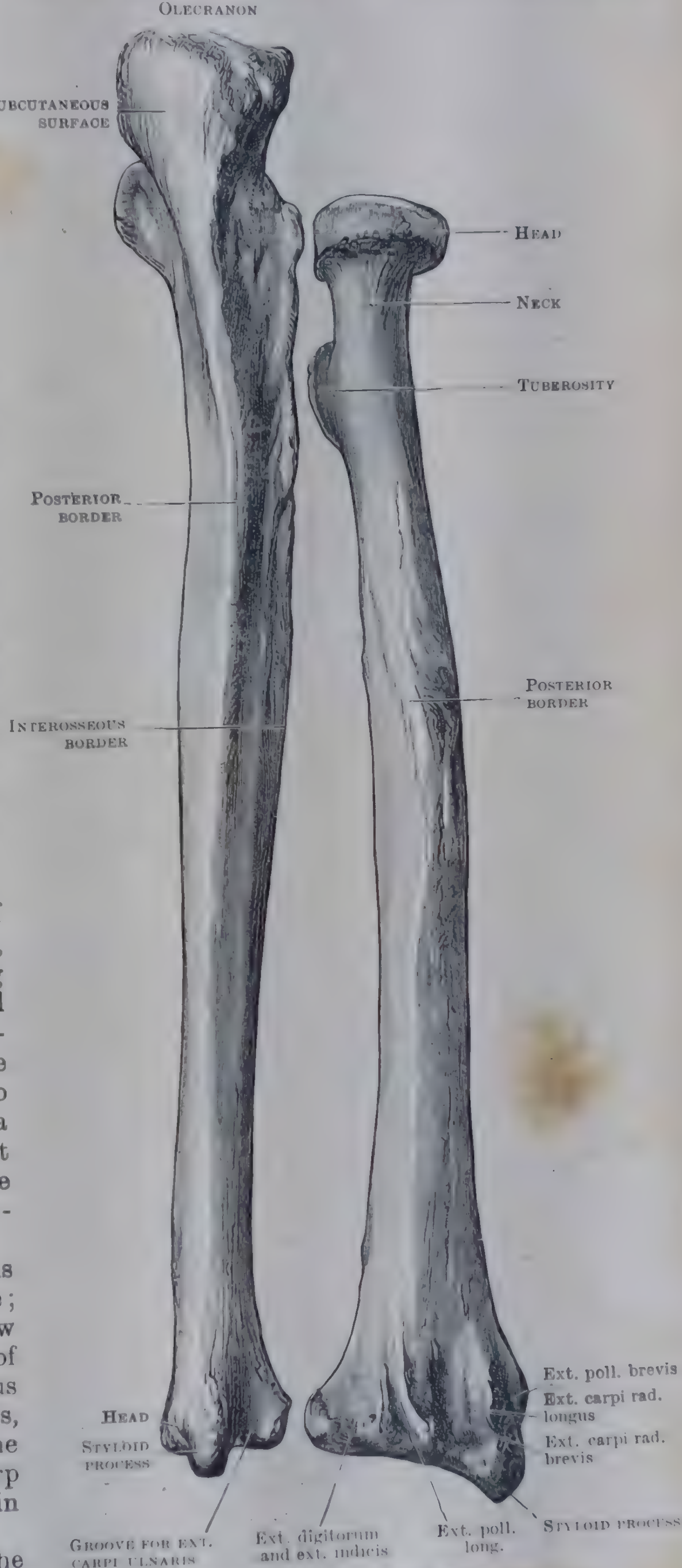


Fig. 234.—Back of Right Radius and Ulna.

The lateral part of the lower end of the radius is prolonged downwards as the short, thick **styloid process**. When the thumb is outstretched a hollow is seen on the radial side of the wrist, called by the French the *anatomical snuff-box*

(tabatière anatomique); its posterior boundary is the tendon of the extensor pollicis longus; anteriorly the tendons of the abductor pollicis longus and extensor pollicis brevis lie together and make a ridge between the front of the wrist and its lateral surface; the styloid process is the bone felt in the proximal part of the floor of the hollow. Its position should be compared with that of the styloid process of the ulna; the radial styloid process is at a lower level than that of the ulna. In the common variety of fracture of the lower end of the radius that relationship may be reversed.

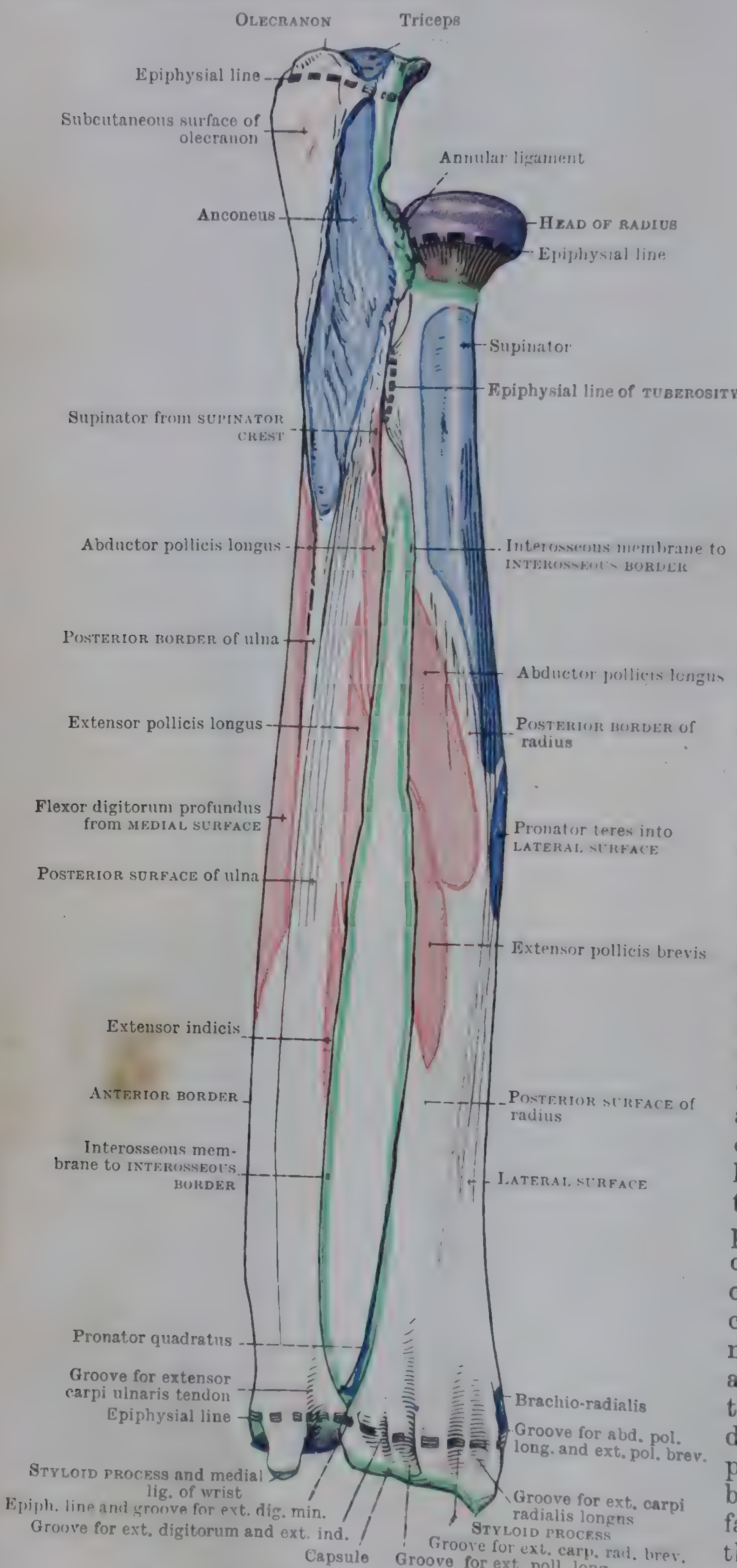


FIG. 235.—BACK OF RIGHT RADIUS AND ULNA.

The **medial surface** is small, smooth and concave and forms the **ulnar notch**. It articulates with the head of the ulna and rotates round it during the rotary movements of the forearm and hand (pronation and supination).

The *distal* or **carpal surface** is concave and smooth, and articulates with bones of the wrist or carpus. It is divided into two areas: a medial area nearly quadrilateral, and a lateral area nearly triangular, the apical part of which extends on to the styloid process. Between the carpal surface and the medial surface there is a sharp edge to which the base of the articular disc is attached. The posterior and lateral boundaries of the surface reach lower down than the others, and in a fall on the hand the posterior and lateral part of the lower end may be chipped off. A break in the lower third of the shaft is, however, more likely with consequent displacement of the lower end of the bone.

Since the anterior surface is concave from above downwards and the posterior surface is slightly convex, the lower end of the bone curves forwards. A broken bone must be 'set' so as to restore the proper shape and to avoid straightening the bone, a fault which would alter the position of the wrist joint and the pull of the tendons.

The **shaft** increases in girth from above downwards, but it is most often broken near the lower end; it has three borders and three surfaces. The **borders** are anterior, posterior, and interosseous; the **surfaces** are posterior, anterior, and lateral.

The **interosseous border** is on the medial side and is the sharpest and most definite of the three; the interosseous membrane is attached to it. It begins near the tuberosity and towards its lower end it divides into two ridges which diverge slightly to become continuous with the margins of the ulnar notch. The **anterior border** begins at the tuberosity and ends at the ridge between the anterior and lateral surfaces of the lower end of the bone. Its upper part is well marked and oblique; its lower part is rounded and indistinct (Fig. 231). The **posterior border** is distinct in the middle third of the bone (Fig. 234); the upper part is an indistinct line that leads from the middle third obliquely towards the back of the tuberosity; the lower part—a smooth, indistinct ridge—runs from the middle third to the dorsal tubercle on the distal end.

The **anterior** and **posterior surfaces** separate the interosseous border from the anterior and posterior borders. The **lateral surface** is between the anterior and posterior borders and is roughened at its middle for the insertion of the pronator teres muscle. Its upper part encroaches greatly on the front and back of the bone owing to the obliquity of the upper parts of the anterior and posterior borders; the lower part of the surface also encroaches on the back, so as to be continuous with the lateral surface of the lower end and with the lateral part of the back.

The **nutrient foramen** is on the anterior surface about the junction of its upper and middle thirds, and it is directed towards the upper end.

Attachments.—The lower margin of the annular ligament and the lateral margin of the quadrate ligament are attached round the **neck**—*loosely*, so as not to interfere with the rotatory movements of the radius. The posterior part of the **tuberosity** is roughened for the insertion of the tendon of the biceps, but the anterior part is smooth for the *bursa* that separates it from that tendon.

At the **lower end**, the anterior radio-carpal ligament is attached to the distal margin of the *anterior surface*; the lateral ligament to the **styloid process**; the posterior ligament to the distal edge of the *posterior surface*; the capsule of the inferior radio-ulnar joint to the anterior and posterior margins of the **ulnar notch**; the base of the articular disc to the border between the notch and the *carpal surface*; the lateral end of the extensor retinaculum to the *sharp border* between the lateral and anterior surfaces, and its septa to the ridges that bound the grooves on the *posterior surface*; the tendon of the brachio-radialis is inserted into the upper part of the *lateral surface*.

At Birth. About 12 years. About 16 years.

Fig. 236.—Ossification of Radius.

On the **shaft**, the oblique cord is attached to the bone immediately below the tuberosity; the interosseous membrane to the **interosseous border** and to the hinder of the two ridges into which the lower end of the border divides. Part of the flexor digitorum sublimis arises from the upper half of the *anterior border*, and the flexor pollicis longus from the upper three-fourths of the *anterior surface*; the pronator quadratus is inserted into the lower fourth of the anterior border and anterior surface, into the anterior surface of the lower end, and into the narrow triangular area above the ulnar notch. The pronator teres is inserted into the rough mark on the middle of the *lateral surface*; the supinator into the upper third, including its encroachments on the front and back. Parts of the abductor pollicis longus and extensor pollicis brevis arise from the *posterior surface*—the abductor immediately above the middle of the bone, and the extensor immediately below.

The radius has a slight double curve—convex in a medial direction in its upper quarter, and in a lateral direction in the lower three-quarters. The biceps and the pronator teres are inserted into the maximum points of the curves, and their value as supinator and pronator (p. 367) respectively, is thus increased. The medial side of the head is deeper and flatter from above downwards than the rest of its circumference. The lower part of the lateral surface of the shaft does not give attachment to any muscle; but it is overlain by the tendons of the brachio-radialis and the radial extensors of the carpus. Occasionally there is a small tubercle on the posterior lip of the groove on the lateral side of the lower end; this is for the attachment of the most lateral septum of the extensor retinaculum. The slight ridge between the two areas on the carpal surface is best marked at its ends where there may be slight notches on the anterior and posterior margins of the carpal surface.

Ossification (Pls. XIII–XV, pp. 260, 268; XVIII, p. 273).—The **primary centre** appears at the eighth week of intra-uterine life. At birth only the lower end, the head, and the tuberosity are cartilaginous.

Secondary Centre.	Appears at	Epiphysis fuses at	Relation of Epiphysial Line to Capsule of Neighbouring Joint.
For lower end	**M.** 1-1½ yr. **F.** 1	**M.** 21. **F.** 19-20	Outside.
For head	**M.** 6-7. **F.** 5-6	**M.** 18-19. **F.** 14-15	Inside.
For tuberosity (occasional)	Puberty	Shortly after puberty	Outside.

Structure and Variations.—The medullary canal reaches the neck but does not reach the lower part of the shaft; its walls are thick compared with the size of the bone; the thickness is especially marked along the interosseous border—imparting rigidity to the curve of the bone. The neck is the most slender part of the bone, but the commonest seat of fracture is near the lower end, for that part of the bone bears the impact of a fall on the hand. The nutrient canal traverses the bone for half an inch before it reaches the medullary cavity.

Absence of the radius has been recorded more than once, and in some of these cases the thumb also was absent.

Supination and Pronation

The terms supination and pronation refer to position and movements of the forearm and hand. The **supine position** is that in which the two bones of the forearm are parallel and the thumb is directed away from the side of the body; in that position the palm of the hand looks forwards when the limb hangs by the side, upwards when the elbow is flexed to a right angle [*supinus* = lying on the back], and backwards when the elbow is acutely flexed. The **prone position** is that in which the thumb is directed towards the side of the body [*pronus* = inclined downwards—here referring to the palm when the elbow is flexed to a right angle.]

When the forearm and hand are placed, say, on a table with the palm facing upwards they are in the *supine* position. If the humerus is kept steady and the forearm is turned to make the palm face downwards, it assumes the *prone* position. In full **supination** the radius and ulna lie parallel. As the forearm is pronated the upper end of the radius revolves within the annular ligament; the lower end is carried round the head of the ulna, and the shaft is rotated and carried obliquely across the ulna. The ulna remains practically stationary. In full **pronation** the radius and ulna are crossed and the hand has been carried medially with the radius and turned until the thumb is situated medially. Description of the radius and ulna is much simplified when the bones are parallel and for this reason full supination is used as the normal *anatomical position*. A normal comfortable position of the forearm is nearly midway between pronation and supination. The slight supination which is usual when the limb hangs naturally is masked by a medial rotation of the humerus. Evidence of this can be had by noting the position of the epicondyles of the humerus. Supination is a more powerful movement than pronation and screws and screwing instruments are made accordingly. (See also p. 367.)

Carpus

The skeleton of the **carpus** or **wrist** consists of *eight* small bones closely held together by ligaments, and arranged in two rows—a proximal and a distal. From lateral to medial side, the names of those in the **proximal row** are: scaphoid,

lunate, triquetrum, pisiform; and in the **distal row**: trapezium, trapezoid, capitate, hamate.

The **pisiform bone** is the hard knob at the medial border of the front of the wrist. It is rather loosely attached and can be moved slightly from side to side if the hand is held slack; the sinew seen and felt descending to it, along the medial border of the forearm, is the tendon of the flexor carpi ulnaris muscle.

The **other bones** of the wrist are so tightly bound together that, until the ligaments are cut, they form **one compact mass** with *six* surfaces—palmar, dorsal, medial, lateral, proximal, and distal. (See Fig. 332, p. 369.)

The *proximal surface* is smooth and convex, and measures much more from side to side than from before backwards; it articulates with the radius and the articular disc to form the radio-carpal joint or wrist joint. The *distal surface* is uneven, and its transverse measurement also is much greater than the antero-posterior; it articulates with the bases of the five metacarpal bones to form the carpo-metacarpal joints. The *medial surface* is small, and can be felt on the medial side of the wrist. The *lateral surface* also is small; it is partly palpable in the "anatomical snuff-box", and is partly hidden by the tendons in the anterior boundary of that hollow; the radial artery crosses it obliquely, under cover of those tendons.

The *dorsal surface* is large, rough and convex from side to side, and is to a large extent concealed by tendons. The *palmar surface* is concave from side to side, the concavity being deepened and, indeed, largely caused by the shape and position of the bones at the sides. The concavity is the **carpal groove** which is converted into a **carpal canal** or tunnel by the *flexor retinaculum*. The retinaculum is a strong flattened band which bridges the groove and holds the flexor tendons in place in the groove. It is attached to projections which can be felt in the living hand. The pisiform bone has been referred to above. Distal to it, the **hook of the hamate bone** (hamatus = hooked) can be felt if deep pressure is made by the thumb of the other hand on the ball of the little finger—*i.e.*, the fleshy eminence on the medial side of the palm. The pressure should be made 15-25 mm. from the pisiform bone on a line drawn from the pisiform towards the centre of the palm. A nerve can often be felt slipping from side to side on the hook; that is the superficial branch of the ulnar nerve.

The **tubercle of the scaphoid bone** can always be felt and is often a visible projection. The guide to its position is the tendon of flexor carpi radialis. This is the most lateral of the group of tendons which run down the middle of the front of the forearm to the wrist. Where it passes out of sight at the wrist the tubercle of the scaphoid bone can be felt—partly under cover of the tendon and partly lateral to it—immediately above the ball of the thumb.

The **crest on the trapezium** is less easily felt. It is immediately distal to the tubercle of the scaphoid in the medial edge of the ball of the thumb, and pressure should be made there with the hand bent backwards; the bony resistance encountered is the crest. It may be felt as a prominence separate from the tubercle of the scaphoid, but the two often are felt as one continuous bony resistance.

If the student has a skeleton of the hand in which the carpal bones are strung or wired together he will be able to identify them from their position. If they are separate he may require the aid of a demonstrator, but should try to identify them himself by means of their chief characters—beginning with those that are more easily recognized.

The **pisiform bone** is the smallest of all. It resembles a large pea with a slice cut off [*pisum* = a pea].

The **hamate bone** has a compressed, curved process that projects from its palmar surface.

The **capitate bone** is usually the largest. Its proximal surface or end is smooth and rounded—resembling a head.

The **scaphoid bone** is one of the larger bones. It bears a slight resemblance to a comma—the tubercle being the bent, narrower end of the comma. Of its *articular* surfaces two are convex and one is concave, fitting the tip of a finger. The bone is called the "scaphoid" from a far-fetched resemblance to a boat given to it by that concave surface [σκάφη (scaphē) = anything dug out—a boat].

The **lunate bone** is one of the smaller bones. Its distal surface is markedly concave in one direction and fits the tip of a finger. On another surface (the lateral) it has an articular facet shaped like a crescent moon, which gives the bone its name.

The **trapezium** is medium in size. One of its articular surfaces is saddle-shaped; one of its non-articular surfaces has the thick crest—mentioned before—with a groove alongside the crest.

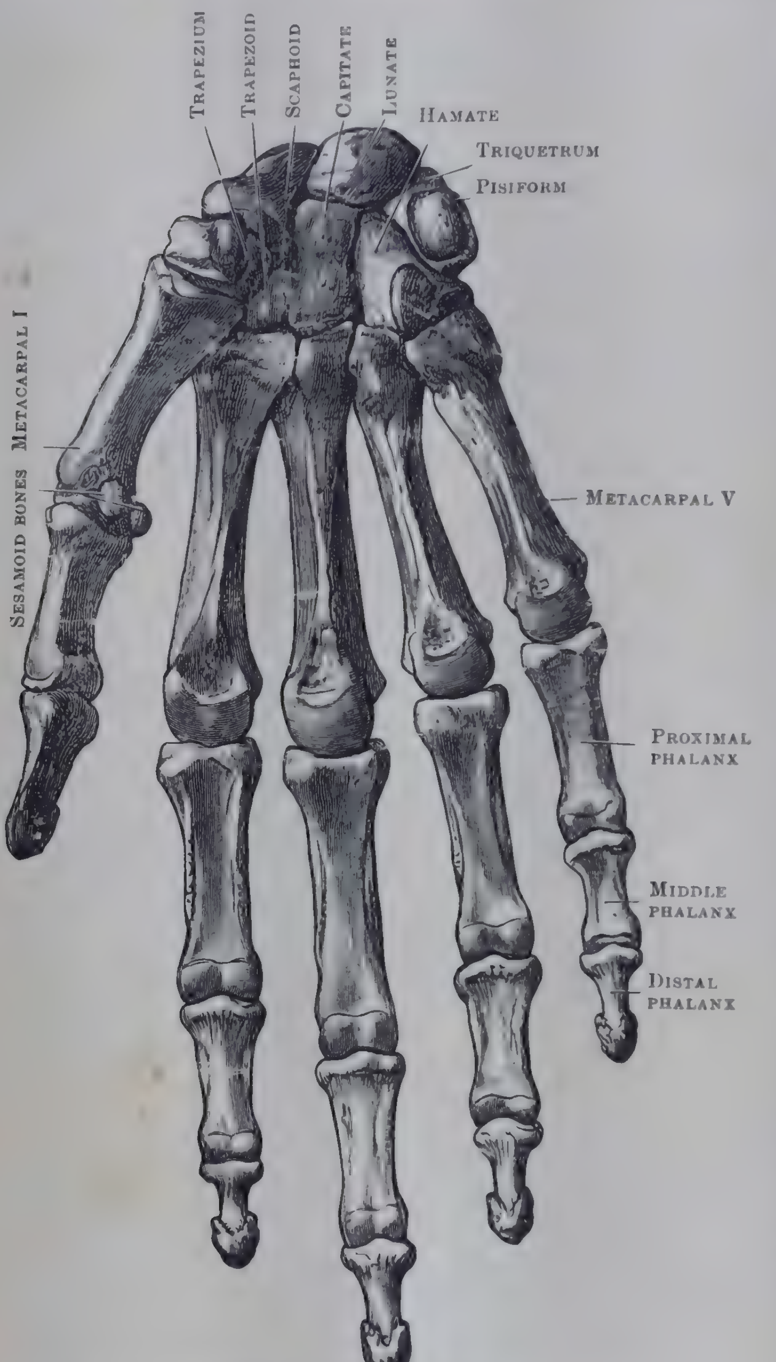


FIG. 237.—PALMAR ASPECT OF BONES OF RIGHT HAND.

The triquetrum and the trapezoid are the only two left. The **triquetrum** is more or less pyramidal in shape [*triquetrus*=three-cornered] and on one of its surfaces it has a circular, flat facet which occupies a great part of that surface. The **trapezoid** though very unlike the others, has no outstanding characters. It has four definite articular surfaces set almost at right angles to one another, and two non-articular surfaces, one of which is considerably larger than the other; when it is placed on that larger surface it has a fanciful resemblance to a Chinese boot.

Each of the carpal bones is conveniently described as having six surfaces—proximal, distal, palmar, dorsal, lateral, and medial.

Scaphoid Bone.—The *proximal surface* is the larger of the two convex articular surfaces; it articulates with the lower end of the radius. The *distal surface* is the smaller of the two convex surfaces, and it articulates with the proximal surfaces of the trapezium and trapezoid. The *dorsal surface* is the narrow strip between the proximal and the distal surface, and it is rough for the attachment of ligaments. The *medial surface* has a smooth area—concave in each direction—for articulation with the lateral surface of the head of the capitate bone, and above that there is a semilunar strip that articulates with the lateral surface of the lunate bone. The *lateral surface* is greatly reduced and is represented by the **tubercle**. The *palmar surface* is concave in one direction and is the concave side of the comma, which forms part of the lateral wall of the carpal tunnel.

Lunate Bone.—The *distal surface* is the concave surface and articulates with the top of the head of the capitate. The *proximal surface*, directly opposite, is convex; it articulates with the lower end of the radius and with the articular disc. The *lateral surface* is the one shaped like a crescent moon, and it articulates with the scaphoid bone. The *medial surface*, directly opposite, is flat and nearly quadrilateral and articulates with the base or lateral surface of the os triquetrum. Between the medial and the distal surfaces there is usually a narrow strip that articulates with the upper edge of the hamate. The *palmar* and *dorsal surfaces* give attachment to ligaments; the palmar surface is convex and is larger and smoother than the dorsal surface.

Triquetrum.—The *palmar surface* is nearly flat; its medial two-thirds is covered with a flat, circular facet that articulates with the pisiform bone. The *distal surface* is concavo-convex

or undulating, and articulates with the medial surface of the hamate bone. The *lateral surface* is the base of the pyramid and articulates with the lunate bone. The *medial surface* is greatly reduced—being only the apex of the pyramid—and can be felt on the side of the wrist distal to the styloid process of the ulna and behind the pisiform bone. The *proximal* and *dorsal surfaces* are confluent, making one uneven convex surface; its lateral part has a poorly marked facet that articulates with the medial ligament of the wrist joint, and, during adduction of the wrist, with the articular disc.

Pisiform Bone.—The *dorsal surface* is oval or circular and is covered with a flat or slightly concave facet for articulation with the triquetrum. It is marked off by a very narrow, circular groove that gives attachment to the capsular ligament of the joint. The remainder is non-articular and rounded. It is shaped as though it had been pulled distally and laterally when soft so that the *distal surface* bulges beyond the articular facet and the *lateral surface* is slightly concave. The concavity of the lateral surface forms part of the medial wall of the carpal tunnel and is related to the flexor synovial sheath. Its anterior edge forms a low overhanging ridge for attachment of the flexor retinaculum, and the adjacent lateral slope of the *palmar surface* is related to the ulnar nerve.

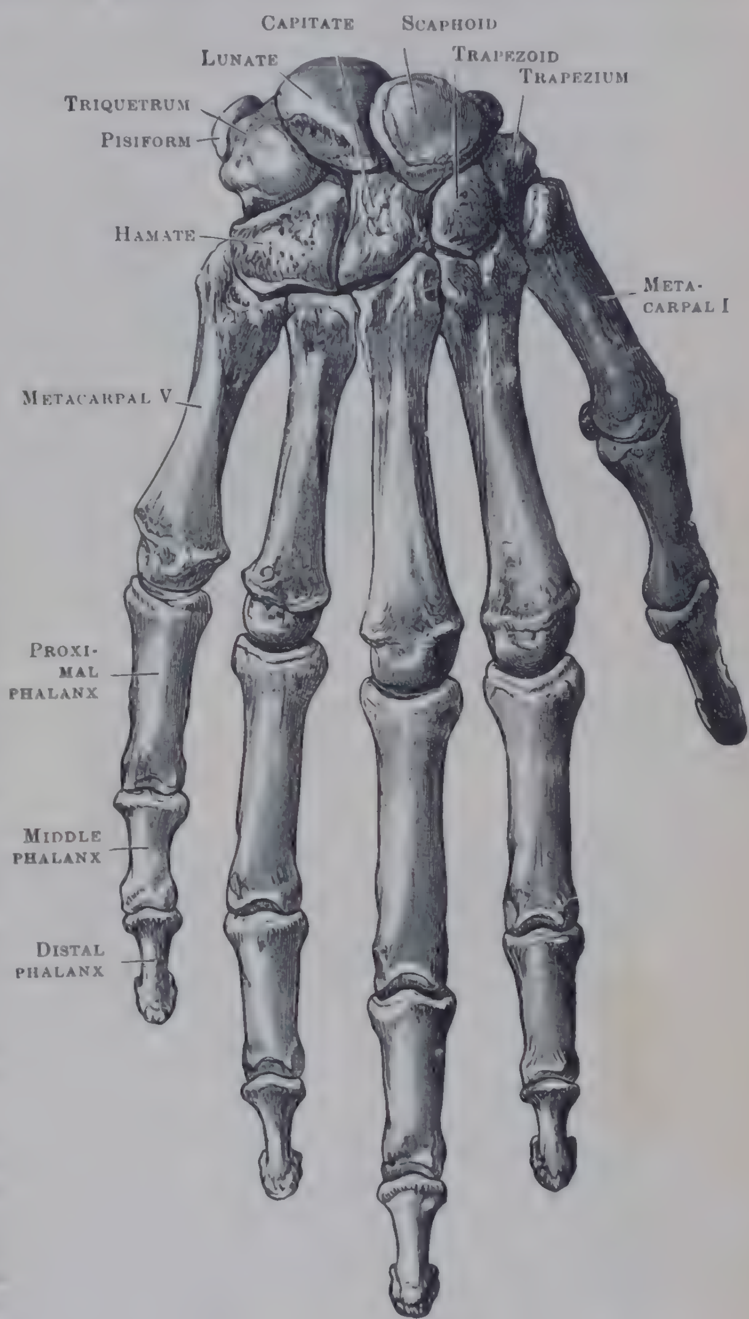


Fig. 238.—Dorsal Aspect of Bones of Right Hand.

Trapezium.—The *distal surface* is saddle-shaped and articulates with the base of the first metacarpal bone. The *proximal surface* is the small, smooth, concave surface opposite; it articulates with the scaphoid bone. The *medial surface* has a large facet which is separated by a smooth ridge from the proximal surface, and it articulates with the lateral surface of the trapezoid; lower down there is a small facet for articulation with the base of the second metacarpal bone. The *palmar*, *dorsal*, and *lateral surfaces* are non-articular. The palmar surface is distinguished from the other two by having the thick *crest* along its lateral margin and a well-defined, narrow groove along the lodges the tendon of the flexor carpi medial side of the crest; the groove radialis. The lateral surface is continuous with the lateral side of the crest, and the dorsal surface is directly opposite the palmar.

Trapezoid.—Beginners find difficulty in identifying its surfaces. The *dorsal* and *palmar surfaces* are both non-articular; the palmar surface is much the smaller. The other four surfaces are articular. The *distal surface* is the largest of these four; it is concave from before backwards and convex from side to side; it articulates with the base of the second metacarpal bone. From the palmar surface a rough strip, which may be V-shaped, passes backwards between the distal and lateral surfaces, and so the *lateral surface* can be identified; it articulates with the trapezium. The *proximal surface*, opposite the distal, articulates with the scaphoid bone. The *medial surface* articulates with the lateral surface of the capitate.

Capitate Bone.—The *proximal surface* is the rounded top of the head and articulates with the concave surface of the lunate bone. The *distal surface* is the base; its greater part articulates with the base of the third metacarpal bone, but at the edges it articulates also with the second and the fourth. The *palmar surface* is rough and protuberant. The *dorsal surface* also is non-articular, but is nearly flat. The *lateral surface* of the head is convex and articulates with the concave facet of the scaphoid bone; lower down, on the lateral surface of the body, there is a facet for articulation with the medial surface of the trapezoid. The *medial surface* has a large, nearly flat facet, which includes the medial side of the head, for articulation with the lateral surface of the hamate bone.

Hamate Bone.—The *hook* juts forwards from the distal and medial part of the palmar surface. The concave side of the hook looks in a lateral direction; it forms the lower part of the medial wall of the carpal tunnel and is lined with the flexor synovial sheath. The medial surface and the tip of the hook are covered with muscles and ligaments; the superficial branches of the ulnar vessels and nerve cross the tip; the deep branches cross the medial surface, and the nerve may groove it. The body of the bone is shaped like a wedge. The base of the wedge is the *distal surface*; it is concave from before backwards and convex from side to side; it articulates with the bases of the fourth and fifth metacarpal bones, and usually an indication of the division into two corresponding parts can be made out. The *proximal surface* is reduced to a blunt border between the medial and lateral surfaces and is the edge of the wedge; it articulates with the lunate bone. The distal and anterior part of the *lateral surface* is rough; the remainder is covered with a large facet for articulation with the capitate bone. The *medial surface* is wholly articular except at its distal margin, and it is undulating; it articulates with the distal surface of the tri-

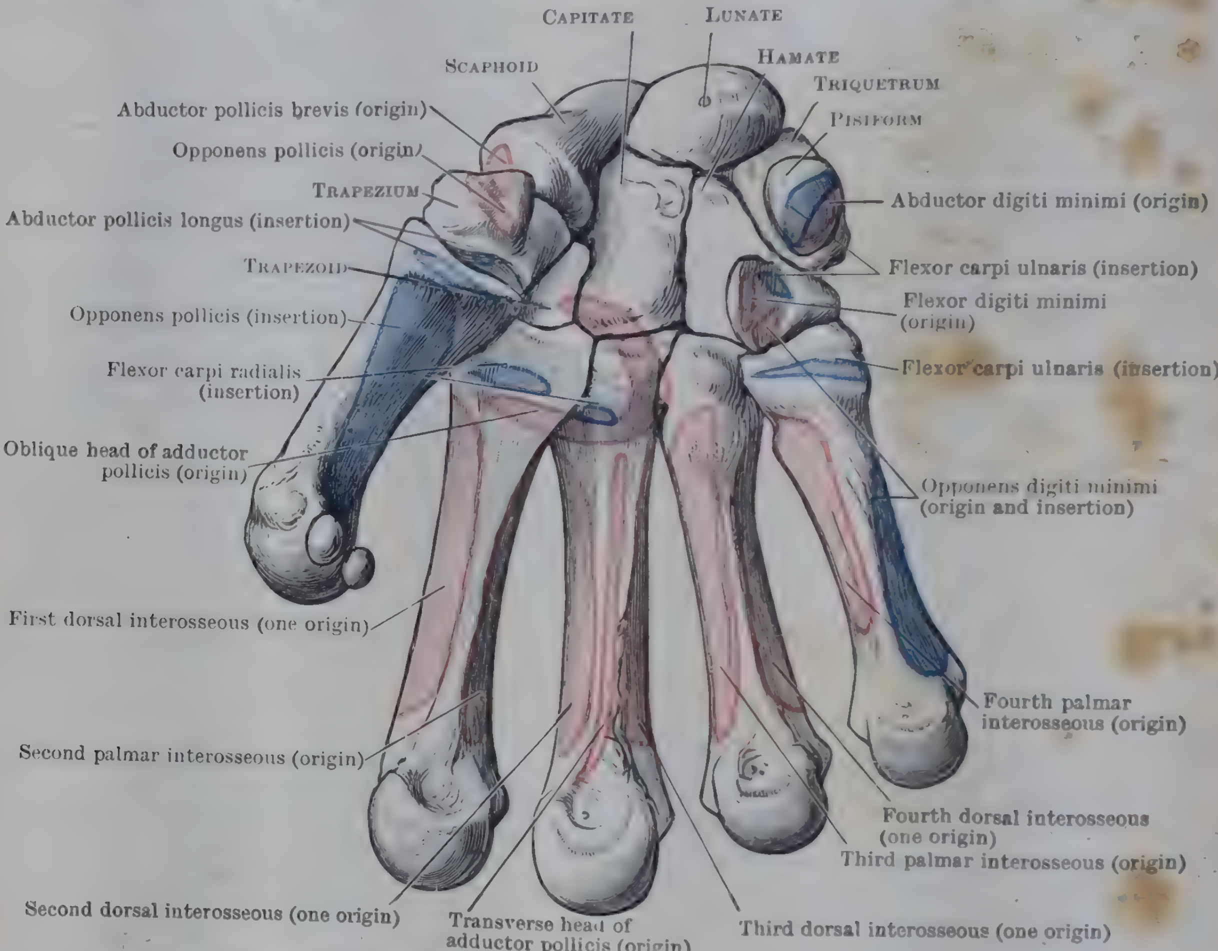


FIG. 239.—FRONT OF RIGHT CARPUS AND METACARPUS WITH ATTACHMENTS MARKED.

quetrum, which is correspondingly concavo-convex. The *dorsal surface* is non-articular and fairly flat. The *palmar surface*, also non-articular, bears the hook.

Attachments.—The pisiform is attached to the front of the triquetrum by a capsular ligament. The other seven bones are closely bound together by ligaments attached (1) to their *palmar* and *dorsal* surfaces, (2) to the rough areas and edges of *contiguous surfaces*, and (3) to the surfaces on the *ulnar and radial borders of the wrist*. The medial and lateral ligaments of the wrist joint also are attached to these surfaces, while the anterior radio-carpal ligament is attached to the palmar surfaces of the *scaphoid* and *lunate bones*, and the posterior ligament to the dorsal surfaces of the *scaphoid, lunate*, and *triquetrum*. The *distal row* of bones is closely bound to the bases of the medial four metacarpal bones by dorsal and palmar carpo-metacarpal ligaments, but the *trapezium* is more loosely attached to the base of the first metacarpal bone by a separate capsular ligament.

One end of the flexor retinaculum is attached to the *pisiform* bone and the *hook* of the hamate, and the other end to the *tubercle of the scaphoid* bone and the palmar surface of the *trapezium*. The extensor retinaculum stretches obliquely from the lower end of the radius to the *triquetrum* and the *pisiform*.

The tendon of the flexor carpi ulnaris is inserted into the front of the *pisiform bone*, leaving the proximal surface of the bone in relation to the fatty, fibrous tissue behind the tendon; but many of the tendinous fibres are continued onwards to the *hook* of the hamate and the base of the *fifth metacarpal* in two distinct strong bands called the piso-hamate and piso-metacarpal ligaments. The abductor digiti minimi arises partly from the *pisiform bone*. The flexor and opponens digiti minimi arise partly from the *hook* of the hamate. The abductor pollicis brevis arises in great part from the *tubercle of the scaphoid* and the *crest* on the *trapezium*; portions of the flexor

PLATE XV

FIG. 1.—RADIOGRAPH OF SHOULDER REGION OF BOY AGED 7. (Dr. J. Duncan White.)

Note that the proximal epiphysis of the Humerus (formed by union of centres for head, greater (and sometimes lesser) tuberosity) fits like a cap on the end of the shaft.

FIG. 2.—RADIOGRAPH OF WRIST OF GIRL AGED 14, TO SHOW THE DISTAL EPIPHYSES OF RADIUS AND ULNA.

[Facing p. 268

PLATE XVI

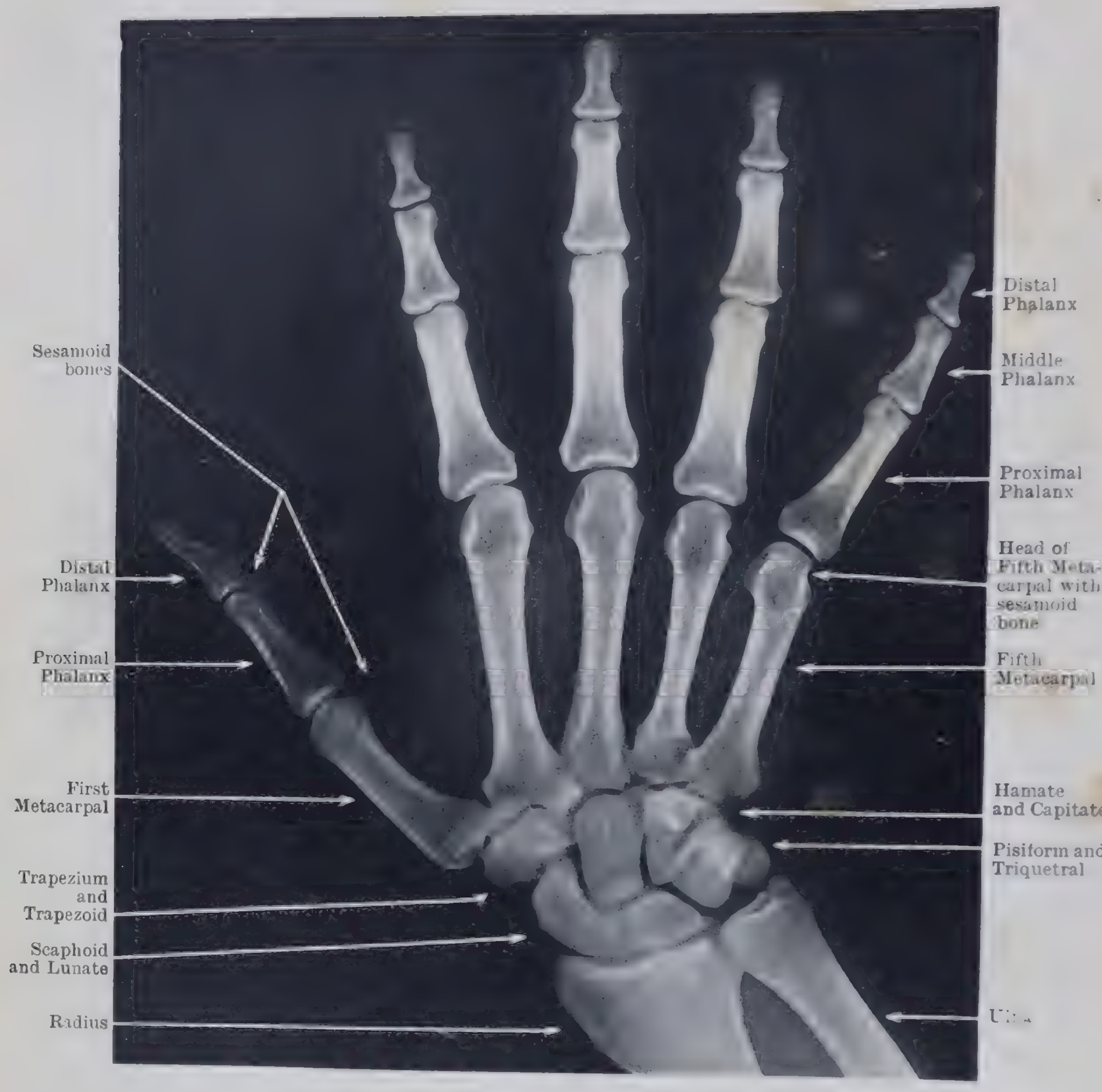


Plate XVI.—Radiograph of Wrist and Hand of Man aged 25.
(Dr. J. Duncan White.)

Compare with Plate XVIII, Fig. 2, p. 273, for the identification and relative position of the carpal bones.

pollicis brevis and opponens pollicis also arise from that crest; and, distal to the crest, the trapezium often receives a slip from the abductor pollicis longus. A portion of the oblique head of the adductor pollicis arises from the palmar surfaces of the *trapezium*, *trapezoid*, and *capitate*.

Metacarpus

The **metacarpus** is the skeleton of the hand proper [μετά (meta) = next after; καρπός (carpos) = wrist]. It consists of five separate bones, called **metacarpal bones**, one corresponding to each digit. They are named by number, *first*, *second*, etc., beginning with the one that corresponds to the thumb. Each of them is a miniature long bone and has a **shaft** and **two ends**. Each is slightly concave lengthwise on the **palmar** surface; the **distal end** is the rounded end and is called the *head*; the **proximal end** is called the *base*. The lateral surface can be distinguished from the medial after the base is examined.

Fig. 240.—First Right Metacarpal Bone.

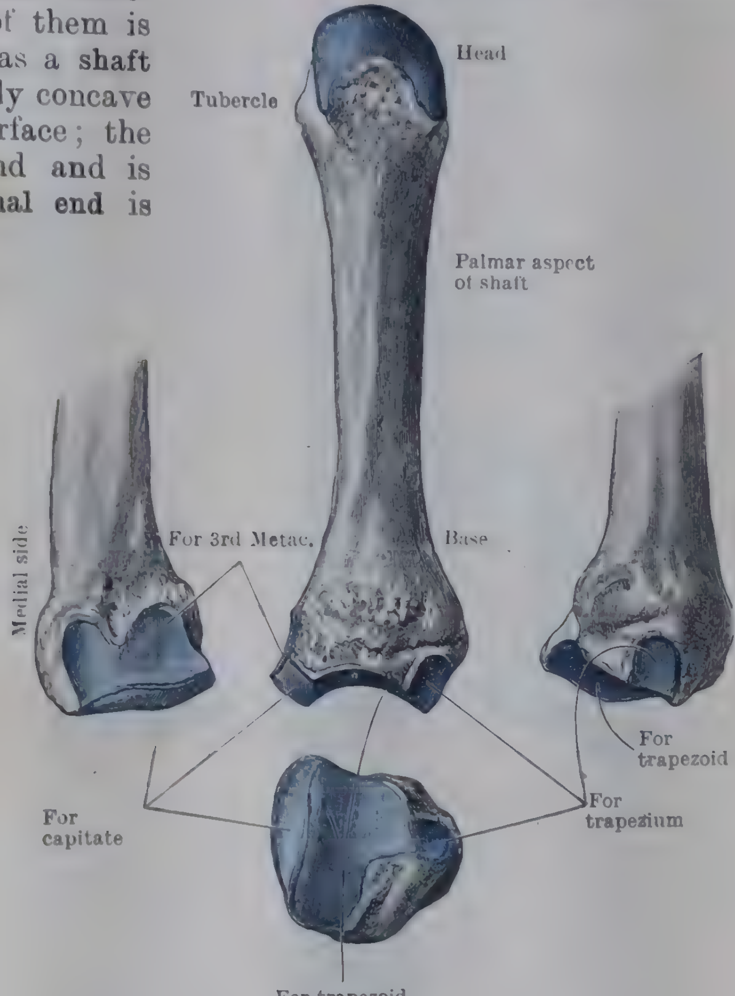


Fig. 241.—Second Right Metacarpal Bone.

The corresponding bones of the **foot** are called *metatarsal bones* and a beginner may mistake the one for the other if they are loose and mixed. Typical metatarsals, however, have tapering shafts terminating in narrow heads, compressed from side to side. The massive first metatarsal has its own special characters (see p. 320). The second to fifth **metacarpals** are between two and three inches long. Each has a rounded head, a more or less cubical base and a shaft which is slightly curved with the concavity on its palmar surface. The *heads* articulate with phalanges of the fingers, but during full flexion they are uncovered distally (except for a thin layer of the soft parts) to form the upper row of knuckles. The *shafts* are largely concealed by the soft parts of the hand but the dorsal surface can be felt in its whole length on the back of the hand. The *dorsal surface* is an elongated nearly flat *triangular area* with its base close to the head of the bone; it is covered to a large extent by an extensor tendon. The *bases* articulate with the carpal bones and with each other, and they also are palpable though covered by tendons. The *styloid process* which can be felt projecting from the lateral side of the base of the third metacarpal should be noted as it may be a separate bone or may be fused with the adjacent capitate

bone or may be broken off. The *first metacarpal* is not unlike a large proximal or middle phalanx (p. 272), its dorsal surface being rounded from side to side, but its base is saddle-shaped and its distal end is large and lacks the groove that gives the head of a phalanx its pulley-shape. In addition, the palmar surface is divided into two areas by a longitudinal ridge never seen on a phalanx.

The **distal ends** or **heads** are familiar as the upper row of knuckles. Each head has pits and tubercles at the *sides* for the attachment of ligaments; the *distal surface* is convex and smooth for articulation with the base of the proximal phalanx when the digit is straightened; the articular surface extends much farther on to the palmar surface than on to the dorsal, for when a digit is *flexed*, as when the hand is closed, the phalanx articulates with the palmar surface of the head. When a finger is *extended* it is in straight line with the hand, and the phalanx articulates with the distal surface of the head. The degree to which the finger can be *dorsiflexed, i.e.*, bent backwards beyond the straight line, varies considerably in different people, and the greater the degree of dorsiflexion possible the more does the articular surface extend on to the back of the head. The edge of the palmar articular surface is notched in the middle, especially in the first and second; the margins of the notch end proximally in prominent tubercles, which may be grooved if sesamoid bones have been present.

The **shaft** is thinnest in the middle. It is slightly curved—being concave forwards to provide room for the structures in the palm. It has a *dorsal surface* which can be felt on the back of the hand, and a *medial* and a *lateral surface*. The *palmar border*, which separates the lateral and medial surfaces, is blunt and broadens out into a surface near each end.

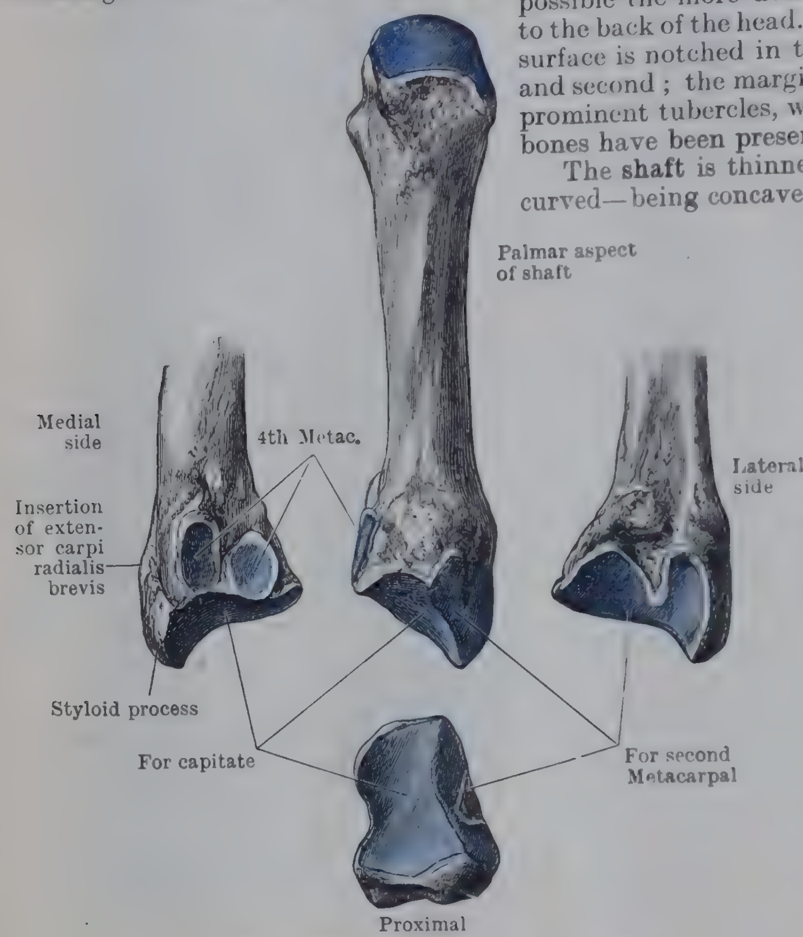


FIG. 242.—THIRD RIGHT METACARPAL BONE.

The **proximal end** or **base** of a metacarpal bone articulates with the carpus by its *proximal surface*, which is therefore smooth; the bases of the medial four articulate with each other by their *sides*, which therefore have articular facets. The readiest means of identifying the individual metacarpal bones is found in the base, and in the medial four the base provides the means of distinguishing the lateral surface from the medial surface.

The **first** metacarpal bone is shorter than the others and is placed farthest forwards; it is set obliquely—diverging from the others, and with its dorsal surface looking laterally rather than backwards. This position and obliquity make it possible to oppose the thumb to the other digits. The bone is slightly compressed from before backwards, and the surfaces of the **shaft** are therefore usually regarded as two—a *dorsal* and a *palmar*; but the palmar surface is divided by a blunt ridge into a radial and an ulnar half, of which the radial or *lateral* half is slightly the larger; the dorsal surface is of equal width from end to end. The **base** has no facets on its *sides*; its *proximal surface* is saddle-shaped and articulates with the distal surface of the trapezium—that surface also being saddle-shaped. The *palmar surface* of the **head** articulates with two sesamoid bones and is grooved for them (p. 274).

The **second** is the longest of the metacarpal bones and its base is the largest. It has a wide groove or *notch* on the *proximal surface* of its **base**, where it articulates with the trapezoid. The edge of the ridge that bounds the notch medially articulates with the capitate bone; the *lateral side* is a pointed tubercle which articulates with the trapezium. The *medial side* of the base bears a facet for articulation with the lateral surface of the base of the third metacarpal.

The **third** metacarpal has a thick, pointed projection, called its **styloid process**, projecting from the junction of the *dorsal* and *lateral* surfaces of the **base**, and by that the **lateral** side can be recognized. The *proximal surface* of the base articulates with the capitate bone; and on the sides there are facets for articulation with the second and fourth metacarpals.

The **fourth** is usually the most slender of the metacarpal bones. It has a cubical **base**. Its *proximal surface* is nearly flat and articulates chiefly with the hamate bone and slightly with the capitate. There are two nearly circular facets on the *lateral surface* of the base for articulation with the third metacarpal, and a single facet on the *medial surface* for articulation with the fifth.

The **fifth** is the shortest metacarpal bone, except the first; the dorsal surface reaches the base, and is wide enough there to exclude the medial surface from the dorsum. Being on the side of the hand, it has a facet on only one side of the **base**, on the *lateral surface*, for articulation with the fourth. There is a tubercle on the *medial surface*. The *proximal surface* is convex from before backwards, slightly concave from side to side, and articulates with the hamate bone.

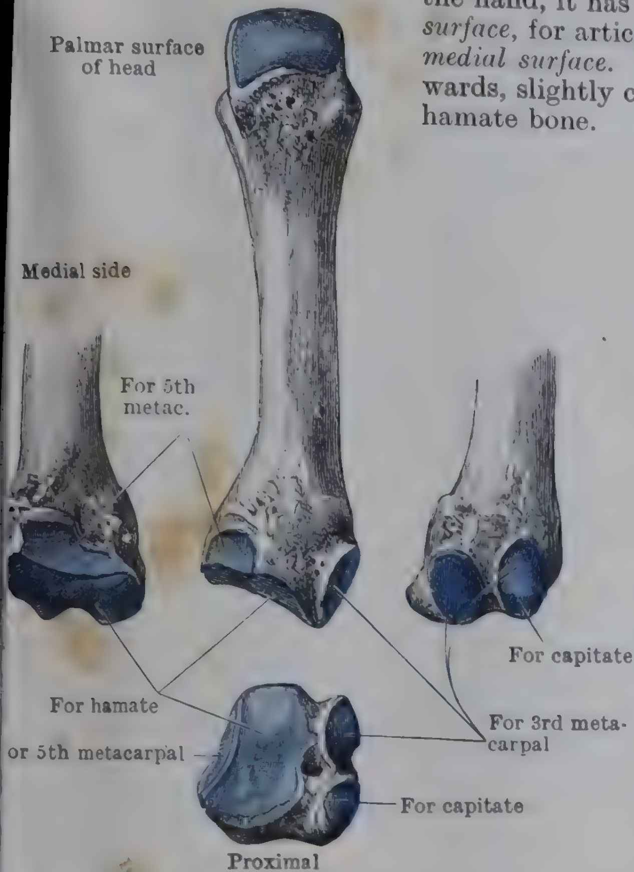


FIG. 243.—FOURTH RIGHT METACARPAL BONE.

FIG. 244.—FIFTH RIGHT METACARPAL BONE.

Attachments.—The **base** of the *first metacarpal* is attached to the trapezium by a capsular ligament. The *other four* are bound to the carpus by carpo-metacarpal ligaments attached to their palmar and dorsal surfaces; they are bound to each other by palmar and dorsal intermetacarpal

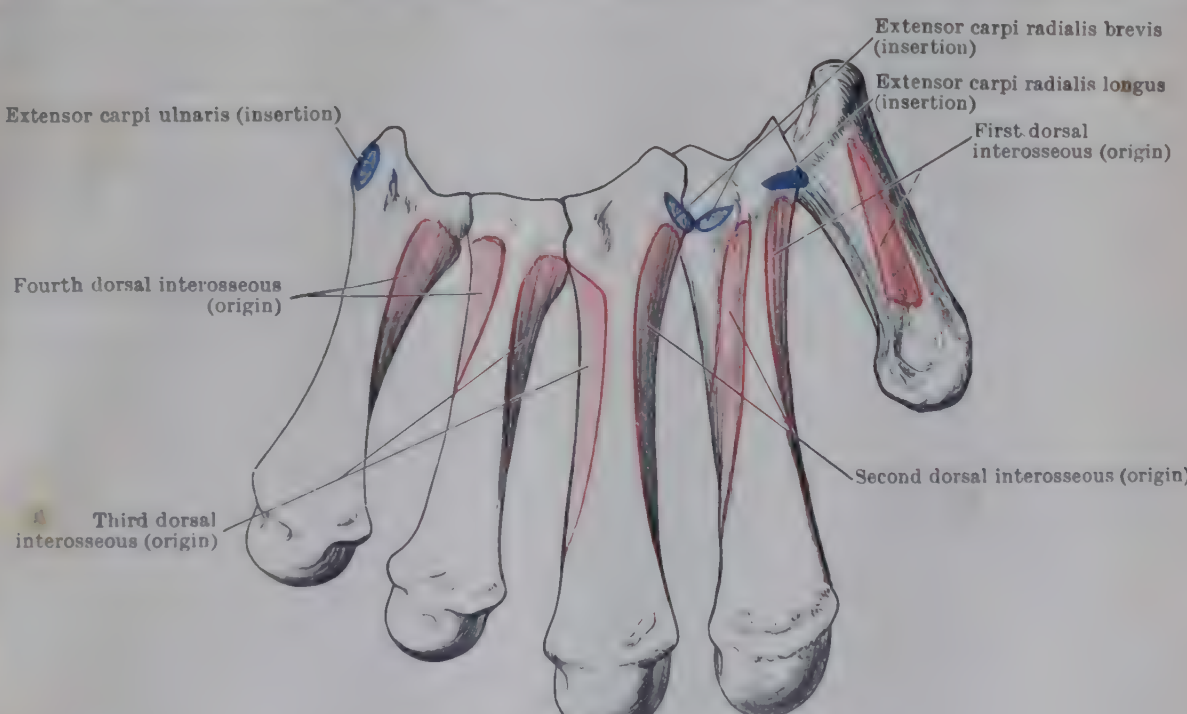


FIG. 245.—BACK OF RIGHT METACARPUS WITH ATTACHMENTS MARKED.

ligaments and by interosseous ligaments attached to the rough parts of their sides; the base of the *fifth* has two additional ligaments—the piso-metacarpal attached to the palmar surface, and the medial ligament of the carpus, which stretches to the tubercle on its medial side. The **head** of each metacarpal is attached to the proximal phalanx by a capsular ligament; this ligament is thickened at the sides to form radial and ulnar collateral ligaments, which are attached to the

sides of the head. It is greatly thickened in front to form the palmar ligament, which is attached loosely to the *palmar surface* immediately above the smooth articular part. On the back, the capsular ligament is fused with the extensor tendon that overlies the joint.

The abductor pollicis longus is inserted into the radial and palmar surfaces of the **base** of the *first*; the flexor carpi radialis into the palmar surface of the base of the *second* and slightly into the base of the *third* also; the extensor carpi radialis longus into the radial part of the back of the base of the *second*; the extensor carpi radialis brevis into the radial part of the base of the *third* at the root of the *styloid process*, and slightly also into the base of the *second*; the extensor carpi ulnaris into the back and ulnar side of the *fifth*. The first palmar interosseous arises from the ulnar side of the base of the *first*; part of the oblique head of the adductor pollicis from the palmar surfaces of the *second*, *third*, and *fourth*.

The opponens pollicis is inserted into the radial half of the palmar surface of the **shaft** of the *first*; the opponens digiti minimi into the ulnar surface of the *fifth*. The four dorsal interosseous muscles lie between the metacarpal bones and are attached to *all* of them; each arises by two heads which spring from the adjacent sides of the two metacarpal bones between which the muscle lies. The medial three palmar interosseous muscles lie in front of the dorsal interosseous; they arise by single heads from the *second*, *fourth*, and *fifth*. The transverse head of the adductor pollicis arises from the palmar border of the *third*.

Phalanges of Fingers

Each **phalanx** is a miniature long bone having a **shaft** and **two ends** [φάλαγξ (phalanx) = a round log or roller]. The **proximal** end is the larger and is called the *base*; the **distal** end is the *head*. The **shaft** is markedly *convex* from side to side on its *dorsal* surface and nearly flat on the *palmar* surface. There is little distinction between the lateral and medial margins of a phalanx.

Fig. 246.—Phalanges of a Finger (Palmar View).

The **proximal** phalanx of a digit is the largest; the proximal surface of its **base** is hollowed out as a single concavity, and its **head** is pulley-shaped. The **head** of the **middle** phalanx also is pulley-shaped, but its **base**, since it articulates with the head of the proximal phalanx, is the reverse of a pulley, having two shallow concavities with a low intervening ridge; that distinguishes the middle phalanx of a large hand from the proximal phalanx of a small hand. The **base** of the **distal** phalanx also is the reverse of a pulley, but it is the smallest phalanx and its **head** is non-articular.

The **thumb** has only *two* phalanges. They are shorter and broader than those of the fingers; the **proximal** phalanx resembles the proximal phalanx of a finger, and the **distal** resembles the distal phalanx of a finger.

The middle finger is the longest; the little finger is the shortest; the other two fingers are nearly equal in length, the ring finger being usually slightly longer than the index. But the relative lengths of the phalanges are such that the finger-tips come into line when the interphalangeal joints are bent.

The phalanges of the toes should not be mistaken for those of the fingers. The proximal phalanx of a toe is about the same length as the middle phalanx of a finger, but its body is much thinner and its base is relatively large. Both of the phalanges of the big toe are so thick, and the middle and distal phalanges of the other toes are so short, that they cannot be mistaken.

The **proximal phalanx** of a finger measures 35-45 mm. in length, and it is slightly curved lengthwise, with the concavity on the palmar surface. The *proximal surface* of its **base** is concave and articulates with the head of the metacarpal; the *sides* of the base are slightly enlarged and give attachment to ligaments. The *dorsal surface* of the **shaft** is markedly convex sideways. The *palmar surface* is nearly flat from side to side and is separated from the dorsum by sharp margins. The **head** articulates with the base of the middle phalanx; the articular surface extends much farther on to the front than on to the back, just as on the head of a metacarpal bone and for the same reason. The *sides* of the head show shallow pits for the attachment of ligaments.

PLATE XVII

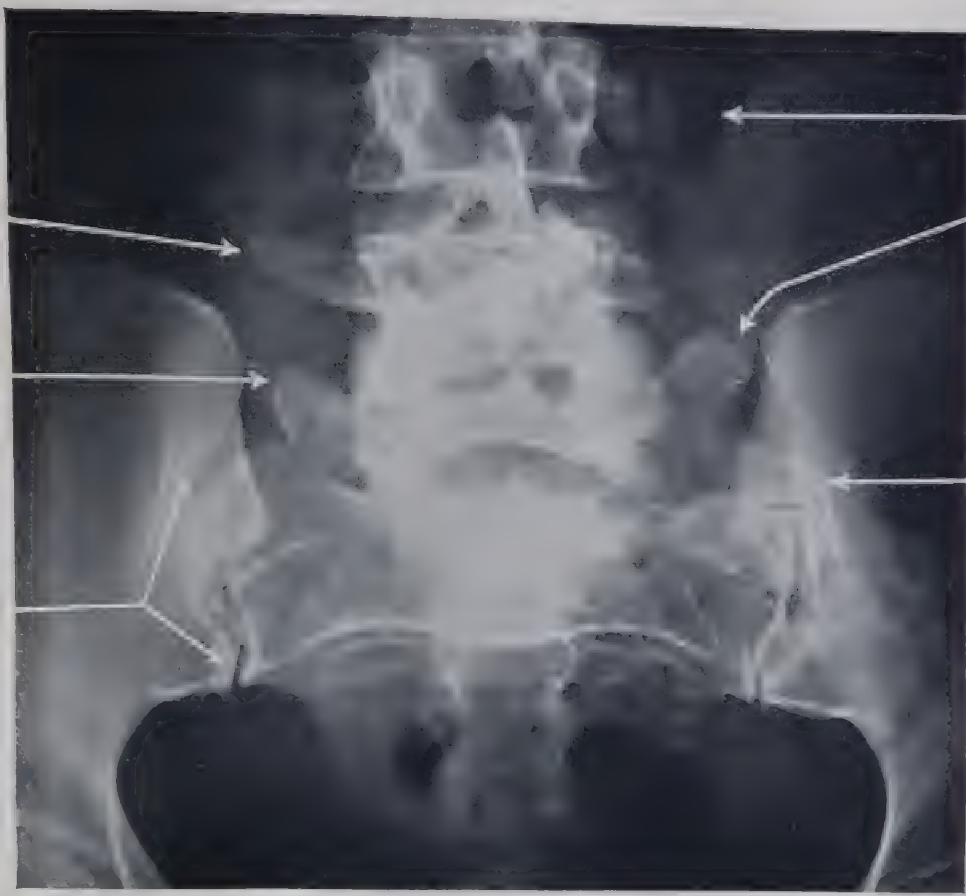


FIG. 1.—THE LEFT TRANSVERSE PROCESS OF THE FIFTH LUMBAR VERTEBRA (FEMALE ADULT IS ENLARGED AND PARTLY UNITED TO THE ALA OF THE SACRUM.

FIG. 2.—THE LEFT TRANSVERSE PROCESS OF THE FIFTH LUMBAR VERTEBRA (MALE ADULT) IS MORE COMPLETELY "SACRALIZED" THAN IN FIG. 1, AND THE RIGHT TRANSVERSE PROCESS SHOWS A PROJECTION TOWARDS THE SACRUM.

PLATE XVII.—RADIOGRAPHS OF LUMBO-SACRAL REGION SHOWING VARIETIES OF SACRALIZATION OF FIFTH LUMBAR VERTEBRA.

See p. 1527 and Figs. 1232, 1233.

[Facing p. 272

PLATE XVIII

Fig. 1.—Radiograph of Wrist and Hand of Full-Time Fœtus.

Note the absence of centres of ossification for the carpal bones. (Cf. Plate XXVIII, Fig. 1, p. 321). In contrast to Fig. 2, the soft tissues are clearly seen owing to differences in the radiographic technique (see p. 1554).

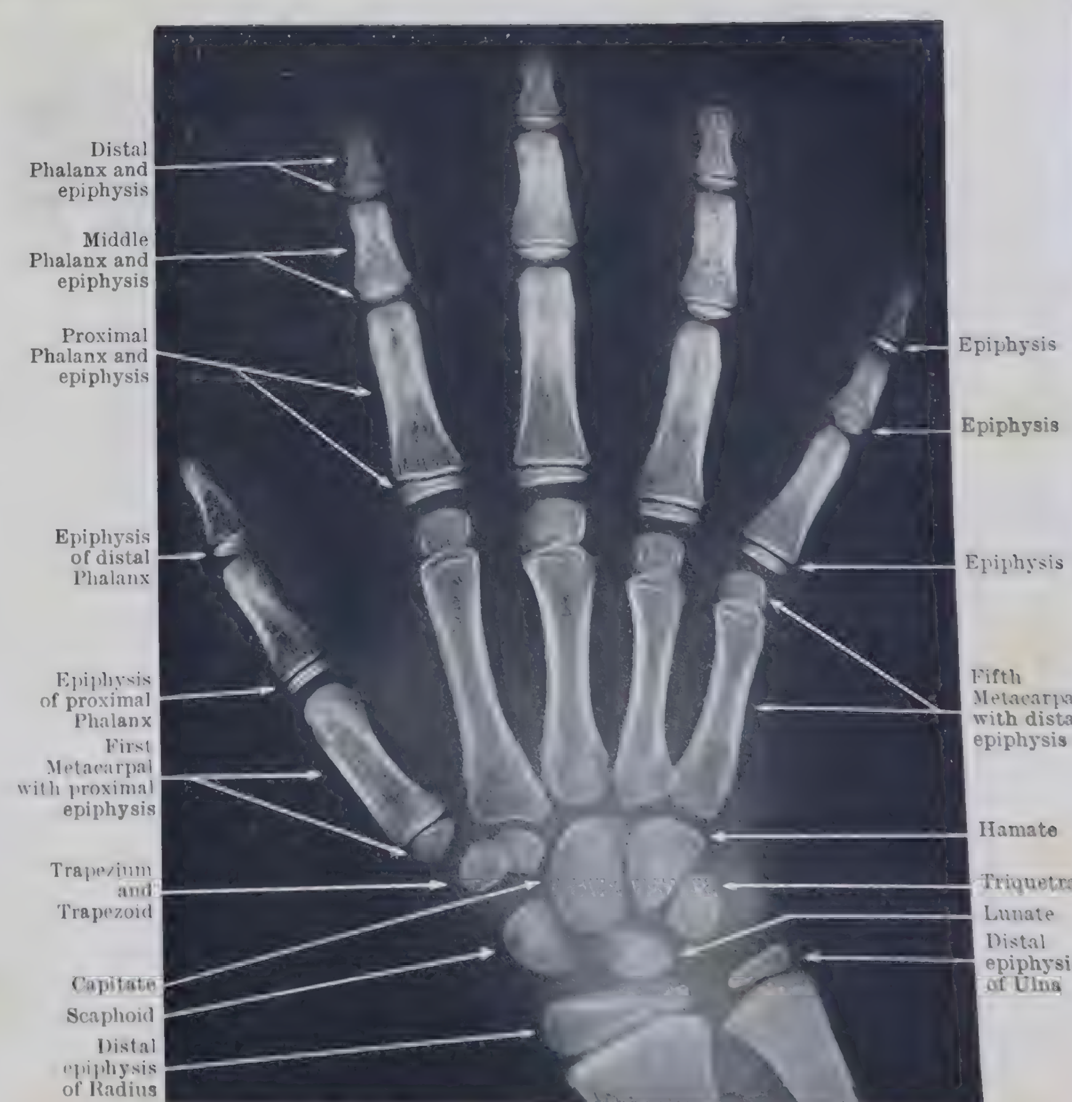


Fig. 2.—Radiograph of Wrist and Hand of Girl aged 7. (Dr. J. Duncan White.)

Note the relative position of the ossifying carpal bones—the pisiform centre has not yet appeared—and compare with Plate XVI, p. 269. Cf. also Plate XXVIII, Fig. 2, p. 321.

The **middle phalanx** is 25-30 mm. Its **shaft** and **head** resemble those of a proximal phalanx, but the **base** differs in the way already mentioned. The **distal phalanx** is very small and is not curved. Its **base** is relatively large and resembles that of a middle phalanx. The **shaft** is short. The **head** is expanded sideways, is non-articular, and is very rough on its palmar surface.

Attachments.—The **base** of the *proximal* phalanx is attached to the metacarpal bone by a capsular ligament, the characters of which are briefly indicated in the account of the metacarpals; the palmar ligament is attached firmly to the palmar surface of the base, and the collateral ligaments to its sides. The *middle* phalanx is attached to the first and the third by similar capsules. Each of the four tendons of the extensor digitorum spreads out on the back of a proximal phalanx to form an *extensor expansion* which is inserted into the back of the base of the middle and distal phalanges of a finger; the tendon of the extensor indicis joins the tendon of the digitorum for the forefinger, and the tendon of the extensor digiti minimi joins that for the little finger; the tendons of the interossei and of the lumbricals are inserted into the extensor tendon of a finger; therefore each *extensor expansion* is made up of several tendons. Each of the four tendons of the flexor digitorum sublimis is inserted into the margins of the **shaft** of a *middle* phalanx. Each of the four tendons of the flexor digitorum profundus is inserted into the palmar surface of the **base** of a *distal* phalanx. The abductor and flexor digiti minimi are inserted into the ulnar side of the **base** of the proximal phalanx of the *little finger*.

The tendons of the long flexors of a digit are held in place along its palmar surface by a fibrous strap, called the fibrous flexor sheath, the edges of which are attached to the margins of the **shaft** of the *proximal* phalanx of the *thumb* and of the *proximal* and *middle* phalanges of the *fingers*, and its distal extremity is attached to the palmar surface of the *distal* phalanx immediately beyond the insertion of the flexor tendon.

Thumb.—The extensor pollicis brevis is inserted into the *dorsal* surface of the **base** of the **proximal phalanx**; the flexor brevis and abductor brevis together into the *radial* side of the base; the first palmar interosseous and transverse head of adductor into the *ulnar* side; oblique head of adductor into both sides. The extensor longus into the *dorsum* of the **base** of the **distal phalanx**; and the flexor longus into the *palmar* surface. The fibrous flexor sheath is attached to the *margins* of the **shaft** of the **proximal phalanx** and the *palmar surface* of the **distal**. Capsular ligaments, like those of the fingers, connect the proximal phalanx with the metacarpal bone and the distal phalanx.

FIG. 247.—RADIOGRAPH OF THE HAND AT BIRTH.

Metacarpus and phalanges well ossified; carpus still cartilaginous. Compare with tarsus at birth, p. 324 and Pl. XXVIII, p. 321.

Ossification of Bones of Hand (Pl. XVIII).—The **carpus** is cartilaginous at birth. Each carpal bone has **one** centre; ossification is completed between 20 and 25.

	Capitate.	Hamate.	Triquetrum.	Lunate.	Scaphoid.	Trapezium.	Trapezoid.	Pisiform.
Centre appears	6 months	6 months	M. 3-4 yr. F. 2-3 yr.	M. 4-5 yr. F. 3-4 yr.	M. 6 yr. F. 4 yr.	M. 6 yr. F. 4-5 yr.	M. 6 yr. F. 4-5 yr.	M. 13-14 yr. F. 9-10 yr.

Metacarpus.—The *primary* centre, one for each metacarpal bone, appears in the ninth week of intra-uterine life. The metacarpal bones are well ossified at birth.

The **first** differs from the other in having the epiphysis at the base instead of at the head, possibly because movement is more free at the carpo-metacarpal joint of the thumb than at the metacarpo-phalangeal joint, while the reverse is the case at the joints of the other metacarpal bones. In rare cases the first has an epiphysis at its head also; and, still more rarely, the second or one of the others has an epiphysis at its base.

Secondary Centre.	Appears at	Epiphysis joins at	Relation of Epiphysial Line to Capsule of Neighbouring Joint.
For base of first	M. $3\frac{1}{2}$ yr. F. $2\frac{1}{2}$	M. 19 yr. F. 17 yr.	Outside.
For head of others	M. 3 yr. F. 2		Outside.

Phalanges.—The *primary* centre for each appears between the eighth and the twelfth week of intra-uterine life. At birth the phalanges are well formed.

Secondary Centre.	Appears at	Epiphysis fuses at	Relation of Epiphysial Line to Capsule of Neighbouring Joint.
For base	M. 3rd yr. F. 2nd yr.	M. 19 F. 17	Outside.

The **distal phalanges** are the first bones of the hand to ossify, and their primary centres appear near their distal ends instead of in the middle.

In rare cases the proximal phalanx has an epiphysis at its head as well as at its base.

It is possible that "double epiphysis" in metacarpals and phalanges is hereditary.

Structure and Variations of Bones of Hand.—**Carpal bones** have the typical structure of short bones. **Metacarpal bones** and **phalanges** have the structure of long bones. The walls of the medullary cavity are thick compared with the size of the bone; that is especially the case in the dorsal wall in a phalanx. The *nutrient foramen* of a metacarpal is near the palmar margin; it is directed towards the head in the first, and towards the base in the others. There are usually two on each phalanx. They are on the palmar surface and are directed towards the head.

Variation in the number of carpal bones may arise from the fusion of two carpal bones or the division of one; but fusion is caused usually by disease. The hook of the hamate bone may be separate; the **os centrale**, though normally a separate bone in the carpus of most mammals, and represented by a separate cartilage in the earlier months of intra-uterine life, is almost always fused with the scaphoid bone, but sometimes it is a separate ossicle on the back of the carpus between the scaphoid, capitate, and trapezoid. Radiographs sometimes reveal what appear to be small additional nodules in the carpus. The *styloid process* of the third metacarpal bone may have an epiphysial centre and may be a separate bone, or it may be fused with the capitate bone or the trapezium instead of with the metacarpal.

Sometimes a *distal phalanx* is bifurcated. The thumb may have three phalanges. Occasionally a phalanx is very short or is absent or has been absorbed by another phalanx.

Sesamoid Bones

The **sesamoid bones** of the hand are two very small nodules that lie in the tendons of insertion of the flexor pollicis brevis and the adductor pollicis. They are blended with the palmar ligament of the metacarpo-phalangeal joint and play against the palmar surface of the head of the metacarpal bone. Occasionally little nodules are found also in the palmar ligament of the other metacarpo-phalangeal joints and in the interphalangeal joint of the thumb (Pl. XVI, p. 269).

The sesamoid bones of the hand are cartilaginous in childhood; they begin to ossify after 13, and they may have more than one centre for each.

BONES OF THE LOWER LIMB

The parts of the **lower limb** are the hip and buttock, the thigh, the leg, and the foot (Figs. 129, 130, pp. 119 and 120).

The **hip** (*coxa*), above and at the side, and the **buttock** (*natis*), below and behind, make up the **gluteal region**, which extends from the waist and the small of the back down to the level of the horizontal crease that limits the buttock below; the crease is called the *fold of the buttock*; the interval between the buttocks is the *natal cleft* [γλουτός (glutos) = *natis* = buttock]. The lower end of the trunk, between the thighs and between the buttocks, is called the *perineum* [περίνεος (perineos) = the perineum: derivation uncertain].

The skeleton of the hip and buttock of each side is a single bone called the **hip-bone** (os coxæ). It is part of the framework of the trunk also, for the right and left hip-bones, together with the sacrum and the coccyx, form the bony walls of the pelvis; and the hip-bone is sometimes referred to as the *pelvic girdle*. (The sacrum and coccyx are the lowest divisions of the backbone; the pelvis is the lower part of the abdomen or belly, and the perineum is included in the pelvis.)

The **thigh** (*femur*) extends from the gluteal region to the knee. On the lateral side it is continuous with the hip; posteriorly it joins the buttock at the fold of the buttock; on the medial side it joins the perineum, which separates it from the other thigh; anteriorly it joins the anterior wall of the abdomen and reaches a higher level than it does behind; the depression between the front of the thigh and the front of the abdomen is the *groin* or *inguinal region* [*inguen* = groin, from *inquinare* = to stain].

The bone of the thigh is the **femur**. At its upper end the femur articulates with the hip-bone to form the *hip joint*. At the *knee joint* the distal end of the femur

articulates (1) with the tibia or shin-bone, which is the larger of the two bones of the leg, and (2) with the patella or knee-cap—the small bone that lies in the front of the knee joint. The ham is the back of the knee and the lower part of the back of the thigh; and the hollow of the ham is called the *popliteal fossa* [*poples* = the hough; the ham of the knee].

The term **leg** (*crus*) is often applied to the whole free part of the lower limb, but anatomically it is limited to the segment between the knee joint and the ankle joint. The two bones of the leg are called the **tibia** and the **fibula**. They articulate with each other at their upper and lower ends, and the joints so formed are the *tibio-fibular joints*. The tibia articulates with the femur at the *knee joint*, but the fibula does not do so; the tibia and fibula both articulate with one of the bones of the foot, the talus, to form the *ankle joint*.

The **foot** (*pes*) is joined to the leg at the ankle joint, and it is divided into the foot proper and the toes. The **foot proper** is all the region from the point of the heel to the roots of the toes. Its upper surface is called the *dorsal surface* or *dorsum* of the foot; the *sole* is often called the *plantar surface* [*planta* = the sole]. The foot proper is divided into—(1) the *tarsus*, which is the hinder half of the foot proper and corresponds to the carpus or wrist, and (2) the *metatarsus*, which is the half next the toes and corresponds to the metacarpus or hand proper.

The bones of the **tarsus** are seven in number, named collectively the **tarsal bones**, and they articulate with one another, forming *intertarsal joints*.

The bones of the **metatarsus** are called **metatarsal bones**. There are five of them, placed side by side, one corresponding to each toe. They are named by number: **first** metatarsal, **second**, etc., beginning with the one that corresponds to the big toe. The posterior ends of the metatarsal bones articulate (1) with the second row of tarsal bones, forming *tarso-metatarsal joints*, and (2) with one another, side by side, forming *intermetatarsal joints*.

Toes or **Digits**.—The big toe is called the **hallux** [probably from *allex* = thumb or big toe]. The other toes are usually designated by number—**second**, **third**, etc.

The bones of the toes are called **phalanges**. The big toe has two phalanges, named the **proximal** phalanx and the **distal** phalanx. Each of the other toes has three phalanges—**proximal**, **middle**, and **distal**. The distal phalanx is sometimes called the *ungual phalanx*, because the nail (*unguis*) is associated with it. The proximal phalanx of a digit articulates with the distal end of the corresponding metatarsal bone to form a *metatarso-phalangeal joint*; and the middle phalanx articulates with the other two, forming *interphalangeal joints*.

Hip-Bone

The **hip-bone** is large, expanded, and unevenly compressed. On one side of it there is a deep cup or cavity with a broken rim; the cavity is the **acetabulum**, and near it there is a large aperture called the **obturator foramen**.

The hip-bone lies in the side-wall and the anterior wall of the pelvis. In the anterior wall it articulates with its fellow of the opposite side to form the *pubic symphysis*. Posteriorly the hip-bone articulates with the side of the sacrum, which lies in the back-wall of the pelvis between the two hip-bones; and the joint is called the *sacro-iliac joint*.

The hip-bone is made up of three originally distinct bones which in the adult are fused together at the acetabulum. The three bones or parts are named the *ilium*, *ischium*, and *pubis*.

The **ilium** is the largest and broadest of the three parts. It is the uppermost part of the hip-bone; and the bone should be held in the hand so that this broad part is uppermost and the deficient side of the acetabulum looks directly downwards. The **ischium** is the thick, three-sided part below and behind the acetabulum and behind the obturator foramen; from the lower end of the ischium a broad, fairly flat bar of bone, the *ramus of the ischium*, projects forwards; it is the lower boundary of the obturator foramen, and it joins the pubis. The **pubis** is the remaining part of the hip-bone, and completes the boundaries of the obturator

foramen. The pubis has three main parts: (1) an expanded part in front, called the *body* of the pubis; (2) a compressed bar of bone, the *inferior ramus* of the pubis, which extends backwards from the body and fuses with the ramus of the ischium; (3) a thicker bar, the *superior ramus*, which extends from the body to the acetabulum.

The position of parts is roughly as follows: the ilium is the upper part; the ischium is the lower and posterior part; the pubis is the lower, anterior, and

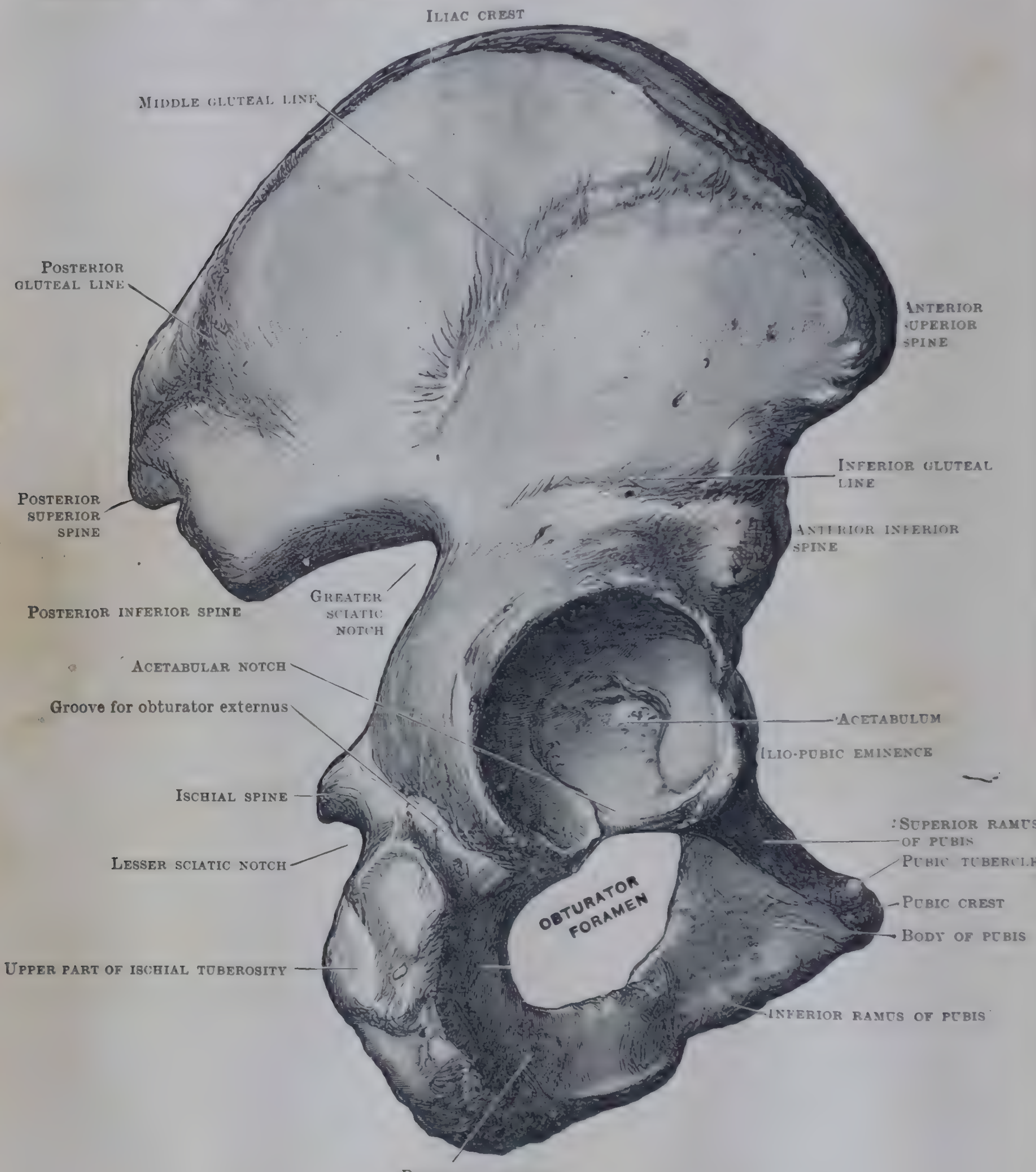


FIG. 248.—RIGHT HIP-BONE SEEN FROM THE LATERAL SIDE.

medial part; the acetabulum is on the lateral surface; the obturator foramen is below and medial to the acetabulum.

The **ilium** (os ilium) is the bone of the flank [*ilia* (plural) = the flank]. It lies below the waist in the uppermost part of the hip. It is large, compressed, and fluted; and it has two ends, three borders, and three surfaces.

The two **ends** are upper and lower. The **lower end** forms the upper part of the acetabulum and is fused there with the ischium and the pubis. The **upper end** is scarcely recognizable as an end, for the ilium in Man is so expanded that the upper end is drawn out like the wide end of an open fan and resembles a border; it is

called the **iliac crest.** The crest is curved like the *italic* letter *f*; the curve of the anterior half is convex in the lateral direction, and the curve of the posterior half is convex in the medial direction. The anterior and posterior ends of the crest are named the **anterior superior iliac spine** and the **posterior superior iliac spine.** The margins of the crest are its *outer* and *inner lips*; the interval between the lips is the *intermediate area.* Two or three inches above and behind the anterior superior spine the crest is thicker than it is elsewhere; the thickening produces a low prominence on the outer lip called the **tubercle of the crest.**

The iliac crest can be felt from end to end in the living body along the lower boundary of the waist. By tracing the crest forwards one can find the anterior superior spine and can almost grip it between finger and thumb when the muscles attached to it are relaxed—as they are when one is sitting. The tubercle of the crest is easily felt, two or three inches behind and above the anterior spine. The posterior superior spine is not distinctly palpable in the living body like the anterior spine; but it can be felt in the floor of a dimple in the skin which can be seen above the buttock about two finger-breadths from the median plane. The spine is at the level of the second spine of the sacrum and the middle of the sacro-iliac joint. The highest point of the crest is about its middle point, one or two inches behind the tubercle of the crest, and it is at the level of the fourth lumbar vertebra. The tubercle of the crest is the highest point that can be seen when the body is examined from the front, and is at the level of the fifth lumbar vertebra.

The **borders** of the ilium are anterior, posterior, and medial.

The **anterior border** begins at the anterior superior spine and extends downwards and backwards to end at the anterior margin of the acetabulum. On the anterior border, a little above the acetabulum, there is a considerable prominence called the **anterior inferior iliac spine.** About an inch medial to the lower end of the anterior border, in front of the acetabulum, the ilio-pubic eminence, a low, diffuse swelling, marks the region where ilium and pubis fuse.

The **posterior border** begins at the posterior superior spine and runs in an undulating manner downwards and forwards to end immediately above the level of the middle of the acetabulum, where it becomes continuous with the posterior border of the ischium. At a point about an inch below the posterior superior spine, the posterior border makes an abrupt bend forwards at the **posterior inferior iliac spine.** The wide notch which is bounded by the part of the posterior border below the inferior spine and by the adjoining part of the posterior border of the ischium is called the **greater sciatic notch.**

The **medial border** is a ridge on the medial aspect of the ilium. It begins at the crest at the point where the posterior half of the crest is most convex, and it ends at the ilio-pubic eminence. Its *lower half* is smooth and blunt; its *upper half* separates a rough region behind from a smooth, concave region in front.

The three **surfaces** of the ilium are the gluteal, the sacro-pelvic, and a third surface moulded into the large concavity of the iliac fossa.

The **iliac fossa** is situated between the anterior and medial borders. Its floor is smooth, and it lodges the iliacus muscle.

The **sacro-pelvic surface** is the region between the posterior and medial borders. Its uppermost and largest part is the iliac tuberosity and is rough for the attachment of muscles and ligaments. The middle part is the **auricular surface**, usually sharply defined and so named because it resembles an ear in shape. It articulates with a corresponding "auricular" surface on the sacrum to form the *sacro-iliac joint*, but though it is an articular surface it is uneven and rather rough. The lobe of the "ear" is the posterior inferior iliac spine. The lowest part of the sacro-pelvic surface is smooth; it is the area between the lower, smooth part of the medial border and the bottom of the greater sciatic notch; it forms part of the side-wall of the true pelvis, which is the basin-like, lower part of the pelvis. By far the thickest, strongest, and oldest part of the ilium is the part in the neighbourhood of the auricular surface; for it is the part that transmits the weight of the trunk to the acetabulum or the ischial tuberosity.

The **gluteal surface** of the ilium is the wide, concavo-convex or undulating surface above the acetabulum, between the anterior and posterior borders; it looks

laterally and backwards, and it is sometimes called the **dorsum ilii**. It is divided into areas by three curved gluteal lines which vary in distinctness with the muscularity of the subject. The *inferior gluteal line* is the least distinct; it begins at the anterior border above the anterior inferior spine and curves backwards, about

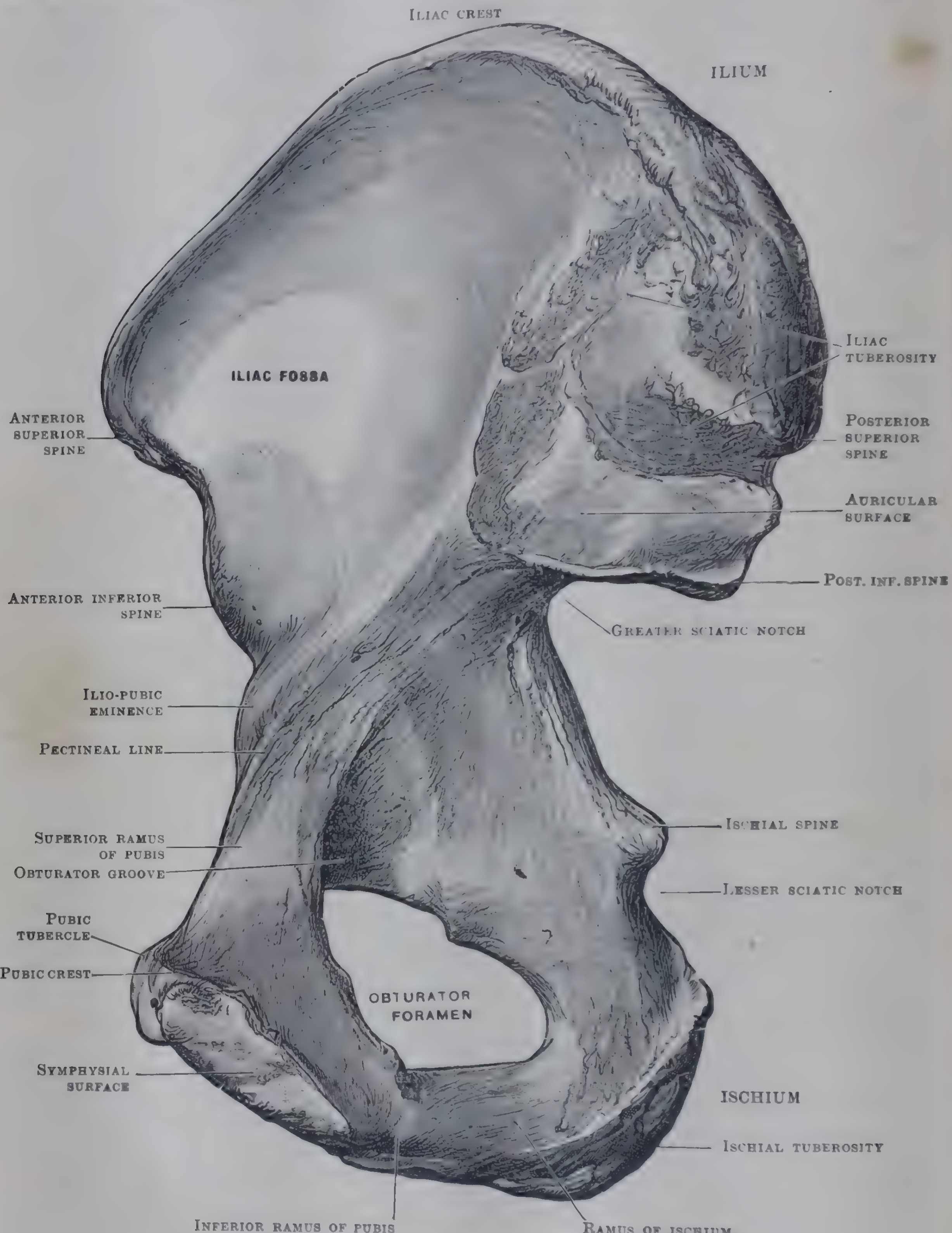


Fig. 249.—Right Hip-Bone seen from the Medial Side.

an inch above the acetabulum, towards the greater sciatic notch. The *middle gluteal* line begins at the crest an inch or more behind the anterior superior spine and arches across the middle of the surface towards the greater sciatic notch. The *posterior gluteal line* begins at the crest two or three inches in front of the posterior superior spine and curves downwards to the greater sciatic notch.

The **ischium** is the thick, prismatic part of the hip-bone below and behind

the acetabulum. In the upright sitting posture the body rests on the two ischia [ἰσχίον (ischion) = buttock. The adjective *ischiadic* has been reduced by time to *sciatic*].

The ischium has two ends, three borders, three surfaces, and a ramus.

The two **ends** are upper and lower. The **upper end** forms part of the acetabulum and is fused with the ilium and the pubis. The **lower end** is free and rough; the rough, lower extremity of the ischium, together with the rough, lower part of its dorsal surface, is the **ischial tuberosity**. The **ramus** of the ischium is the compressed bar of bone that projects from the lower end of the ischium and fuses with the inferior ramus of the pubis below the obturator foramen.

The **borders** of the ischium are anterior, posterior, and lateral. The **anterior border** is one of the boundaries of the obturator foramen. The **posterior border** is continuous with the posterior border of the ilium at the lower part of the greater sciatic notch and extends to the lower end of the ischium; near its upper end a sharp, triangular **ischial spine** juts backwards and medially from it. The spine forms the lowest part of the boundary of the greater sciatic notch and the upper boundary of the **lesser sciatic notch**, which is the smooth, shallow concavity between the ischial spine and tuberosity. The **lateral border** extends from the posterior margin of the acetabulum to the lower end of the ischium; its lower part is the lateral margin of the tuberosity; between the tuberosity and the acetabulum it is almost obliterated by a short, wide, horizontal groove.

The **surfaces** of the ischium are dorsal, pelvic, and femoral. The **dorsal surface** is continuous with the gluteal surface of the ilium across the back of the acetabulum, and its lower part is occupied by the tuberosity. The **pelvic surface** is the large, smooth area between the anterior and posterior borders; it forms part of the side-wall of the cavity of the true pelvis and is continuous superiorly with the sacro-pelvic surface of the ilium. The **femoral surface** is the flat area below the acetabulum; it looks towards the thigh.

The **pubis** lies in the anterior or lower wall of the pelvis; and it can be felt at the lowest part of the front of the abdomen and at the upper end of the thigh where the medial side and the front of the thigh merge into each other. It is named from the region in which it lies. [The *pubis* is the region covered with hair at the lowest part of the front of the abdomen: from *pubes* = the hair that appears at puberty.]

The pubis is divisible into an expanded, compressed *body*, and two bars of bone, the superior and inferior *rami*.

The **body** lies alongside the median plane, articulating with the body of the other pubis. The two are joined by a plate of fibro-cartilage to form the pubic symphysis and the articulating surface is called the *symphysial surface*. It is a narrow oval in outline and is rough and ridged. The other surfaces of the body are named pelvic and femoral. The *pelvic surface* is smooth, and is gently convex antero-posteriorly; it looks *upwards* into the cavity of the pelvis and is closely related to the urinary bladder. The *femoral surface* looks downwards into the thigh and is nearly flat. It is roughened for the attachment of muscles. The anterior border of the body is thick, rough, and bent downwards, and is called the **pubic crest**. The lower, lateral part of the crest swells out into a small prominent **pubic tubercle**. The pubic symphysis, crest, and tubercle can all be felt at the lower part of the abdomen; the tubercle is about an inch from the median plane, and it is often referred to as a landmark. When the hip-bone is held in the position it occupies in the erect body, the pubic tubercle and the anterior superior iliac spine lie in one vertical plane; the hip-bone is therefore in its proper position when it is placed against a wall with only those two points touching, and the defective side of the acetabulum looking straight downwards. The *inguinal ligament* stretches between the pubic tubercle and the anterior superior iliac spine. It can be felt in the living groin as a tense, resisting cord along the floor of the curved groove between those two bony points. Though called a 'ligament' it is the lower edge of the aponeurosis of the external oblique muscle of the abdomen. [An *aponeurosis* is a tendon or sinew in the form of a wide sheet: ἀπό (apo) = from; νεῦρον (neuron) = *nervus* = a sinew (though now both *neuron* and *nervus* always signify *nerve*).]

The **inferior ramus** is the short, compressed bar which begins at the posterior part of the body of the pubis and passes backwards, downwards, and in a lateral direction to meet and fuse with the ramus of the ischium; the position of their junction may be marked by a thickening or a ridge, but it is often difficult to make it out in an adult bone. The two fused rami form the **conjoined rami** of ischium and pubis. This bar of bone has two surfaces and two borders. The *inner surface* is divided lengthwise by a ridge into an upper and a lower part; the upper part looks into the pelvis; the lower part looks into the perineum and gives attachment to the crus of the penis or of the clitoris. The *outer surface* is directed towards the thigh and gives attachment to muscles of the thigh. The *upper border* is the lower boundary of the obturator foramen. The *lower border* can be felt in the boundary between the medial side of the thigh and the anterior part of the perineum. The conjoined rami of the right and left hip-bones constitute the sides of the **pubic arch** which lies below and behind the pubic symphysis.

The **superior ramus**, though named 'ramus', is the true pubic bone. It has two ends, three borders, and three surfaces.

The **ends** are medial and lateral. The **medial end** is wide and compressed, and is described above as the 'body' of the pubis. The **lateral end** is expanded to form part of the acetabulum, and it fuses there with the ilium and the ischium. The *ilio-pubic eminence*, in front of the acetabulum, marks the position of its union with the ilium.

The **borders** are anterior, posterior, and inferior. The *anterior border* is the **pectineal line** [*pecten* = a crest or comb], a sharp edge which begins at or near the pubic tubercle and extends to the upper part of the ilio-pubic eminence. There it is continuous with the lower, smooth part of the medial border of the ilium. The *inferior border* is the **obturator crest**. It is a strong ridge which begins near the pubic tubercle and runs to the acetabulum to end at the anterior part of the gap in its rim. The **posterior border** is seen best from the pelvic side. It is the anterior boundary of the obturator foramen as seen from that aspect.

The **surfaces** of the superior ramus are named pectineal, pelvic, and obturator. The **pectineal surface** is the triangular area between the pectineal line and the obturator crest; the pectineus muscle arises from it. The femoral artery crosses its lateral end, but is separated from the bone by the psoas major muscle. The **pelvic surface** is continuous with the pelvic surface of the body. The **obturator surface** forms the floor of a broad, oblique groove in the anterior boundary of the obturator foramen; through that groove the obturator vessels and nerve pass out of the pelvis into the thigh.

The **acetabulum** is the large, cup-shaped cavity on the lateral side of the hip-bone [*acetabulum* = a vinegar-cup]. It looks not only in a lateral direction, but also forwards and downwards and articulates with the head of the femur to form the *hip joint*. The lower part of its wall is deficient, and the gap is called the **acetabular notch**. The notch is bridged by the *transverse ligament*, a fibrous band which completes the rim. The floor of the acetabulum above the notch shows a large, rough depression called the **acetabular fossa**. The rest of the inside of the cup is smooth and articular. The pubis forms about one-fifth of the acetabulum, the ischium rather more than two-fifths, and the ilium rather less than two-fifths.

The **obturator foramen** is bounded by the ischium and pubis and their rami. It is almost completely closed by the *obturator membrane*, a thin strong membrane from which the foramen gets its name [*obturare* = to close up]. The outer and inner surfaces of the membrane are directed, respectively, towards the thigh and towards the cavity of the pelvis.

Ossification.—From *three* **primary** centres and several secondary centres (Pls. XX, p. 289; XXII, p. 296).

Primary Centre appears for	**Ilium**, above greater sciatic notch, early in 3rd month.	**Ischium**, below acetabulum, in 4th month.	**Pubis**, in superior ramus, in 5th month.

At birth the larger part of each bone is ossified, including a portion of its acetabular end, but a great deal is still cartilage, viz.: upper part of ilium, greater part of acetabulum, lower end of

ischium, medial part of body of pubis, and the conjoined rami. By the tenth year most of the cartilage is ossified, that between the three bones at the *acetabulum* being reduced to a triradiate strip; and the *conjoined rami* are completely ossified and fused together. Secondary centres appear in the acetabulum at twelve and in the other parts at puberty.

Secondary Centre.	Appears at	Epiphysis unites at	Relation of Epiphysial Line to Capsule of Neighbouring Joint.
Two or three for triradiate strip	12th year	17	Inside laterally, outside medially.
One or two for iliac crest including superior spines	Puberty	20-25	None.
For anterior inferior spine	Puberty	20-25	Outside.
For ischial tuberosity	Puberty	20-25	None.
For symphysial part of pubis	Puberty	20-25	No joint cavity.

Occasionally small epiphyses, which appear and fuse at the same times as those in the list above, are present for the ends of the pubic crest and for the ischial spine. The portions ossified from the centres in the acetabulum fuse with the nearest bone; *os acetabuli* is the name given to the part that joins the pubic bone.

Structure and Variations.—The hip-bone is composed of spongy bone enclosed in compact bone. In the centre of the iliac fossa and the floor of the acetabulum the bone is so thin that the spongy substance is absent and the bone is translucent or even, on occasion, defective. The compact bone is thick on the gluteal side of the ilium, and more so at and near the medial border. The whole bone is thickest and strongest above the acetabulum, between it and the auricular surface, for through that part the weight of the trunk is transmitted from the sacrum to the femur. The ischium is wider at its upper end than at its lower end and is widest at the ischial spine. The *nutrient foramina* are scattered.

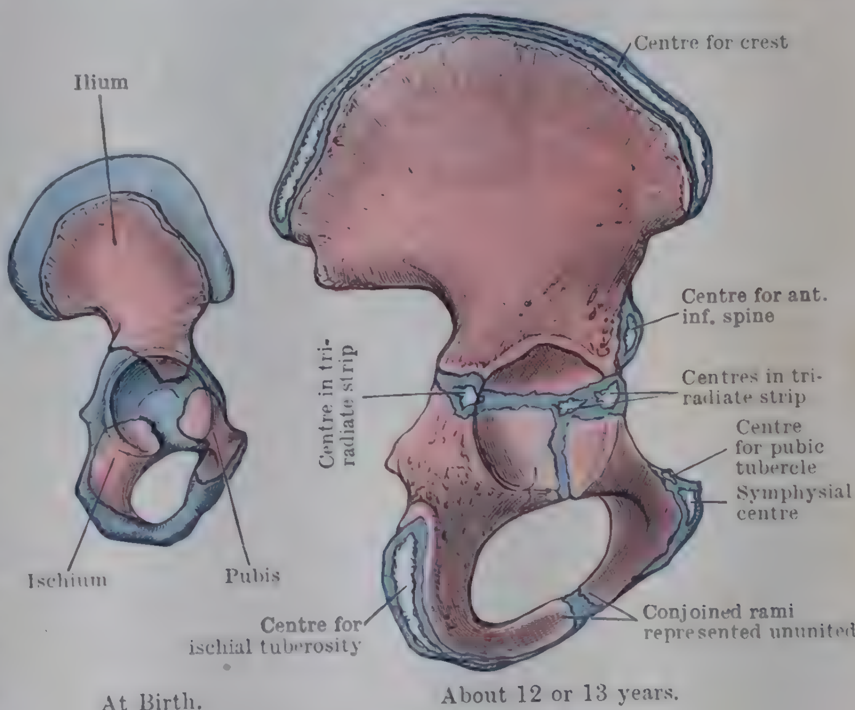


FIG. 250.—OSSIFICATION OF HIP-BONE.

The obturator foramen varies in outline from oval to triangular; and it is relatively wider in women than in men. The **anterior obturator tubercle** is a small spur occasionally present on the posterior border of the superior ramus of the pubis. The **posterior obturator tubercle**, more often present, is a little, rough protuberance on the free edge of the acetabular fossa at or near the junction of the pubis and the ischium. The thickened upper part of the obturator membrane stretches across between the tubercles and converts the groove for the obturator nerve and vessels into the *obturator canal*; in rare cases it is ossified. The *os acetabuli* may remain a separate bone; the acetabular notch may be absent. A separate articular facet may be present above the auricular surface for articulation with a small facet on the back of the sacrum lateral to the first sacral foramen (Derry, 1911*a*). The ischial and pubic rami sometimes fail to unite.

Attachments.—See p. 286.

Pelvis

The **pelvis** is the lower division of the abdomen [*pelvis* = a basin], and its bony framework is also called the pelvis. The bony pelvis is made up of the two hip-bones and the portions of the backbone or vertebral column which are called the

sacrum and the coccyx. The two hip-bones form the sides of the pelvis and its ventral wall, the right and left pubic bones being joined together by the symphysis at the median plane in front; the sacrum and coccyx form its dorsal wall, the sacrum being wedged in between the hip-bones and held in place by strong ligaments, while the coccyx lies below the sacrum between the hip-bones and also is attached to them by ligaments.

The pelvis provides a large surface for the attachment of muscles, especially those which move the lower limb; it contains and protects the urinary bladder, some of the organs of reproduction, and part of the alimentary canal; but the chief use of the bony pelvis is to serve as a firm base for the trunk resting on the thighs. The curved or ring-like construction of the pelvic framework prevents

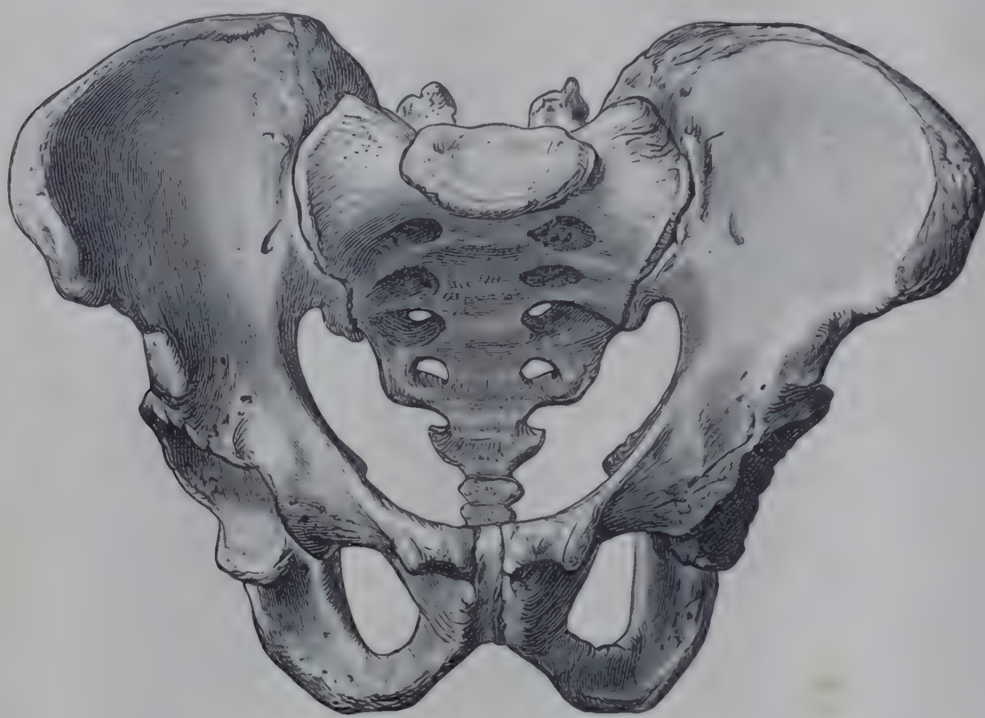


FIG. 251.—MALE PELVIS SEEN FROM IN FRONT.

its collapse under the weight of the body, which is borne at only two points on the framework—where the thigh-bones articulate with the pelvis.

The pelvis does not occupy the position in the body which is suggested by its stance when it is set on a table. Its upper part is tilted forwards, so that when the body is in the erect posture the pubic tubercles and the anterior superior iliac spines are all in one vertical plane, and the tip of the coccyx is on a level with the upper margin of the pubic symphysis. The ventral wall is therefore largely *inferior*, and the dorsal wall is largely *superior*.

A wide interval separates the lower part of the hip-bone from the coccyx and the lower part of the sacrum. The interval is crossed by two fibrous bands, named the *sacro-tuberous* and *sacro-spinous ligaments*, which are preserved in many prepared skeletons. The **sacro-tuberous ligament** is a long, strong band which stretches from the sacrum and coccyx to the ischial tuberosity. The **sacro-spinous ligament** is a shorter, flatter band that stretches across the pelvic surface of the sacro-tuberous ligament from the sacrum and coccyx to the ischial spine. Those two ligaments convert the sciatic notches of the hip-bone into the **greater** and **lesser sciatic foramina**, through which muscles, nerves, and vessels pass between the pelvis and the gluteal region. The dissector of the lower limb encounters both the ligaments and the foramina during the dissection of the gluteal region. (See Figs. 334, 335, pp. 374, 376, in the Section on Joints.)

The **pubic arch** is the arch formed by the conjoined rami of ischium and pubis of the two sides. The apex of the arch is the posterior end of the pubic symphysis. The archway is to a large extent filled in by the *perineal membrane*, a fibrous sheet which is comparable to the obturator membrane.

The bony pelvis as a whole is divisible into two parts—false and true. The **false pelvis** is the upper part; it is the skeleton of the lower part of the abdomen proper, and it bounds the iliac fossæ.

The **true pelvis** is more important. When reference is made to "the pelvis" in the description of muscles, viscera, etc., it is usually the true pelvis only that is meant. The bones that enclose it are the sacrum and coccyx and the lower half of the hip-bone—the pubis, the ischium, and the lower part of the sacro-pelvic surface of the ilium.

The **cavity** of the true pelvis is a short, wide canal or tunnel which is curved in general conformity with the curve of the sacrum and coccyx; in length it measures five or six inches along the sacrum and coccyx, but only one and a half or two inches along the pubic symphysis. The cavity is continuous with that of the abdomen proper at the **inlet** of the pelvis. The inlet looks forwards and slightly upwards, and its boundary is the **brim** of the pelvis. The brim is formed by the

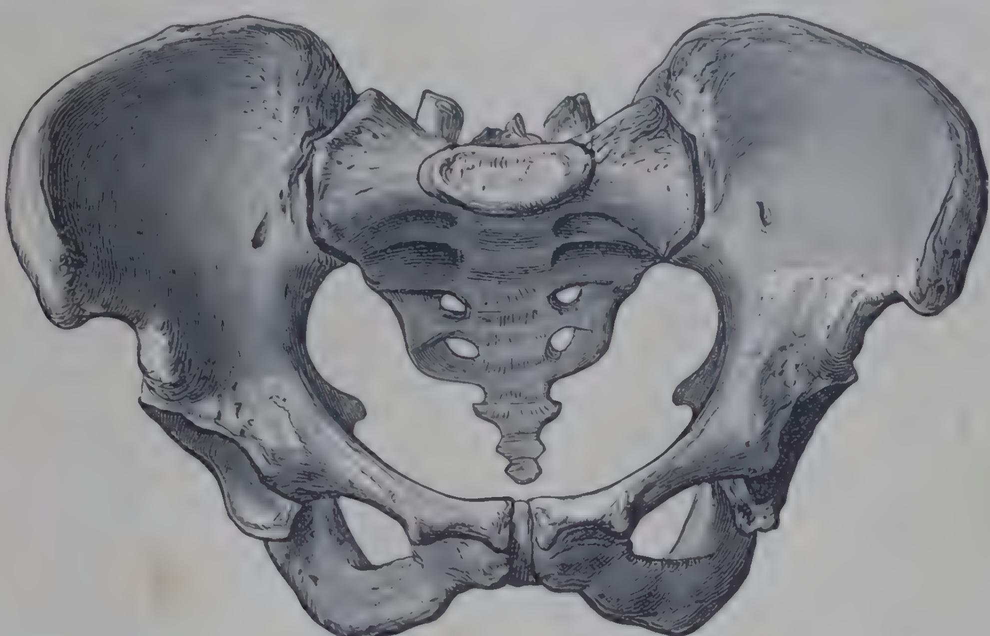


FIG. 252.—FEMALE PELVIS SEEN FROM IN FRONT.

arcuate lines, a pair of curved bony edges divided into sacral, iliac, and pubic parts. The *sacral part* of the arcuate line is the sacral promontory and the lower margin of the ala; the *iliac part* is the lower half of the medial border of the ilium; the *pubic part* is the pectineal line and the pubic crest and symphysis. The **outlet** is *bounded* by: (1) the coccyx in the median plane *behind*; (2) the pubic symphysis in the median plane *in front*; and, *on each side* from behind forwards, (3) the sacro-tuberous ligament, (4) the lower end of the ischium, and (5) the side of the pubic arch. These are also the boundaries of the *perineum*, which is shut off from the cavity of the pelvis by (1) a sheet of muscle, called the sphincter urethræ, that lies in the pubic archway on the upper surface of the perineal membrane; and (2) a pair of thin, curved sheets of muscle, the levatores ani, which are placed farther back—between the ischia.

Planes and Axes of the Pelvis.—The **plane of the inlet** forms an angle of about 60° with the horizontal. The **plane of the outlet** forms an angle of only 10° to 15° with the horizontal, because the symphysis is much shorter than the sacrum and coccyx. The **planes of the cavity** are a plane that passes through the middle of the third sacral vertebra and the middle of the pubic symphysis, and any number of planes set between that plane and those of the inlet and outlet. The **axis of the inlet** is a line drawn at right angles to the centre of its plane; the line, if continued, would pass through the umbilicus and through the tip of the coccyx. The **axis of the outlet** is a line drawn at right angles to the centre of its plane; if continued upwards the line would strike the sacral promontory. The **axis of the pelvis** is a line drawn through the centres of all the planes; it is therefore nearly parallel to the curve of the sacrum and coccyx.

Diameters of the Pelvis.—The **intercristal diameter** is the distance between the outer lips of the two iliac crests where they are farthest apart. The **interspinous diameter** is the distance between the two anterior superior iliac spines. The **external antero-posterior diameter**

is the distance between the first sacral spine and the anterior (upper) margin of the pubic symphysis. Those three diameters are usually slightly greater in a man than in a woman.

The **diameters of the true pelvis** are of more importance.

Diameters of Inlet.—*Antero-posterior* or conjugate: from the middle of the sacral promontory to the anterior (upper) margin of the symphysis. *Transverse*: across the inlet where it is widest. *Oblique*: from one sacro-iliac joint to the ilio-pubic eminence of the other side.

Diameters of Cavity.—*Antero-posterior*: from the centre of the pelvic surface of the middle piece of the sacrum to the middle of the pelvic surface of the pubic symphysis. *Transverse*: across the cavity where it is widest. *Oblique*: from the posterior end of one sacro-iliac joint to the centre of the obturator membrane of the other side.

Diameters of Outlet.—*Antero-posterior*: from the tip of the coccyx to the posterior (lower) margin of the pubic symphysis; it varies in the same pelvis, especially in the female, owing to the mobility of the coccyx. *Transverse*: between the ischial tuberosities. *Oblique*: from the point where the sacro-tuberous and sacro-spinous ligaments cross each other to the junction of the pubic and ischial rami of the other side.

All the diameters of the true pelvis are longer in a woman than in a man. Measurements vary in individuals of the same sex. In the following table the figures are average measurements in millimetres as given by Bryce (1915). The source of his material is not mentioned; and the figures for the female pelvis differ slightly from those given in standard obstetrical text-books.

	Female.			Male.		
Intercristal . . .	279			286		
Interspinous . . .	250			241		
External antero-posterior	180			184		
True Pelvis.	Inlet.	Cavity.	Outlet.	Inlet.	Cavity.	Outlet.
Antero-posterior . .	114	127	108	102	108	85
Transverse . . .	133	127	121	127	121	88
Oblique	127	140	114	121	114	102

More recent measurements have been made by Nicholson (1943, 1945) by stereometric radiography of 640 living subjects. They also are open to the same criticism, but in the opposite sense, in that the patients measured were a selected group, all being primigravidae. The results, however, indicate the pelvic capacity in living subjects at a time when such measurements are important.

Nicholson measured the obstetrical conjugate, which is about 5 mm. less than the anatomical, or true, conjugate, and the transverse diameter of the inlet of the pelvis. Yearly averages over seven years ranged from 118·1 mm. to 121·6 mm. for the *antero-posterior* (conjugate) measurement; but the yearly averages for the previous three years were significantly lower, 114·2 mm. to 115·4 mm., leading to the suggestion that malnutrition (during the 1914–1918 war) might have affected growth and the length of the conjugate. Yearly averages for the *transverse diameter* did not appear to be affected in this way, the figures ranging from 130·2 mm. to 133·3 mm. for the 7-year period and from 130·5 mm. to 133·3 mm. for the preceding years.

The above figures indicate that pelvic measurements not only vary between selected groups but may vary within a more or less homogeneous group as a result of external conditions. Shrinkage of macerated specimens also has to be taken into account when making comparisons.

Sexual Differences.—The pelvis of a woman differs from that of a man in many particulars, because the female pelvis is modified for the function of child-bearing. Distinctive sex-characters are present in the fœtal pelvis—appearing as early as the third or the fourth month of intra-uterine life (Fehling, 1876, quoted by Thompson, 1899). They are less marked in childhood; they become fully developed after puberty. The essential differences between male and female pelves are in the true pelvis. In the female it is absolutely wider in all the diameters; this is especially marked in those of the outlet, and the cavity is therefore less funnel-shaped. But the cavity is shorter. Nearly all the differences in detail are due to the fact that the cavity of the **true pelvis** in the **female** is *roomier*, *less funnel-shaped*, and *shorter*.

When a series of pelves is examined it may be surprisingly difficult to find samples which are female in all respects and pelves are often found which are intermediate in most characters or which are, for example, female in type anteriorly but show male characters posteriorly. It is

advisable to know what types of pelvis to expect and the significance of the features found, especially those which can be detected in the living subject.

In the normal female pelvis the subpubic arch is wide (about 90°) with a rounded apex and can be represented fairly well by the angle between outstretched thumb and forefinger; the depth from the pectineal line to ischial tuberosity averages 90 mm., or $3\frac{1}{2}$ inches. In the male the angle is narrow and pointed and can be represented by the angle between outstretched index and middle finger. (Cf. pls. XIX and XX, p. 288.) The depth is greater, averaging 101 mm., or 4 inches. A wide intertubercular measurement or a shallow pelvis will automatically increase the slope of the ramus and produce a wide subpubic angle. A slender ramus set at the lateral side of a pubic body which has been widened by growth at the pubic symphysis will cause a wide rounded apex to the subpubic angle. The subpubic angle, then, indicates the form of the ischio-pubic part of the pelvis and, in particular, a narrow angle means side-walls converging towards the outlet. A wide angle indicates a female type of fore-pelvis but in practice it is not a reliable indication of the size of the pelvic cavity.

In the female the great sciatic notch is wide (about 90°); in a heavy male pelvis its outline resembles a hairpin bend. Heavy bone and an extensive sacro-iliac articulation tend to depress the posterior part of the upper margin of the notch and the posterior inferior iliac spine, and a sacrum with its lower end tilted in has a similar effect on the margin of the notch. A wide angle then indicates a roomy posterior part of the pelvis, a narrow angle indicates a long narrow pelvis.

In the female the space between the spine of the ischium and the sacrum should accommodate three fingers with ease; in the male the distance is about two finger-breadths indicating a short sacro-spinous ligament and a spine which projects into the cavity. For further information on this subject and its clinical applications see Caldwell & Moloy (1933) and Caldwell, Moloy & D'Esopo (1934; 1935).

Apart from severe pathological conditions, the normal mechanics of the pelvis may produce a further variant if there has been slight abnormal softening of the bone. Since the body-weight tends to thrust the sacrum down into the pelvis, it produces a pull on the posterior sacro-iliac ligament. This in turn pulls the posterior part of the iliac crest medially and, using the ala of the sacrum as a fulcrum, levers out the side wall of the pelvis to put the fore-part of the pelvic wall under tension. If this yields, its curve will straighten out to produce a flat pelvis with a reduced antero-posterior diameter while, at the same time, widening the measurement between the anterior superior spines of the iliac crest and reducing the difference between it and the intertubercular measurement of the crest.

The differences in detail are very numerous. The chief of them are that **in the female**:—The bones are lighter and thinner, and muscular markings are less evident. The *ilium* is less everted and the *iliac fossa* is shallower. The **inlet** is larger and is kidney-shaped rather than heart-shaped; its *plane* forms a wider angle with the horizontal, for the tilt of the pelvis is greater (the anterior superior iliac spines being even farther forward than the pubic tubercles); the *sacral promontory* projects less, and the *pubic tubercles* are wider apart. The **cavity** is less funnel-shaped, is shorter, but is much roomier. The *sacrum* is shorter and wider, and its curve is less uniform—being flatter above and more sharply turned forwards below—and each ala nearly equals the first sacral body in width. The **outlet** is much larger. The *coccyx* is more movable. The *ischial spine* is less inturned. The *obturator foramen* is smaller and may be triangular in outline rather than oval. The *acetabula* are farther apart and are smaller, especially relatively, for the head of the femur is smaller in a woman while the hip-bone is larger, so that the width of the acetabulum is about an inch less than the distance of its anterior border from the symphysis. A pre-auricular sulcus is present immediately in front of the convex margin of the auricular surface of the ilium (Derry, 1911*b*).

Growth of the Pelvis.—At birth, in both sexes, the pelvis is relatively small; the ilium is relatively narrow and is more upright than in the adult; the iliac fossa is shallower and looks more forwards. The pubic arch is more acute, the ischia are closer together, and the cavity is consequently more funnel-shaped. The sacrum is narrow, more upright and less curved, and its promontory projects less. The lower limbs also are relatively small—being only about a quarter of the length of the body. After birth the lower limbs grow much more rapidly than the rest of the body, especially after the first year when the child begins to learn to walk. The whole pelvis keeps pace with the lower limbs; it gives origin to a great number of the muscles that move the limbs, and grows concurrently with them to provide them with adequate attachments. At birth the true pelvis is not big enough to hold the pelvic organs; the greater part of the urinary bladder and, in the female, the uterus and ovaries are in the abdomen proper. By the sixth year the pelvis has grown large enough to contain the greater part of them, but the pelvic organs are not wholly pelvic in position till puberty. The rate and manner of growth are similar in boys and girls till puberty, when the growth is modified to produce the distinctive sex-characters of the adult pelvis. Such growth will take place at the cartilaginous surfaces of the bones where they join in the acetabulum, at the sacro-iliac joint and symphysis pubis and between the pubic and ischial rami. In addition, absorption and accretion on the surfaces will produce modelling of the bone such as is required to maintain its proper strength and shape (Payton, 1935).

Besides mere relative increase of size, there are other changes in the pelvis when the child, learning to walk, straightens out the lower limbs and adopts the erect attitude. The principal changes are: (1) The upper part of the pelvis is tilted forwards so that the sacro-vertebral angle becomes less obtuse. (2) The basal part of the sacrum, now bearing the weight of the trunk

obliquely, sinks more deeply between the two hip-bones, and that further accentuates the sacro-vertebral angle. (3) The sacrum becomes more curved also, for, while the weight of the trunk bends the basal part downwards, the apical part is held down and prevented from tilting up by the sacro-tuberous and sacro-spinous ligaments. (4) At the same time the hip-bone, where it bounds the true pelvis, becomes curved outwards, and thus the true pelvis is widened; for those parts of the two hip-bones, at that time, resemble the limbs of the letter V, the apex being at the symphysis; the sacrum lies between the upper ends of the limbs of the V, and the weight of the trunk is transmitted to them through the sacrum; they are fastened to the sacrum at their upper ends and to each other at the apex, *i.e.*, at the symphysis, and therefore, under the weight of the trunk, have to bend outwards in the middle. (5) The acetabulum (which is relatively shallower at birth than it is at the sixth month of intra-uterine life) becomes deeper to make the hip joint more stable, especially after the third year, when the child begins to run about more actively and to jump. (6) The part of the ilium between the acetabulum and the auricular surface, which transmits the weight of the trunk from sacrum to femur, grows stronger, and in consequence of its growth the iliac part of the arcuate line becomes better defined.

Attachments.—(A) **Of Structures encountered in the Dissection of Lower Limb.**—The lateral end of the inguinal ligament is attached to the **anterior superior iliac spine**. The sartorius arises from that spine and from part of the notch below; the tensor fasciæ latæ from the spine and the adjoining two inches of the outer lip of the **iliac crest**. The lateral part of the fascia lata is attached to the whole length of the outer lip of the crest, its ilio-tibial tract being attached to the **tubercle of the crest**; the ilio-femoral ligament to the lower part of the **anterior inferior spine**; the straight head of the rectus femoris from its upper part; the reflected head from the rough depression on the **gluteal surface** immediately above the acetabulum; the gluteus minimus from the area between the *inferior* and *middle gluteal lines*; the gluteus medius from the area between the *middle* and *posterior gluteal lines*; the gluteus maximus from the upper, rough part of the area behind the *posterior line* and from the *back* of the **sacrum** and *sacro-tuberous ligament*; the iliacus from the floor of the **iliac fossa**; the piriformis from the *pelvic surface* of the middle three pieces of the **sacrum**, and from the upper margin of the **greater sciatic notch** and the sacro-tuberous ligament as the muscle emerges from the pelvis through the *greater sciatic foramen*; the obturator internus from the side-wall of the cavity of the pelvis, viz., the inner surface of the **obturator membrane**, the bone around the obturator foramen, especially the wide, flat area between the foramen and the greater sciatic notch, and the fibres converge on the tendon, which leaves the pelvis through the *lesser sciatic foramen*; the superior gemellus from the **ischial spine** where it forms the upper boundary of the lesser sciatic foramen; the inferior gemellus from the **ischial tuberosity** where it forms the lower boundary. The sacro-spinous ligament stretches from the tip of the *ischial spine* to the side of the last piece of the *sacrum* and first piece of the *coccyx*. The sacro-tuberous ligament covers the dorsal surface of the medial and larger part of the sacro-spinous ligament; its upper end widens out to be attached to the side of the *coccyx* and *sacrum* and to the **posterior superior** and **posterior inferior iliac spine**; its lower end widens out to be attached to the medial margin and lower medial area of the **ischial tuberosity**, and it sends a prolongation, called its *falciform process*, forwards along the inner surface of the *ischial ramus*. The quadratus femoris arises from the *lateral margin* of the **ischial tuberosity**. The surface of the tuberosity is divided by a transverse line into an upper and a lower part, and each of those is divided into a lateral and a medial part. The tendon of the semimembranosus arises from the *upper lateral* area; the tendons of the semitendinosus and the long head of the biceps conjointly from the *upper medial* area; the adductor magnus muscle from the *lower lateral* area and from the lower part of the outer surface of the *conjoined rami*, the sacro-tuberous ligament being attached to the *lower medial* area.

The medial end of the inguinal ligament is attached to the **pubic tubercle**, and its pectineal part to the medial inch of the **pectineal line**. The pectineus muscle arises from the *pectineal line* and *pectineal surface* of the **pubis**; the tendon of the adductor longus from the *femoral surface* of the body of the pubis in the angle between the crest and the symphysis; the gracilis muscle from the margin of the *symphysis* and of the **inferior ramus**; the adductor brevis muscle from a broad strip lateral to the gracilis and below the adductor longus; the obturator externus muscle from the area below and in front of the obturator foramen and from the adjoining half of the **obturator membrane**, and as it winds backwards below the neck of the femur the deeper part of it lies in the wide groove below the acetabulum.

The fascia lata has a continuous attachment to the inguinal ligament, the lower lip of the pubic crest, the margin of the pubic symphysis, the lower margin of the conjoined rami, the medial margin of the ischial tuberosity, the medial margin of the sacro-tuberous ligament, the back of the sacrum and coccyx, and the whole length of the outer lip of the iliac crest.

The transverse ligament bridges across the *acetabular notch* and completes the rim of the acetabulum. The ligament of the head of the femur spreads out to be attached to the transverse ligament and the margins of the **acetabular notch** and **fossa**. A fibro-cartilaginous ring, called the labrum acetabulare, is attached to the *rim* and serves to deepen the cavity of the acetabulum and narrow its mouth. The capsular ligament of the hip joint is attached to the labrum below and in front, to the bony rim above and behind, and to the rough strip above the acetabulum. The thickened parts of the capsule are attached as follows: the ilio-femoral ligament to the lower part of the *anterior inferior iliac spine*; the pubo-femoral ligament to the lateral end of the *obturator crest*; the ischio-femoral ligament to the *ischium* below the acetabulum.

(B) **Of Structures encountered in the Dissection of other Parts.**—The iliacus arises

from the upper and larger part of the floor of the **iliac fossa**. The fascia iliaca and part of the transversalis fascia are continuous with each other at the *inner lip* of the **iliac crest** above the iliac fossa and are loosely attached to that part of the lip. Part of the transversus abdominis arises from the anterior half of the inner lip; part of the quadratus lumborum from the inner lip immediately behind the transversus, above the posterior part of the iliac fossa; a slip of the latissimus

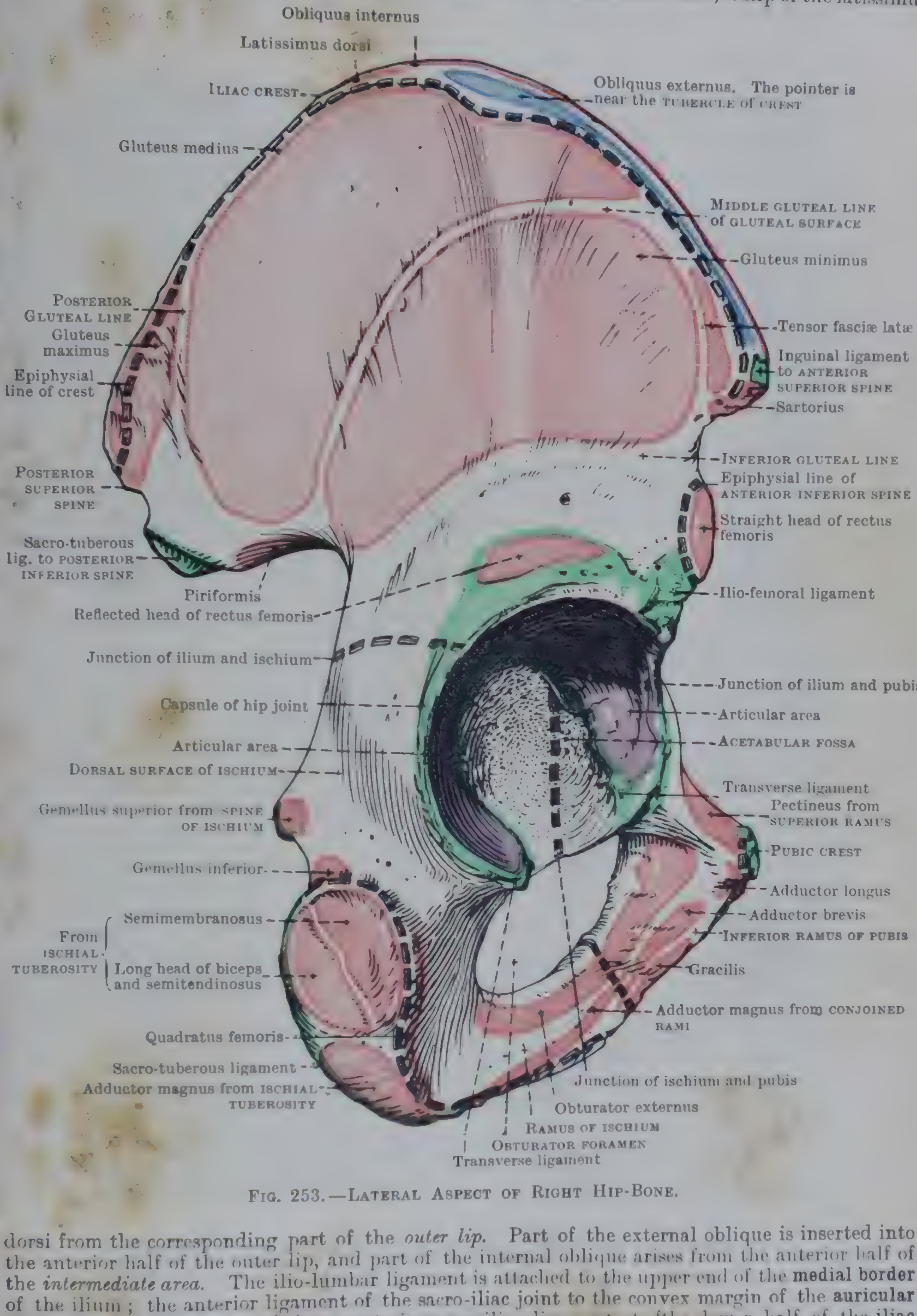


FIG. 253.—LATERAL ASPECT OF RIGHT HIP-BONE.

dorsi from the corresponding part of the *outer lip*. Part of the external oblique is inserted into the anterior half of the outer lip, and part of the internal oblique arises from the anterior half of the *intermediate area*. The ilio-lumbar ligament is attached to the upper end of the **medial border** of the ilium; the anterior ligament of the sacro-iliac joint to the convex margin of the **auricular surface**; the interosseous and short posterior sacro-iliac ligaments to the lower half of the **iliac tuberosity**; the lower part of the sacro-spinalis arises from the upper half, and from the back of the *sacrum*. The long posterior **sacro-iliac ligament** stretches from the **posterior superior iliac spine** to the side of the back of the sacrum half-way down; the sacro-tuberous ligament stretches from both *posterior spines* and from the side of the sacrum and coccyx to the lower part of the **ischial tuberosity** and the *ischial ramus*. The **sacro-spinous ligament** stretches from the tip of the ischial

spine, across the pelvic surface of the sacro-tuberous ligament, to the side of the last piece of the sacrum and the first piece of the coccyx ; the coccygeus muscle lies on the front of the sacro-spinous ligament and has the same attachments—the ligament being merely the degenerated dorsal fibres of the muscle. The piriformis muscle arises from the *pelvic surface* of the second, third, and fourth pieces of the **sacrum**, from the upper margin of the *greater sciatic notch*, and from the sacro-tuberous ligament ; the obturator internus from the side-wall of the pelvic cavity ; the

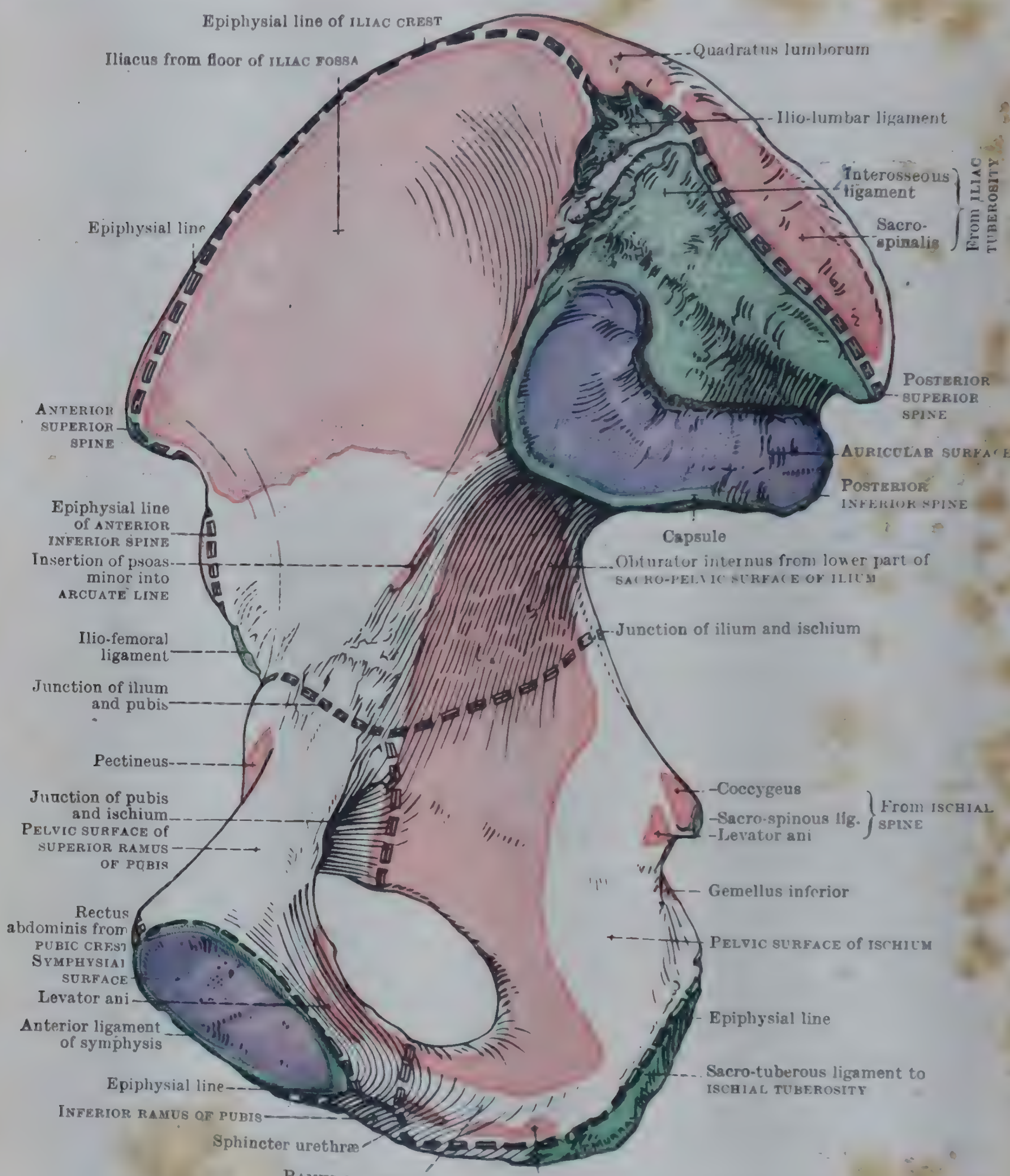


FIG. 254.—MEDIAL ASPECT OF RIGHT HIP-BONE.

posterior fibres of the levator ani from the *ischial spine*, its anterior fibres from the *pelvic surface* of the **body of the pubis** below its middle, and the rest of the muscle from the fascia that covers the obturator internus. The pubo-prostatic ligaments are attached to the pubis above the levator ani.

The cartilage of the pubic symphysis is attached to the **symphysial surface** ; the superior, anterior, posterior, and inferior pubic ligaments to the *margins* of that surface, and the inferior ligament curves backwards on to the inferior pubic ramus.

Part of the fascia transversalis is attached to the upper lip of the **pubic crest** and to the medial half of the **pectineal line**. The rectus abdominis arises from the crest below the fascia and from the anterior pubic ligament ; the pyramidalis from the crest below the rectus. The conjoint tendon is attached to the anterior ligament of the *symphysis* below the rectus, to the

PLATE XIX.—RADIOGRAPH OF DRIED MALE PELVIS (MAN AGED 22).

Compare with Fig. 251, p. 282, and with radiograph of Female Pelvis, Plate XX, noting the differences in proportion of the Pelvis as **a whole and in the form of the Pubic Arch and the Inlet of the True Pelvis.**

PLATE XX

PLATE XX.—RADIOGRAPH OF LIVING FEMALE PELVIS (GIRL AGED 17).
(Dr. J. Duncan White.)

[Facin

crest below the pyramidalis, and to the *pectineal line* below the fascia transversalis; the lower medial part of the external oblique aponeurosis to the lower lip of the pubic crest and to the anterior ligament of the pubis below the conjoint tendon (Fig. 391, p. 460).

The inguinal ligament stretches from the anterior superior iliac spine to the pubic tubercle and, by means of its pectineal part, to the medial inch of the *pectineal line* below the conjoint tendon. One end of the loops of the cremaster muscle is attached to the pubic tubercle behind the inguinal ligament. The tendon of the psoas minor is inserted partly into the arcuate line and iliopubic eminence.

The membranous layer of the superficial fascia of the perineum is attached to the lower margin of the **ischial ramus**. The crus penis or crus clitoridis is attached to the lower half of the *inner surface* of the **conjoined rami**, the lower half usually being grooved lengthwise for the lodgment of the crus. The ischio-cavernosus and superficial transversus perinei arise from the posterior end of the groove. The deep transversus and sphincter urethrae are attached to the ridge between the upper and lower halves of the surface. The same ridge gives attachment to fibrous structures:—(1) the perineal membrane immediately below these muscles; (2) the falciform process of the sacro-tuberous ligament and the prolongation of the inferior pubic ligament immediately above the muscles. Fibres of the obturator internus arise from the upper half of the surface, *i.e.*, the strip between the ridge and the obturator foramen, and the fascia that covers that muscle blends with the falciform process.

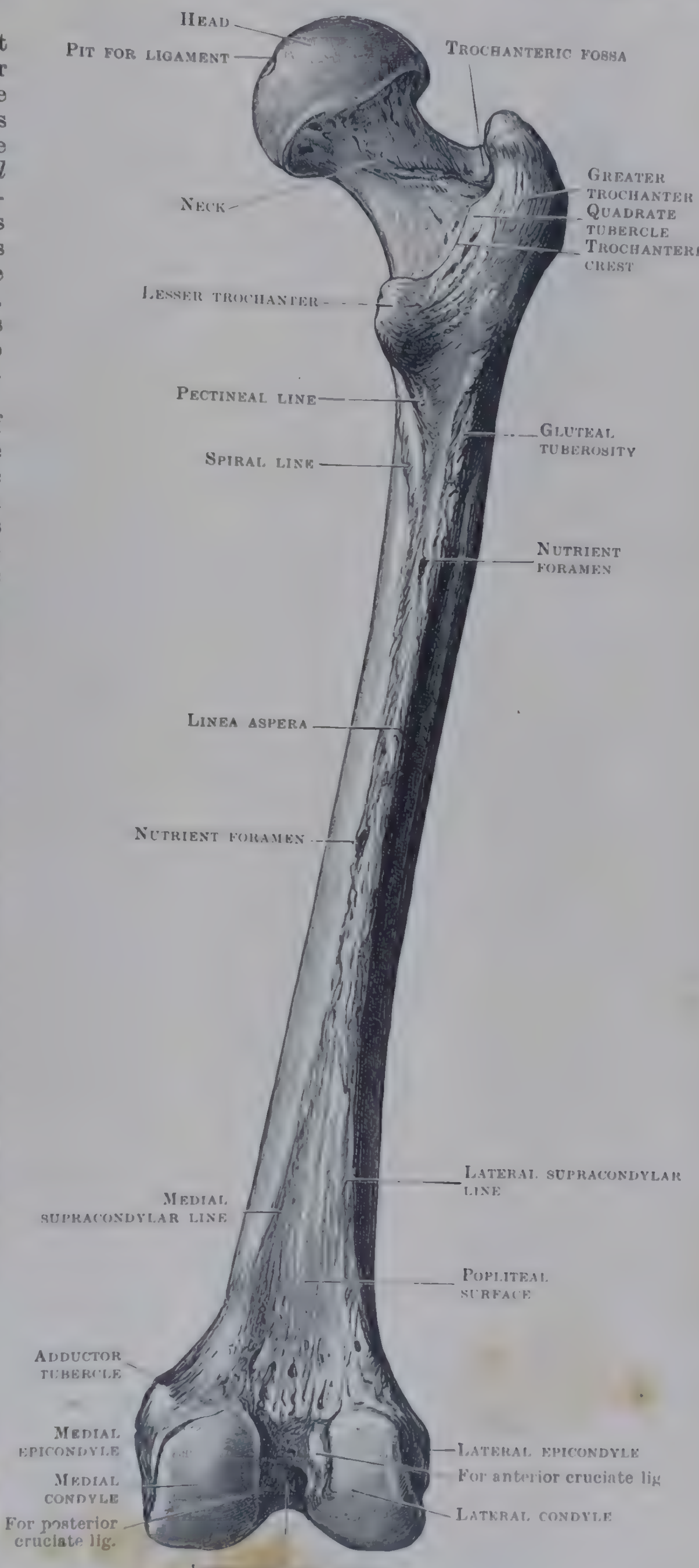


Fig. 255.—Right Femur seen from Behind.

Femur

The **femur** or thigh-bone is the longest and strongest and heaviest bone in the skeleton, and is between a third and a fourth of the length of the body. It has a **shaft** and **two ends**. It is so thickly covered with muscles that, in the living body, it can be palpated only at and near the ends. The beginner should at once proceed to distinguish the upper

end from the lower end, the front of the bone from the back, and the medial side from the lateral side. The larger end of the bone is the **lower end,** and it is partially divided into two, the wide notch between the two parts being on the **posterior** aspect; the globular head at the upper end is on the **medial** side.

Fig. 256.—Right Femur seen from in Front.

The **upper end** includes the head, the neck, the greater trochanter and the lesser trochanter.

The **head** is smooth and is about two-thirds of a sphere. It fits into the acetabulum to form the *hip joint.* On its medial aspect there is a rough, shallow pit for the apex of a triangular fibrous band.

The **neck** is the thick bar that connects the head with the shaft in the region of the trochanters. It is nearly two inches long, is narrowest in the middle and widens towards each end, especially the end which joins the shaft, and the lower border is therefore more oblique than the upper. The neck joins the shaft at an angle and is therefore liable to be broken; but a long neck joined to the shaft at an angle enables the femur to be moved freely and extensively, even though the head is deeply and stably socketed in the side of the pelvis.

The **greater trochanter** is the large, square prominence on the lateral side where the neck joins the shaft; its upper part stands up above the level of the adjacent part of the neck; its root is marked off from the shaft by a more or less horizontal ridge. It is the bone felt in front of

the hollow on the side of the hip, and the body falls on it in a fall sideways; its upper border is at the level of the upper border of the pubic symphysis and the centre of the hip joint. Many of the muscles of the gluteal region are inserted into the greater trochanter [τροχαντήρ (trochantēr) = a runner]. The rough pit on the medial side of the trochanter, where it joins the back of the neck, is the **trochanteric fossa.**

The **lesser trochanter** is the rounded, conical projection on the postero-medial aspect of the bone where the lower part of the neck joins the shaft.

The ridge that connects the lesser trochanter with the back of the greater trochanter is the **trochanteric crest.** The low, rounded swelling on or alongside the crest, on the back of the trochanter major, is called the **quadrate tubercle** because part of the quadratus femoris muscle is inserted into it. The **trochanteric line** is the rough, broad line which extends from the upper part of the front of the greater trochanter towards the lesser trochanter and marks the union of the front of the neck with the front of the shaft; it does not reach the lesser trochanter but becomes continuous with a faint *spiral line*, which winds to the back of the bone below the lesser trochanter.

The **lower end** of the femur is made up of two large masses called *condyles*, separated posteriorly by a wide, deep interval called the *intercondylar notch.*

Anteriorly the **condyles** are nearly in line with the front of the shaft, but they bulge backwards considerably beyond the shaft. The anterior, lower, and posterior surfaces of each condyle are confluent, smooth, and articular. The *anterior parts* of the two are joined together, forming a wide surface for articulation with the patella. This **patellar surface** is deeply concave from side to side and slightly convex from above downwards; its lateral part is more prominent than the medial and extends farther up, and the upper margin of the surface is therefore sloping. The tibia articulates with the *lower surfaces* when the knee is extended, and with the

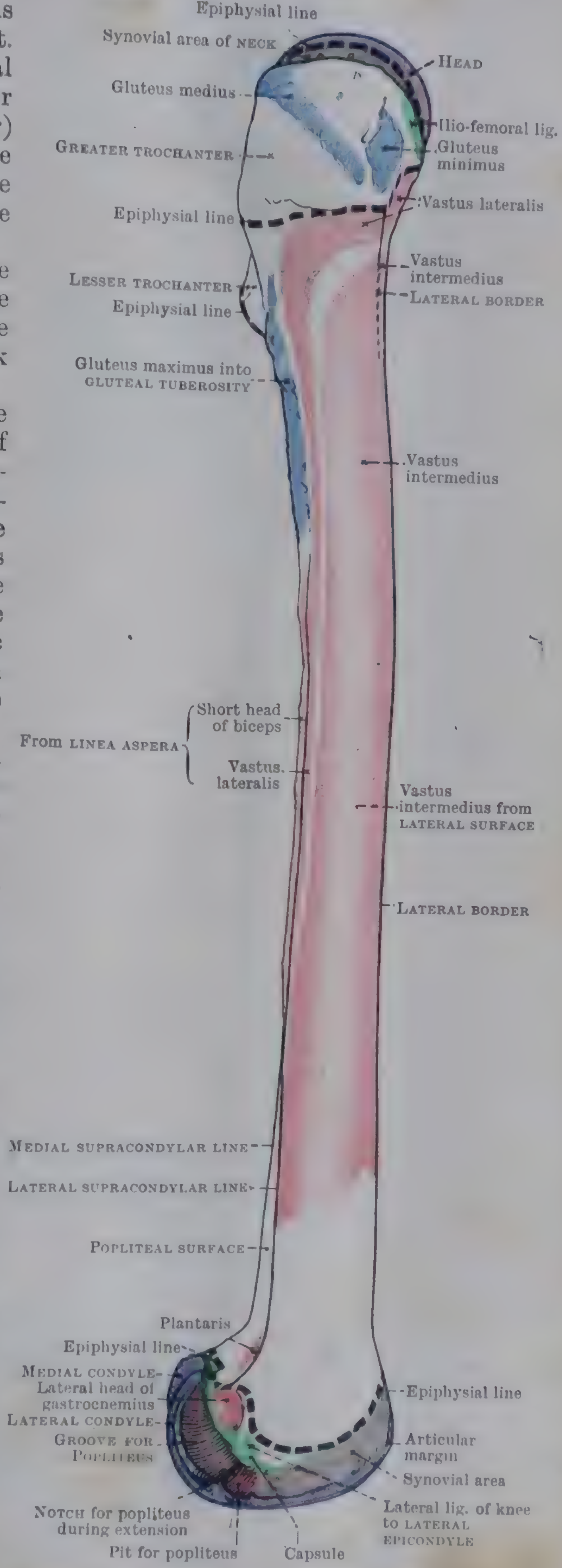


FIG. 257.—LATERAL ASPECT OF RIGHT FEMUR.

posterior surfaces when the knee is flexed. The surfaces that form the sides of the intercondylar notch are rough for the attachment of the cruciate ligaments, which lie between the condyles and hold the femur and tibia together.

On the *lateral surface* of the **lateral condyle** there is a prominence, called the *lateral epicondyle* —much nearer the back of the bone than the front. Above the epicondyle there is a pit or impression for the origin of the lateral head of the gastrocnemius muscle which forms the superficial part of the fleshy mass of the calf. Below the epicondyle there is a pit for the origin of the tendon of the popliteus muscle; a groove, in which the tendon lies when the knee is acutely flexed, runs upwards and backwards from the pit close alongside the articular margin.

The **medial condyle** stands farther away from the shaft than the lateral condyle does. Its medial surface is rough and convex and its most prominent part is the *medial epicondyle*. On the uppermost part of the condyle there is a small, sharp prominence, called the **adductor tubercle** because the tendon of the adductor magnus is inserted into it.

The condyles can be felt as large prominences at the sides of the knee; the adductor tubercle can be felt at the uppermost part of the medial condyle, and is often used as a landmark; if the knee is bent to a right angle, the tendon of the adductor magnus can usually be felt as it descends to the tubercle (but it is not the only tendon that can be felt at the medial side of the knee). When the knee is flexed, the patellar surface of the femur can be felt (or, at any rate, its lateral and medial margins), for the patella is drawn off it when the knee is bent; and a portion of the distal surface of each condyle can be felt at the side of the *ligamentum patellæ*—which is the thick, broad band felt between the patella and the tibia.

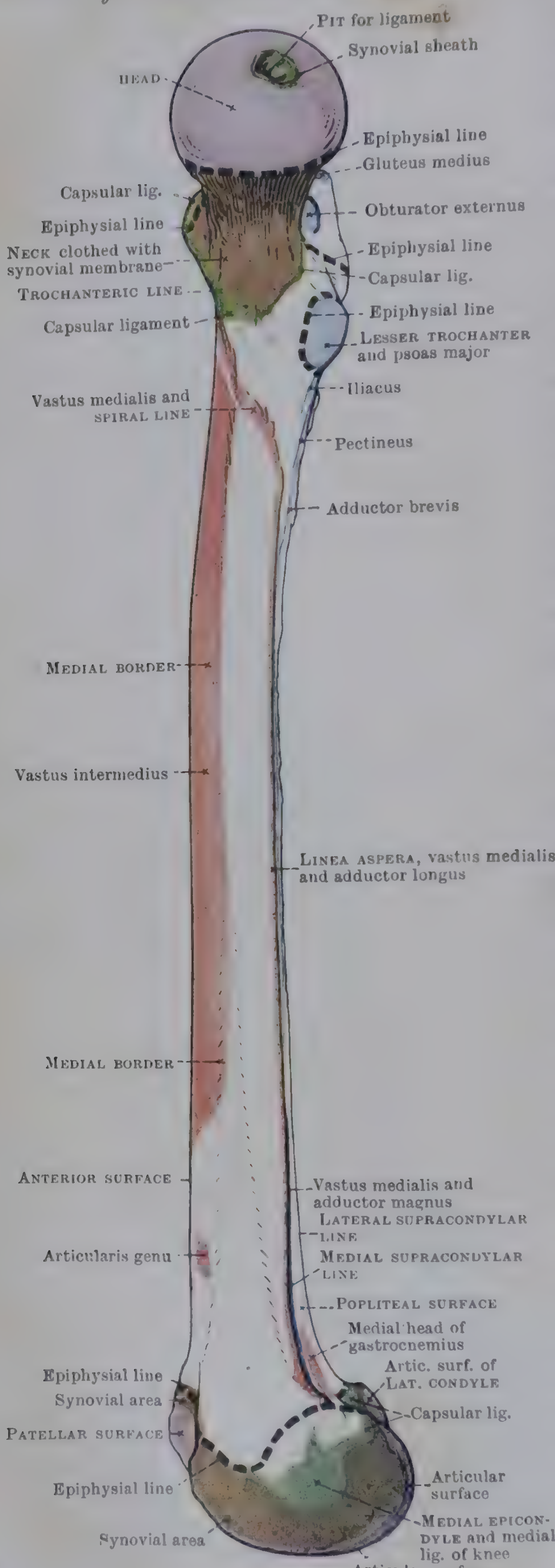


Fig. 258.—Medial Aspect of Right Femur.

The **shaft** is thinnest in its middle third and widens sideways towards each end, especially the lower end.

The **middle third** has three surfaces and three borders. The *surfaces* are anterior, medial, and lateral; the *borders* are posterior, lateral, and medial.

The *lateral* and *medial borders* are blunt and ill-defined, so that the *anterior surface* is not sharply marked off from the *lateral* and *medial surfaces*; but the *posterior border*, or linea aspera, which separates the medial surface from the lateral surface, is well-defined.

The **linea aspera** is the rough ridge on the back of the femur, limited to the middle

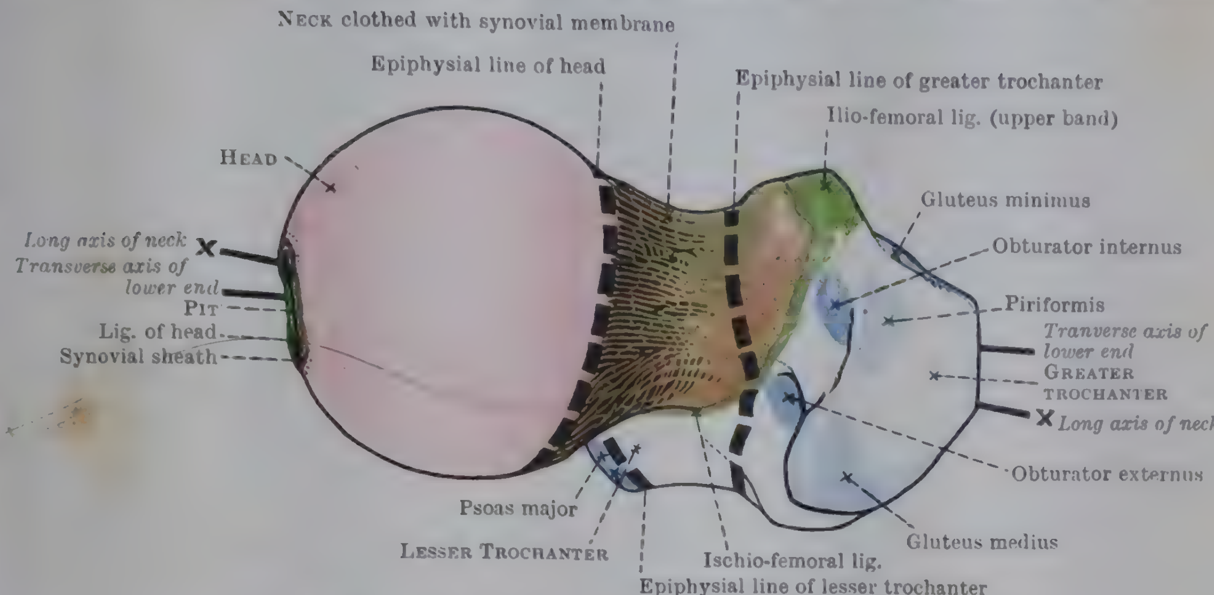


FIG. 259.—UPPER ASPECT OF UPPER END OF RIGHT FEMUR.

third of the bone. Its margins are called its *lips—lateral* and *medial*; the lateral lip is the sharper and better defined of the two. At the upper and lower ends of the linea aspera the lips diverge from each other and become continuous with ridges, bearing different names, on the upper and lower thirds of the femur.

At the **upper third** the *medial* lip becomes continuous with the **spiral line**, which winds obliquely round the medial side of the femur on to the front of the bone and becomes continuous with the trochanteric line. The *lateral* lip becomes continuous with a long, broad, rough mark, the **gluteal tuberosity**, which is situated on the back

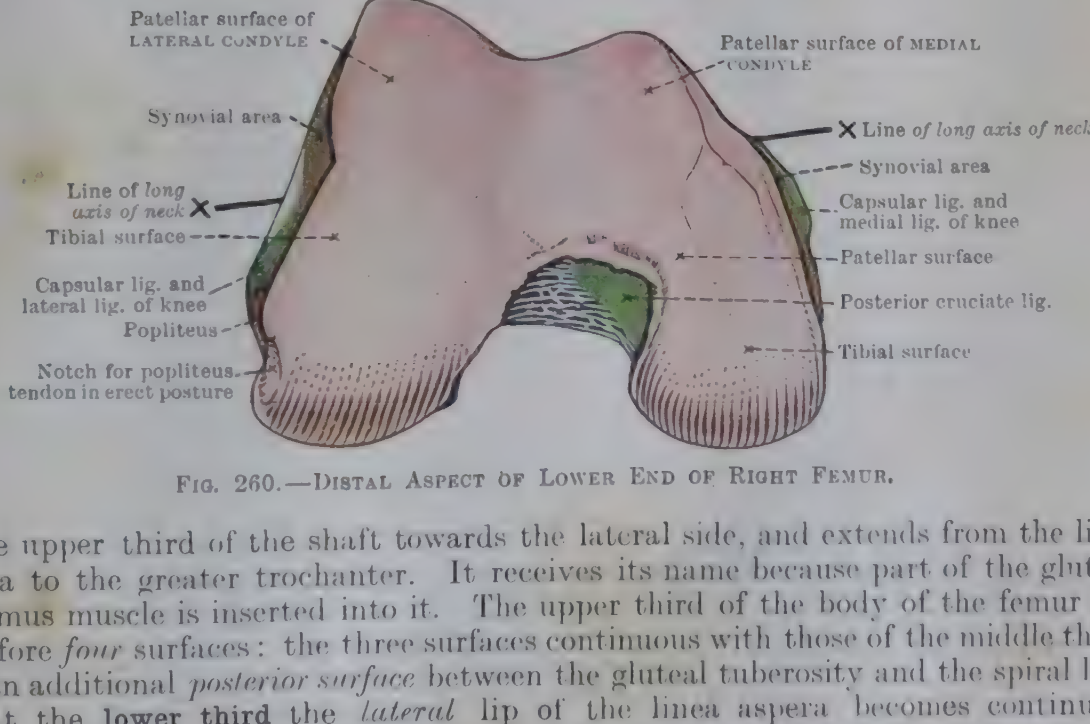


FIG. 260.—DISTAL ASPECT OF LOWER END OF RIGHT FEMUR.

of the upper third of the shaft towards the lateral side, and extends from the linea aspera to the greater trochanter. It receives its name because part of the gluteus maximus muscle is inserted into it. The upper third of the body of the femur has therefore *four* surfaces: the three surfaces continuous with those of the middle third, and an additional *posterior surface* between the gluteal tuberosity and the spiral line.

At the **lower third** the *lateral* lip of the linea aspera becomes continuous with the **lateral supracondylar line**, which extends as a well-defined line to the lateral condyle. The *medial* lip becomes continuous with the **medial supracondylar line**, which extends to the adductor tubercle and serves as a guide to it.

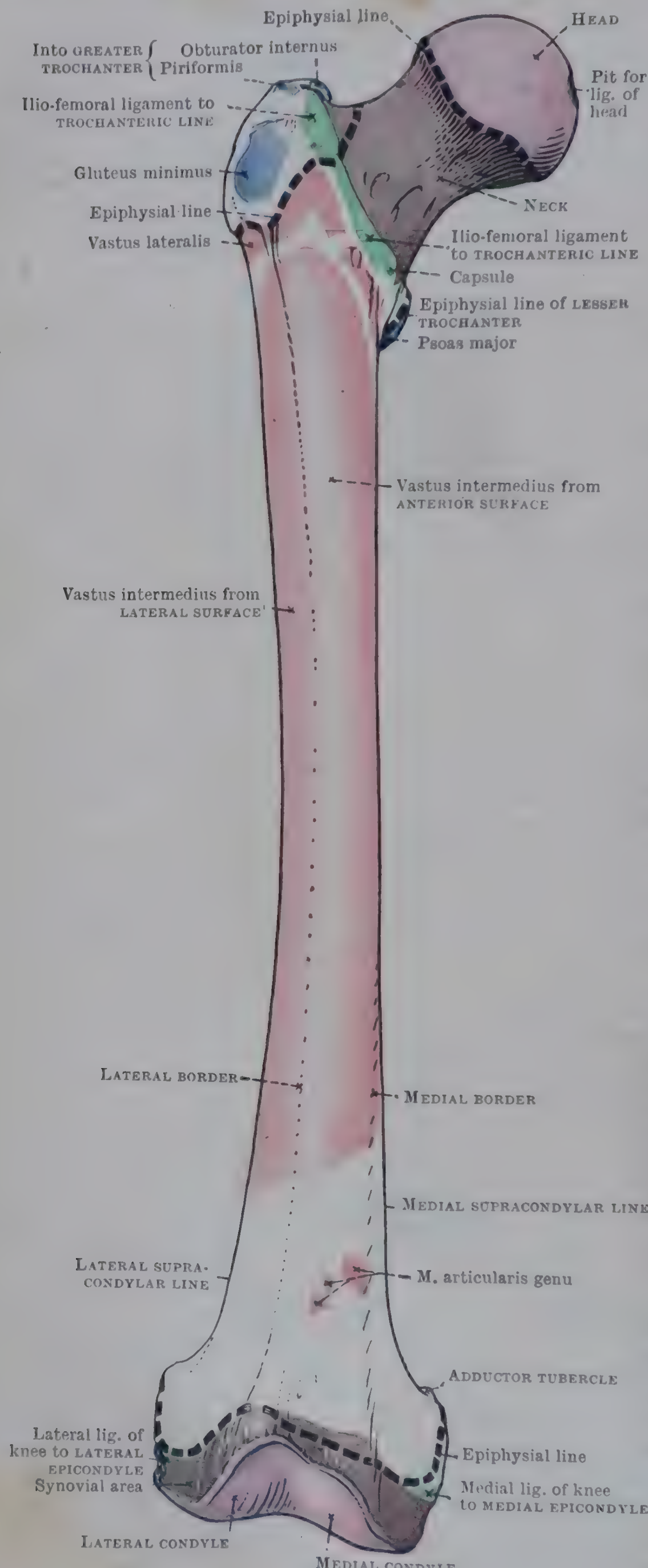


FIG. 261.—FRONT OF RIGHT FEMUR.

The medial supracondylar line is never so well defined as the lateral, largely because it is smoothed by the femoral vessels as they pass from the medial side of the thigh into the popliteal fossa and change their name to popliteal vessels. The lower third of the shaft also has *four* surfaces: anterior, medial, and lateral, continuous with those of the middle third, and a *posterior surface* between the supracondylar lines. The posterior surface is usually called the **popliteal surface**, because it forms a great part of the floor of the popliteal fossa; on its lower part, above the medial condyle, there is a rough, raised mark, about half an inch wide each way, from which the medial head of the gastrocnemius muscle arises.

The **nutrient foramen** of the femur is situated on or near the linea aspera and is directed towards the upper end. There may be two nutrient foramina.

The **head** usually looks upwards and slightly forwards as well as medially. It is relatively smaller in women than in men. The pit for the ligament of the head of the femur is situated below and behind the centre of the head; blood-vessels from the ligament enter through it, and the head thus obtains a double blood-supply; sometimes the pit is absent, as in the orang. The articular margin is undulating and is sharper behind than in front.

The **neck** extends laterally, downwards and slightly backwards from the head. Its antero-posterior diameter is less than the vertical. Its posterior surface is concave lengthwise and convex from above downwards; usually a shallow, horizontal groove can be seen on it, leading into the trochanteric fossa; the tendon of the obturator externus lies in the groove. Its anterior surface is nearly flat and nearly in the same plane as the head and shaft. Near the head it often presents a smooth patch, produced by pressure against the ilio-femoral ligament.

The neck is joined to the shaft at an angle which varies but averages 125°. The angle is less in the adult than in the child, and less in short-limbed people, especially in women; the upper ends of the shafts are separated by the width of the pelvis and by the length of the two necks, but the knees are in contact or almost so; the shaft is therefore oblique; the obliquity is more marked in short-limbed men, and still more so in women, for the pelvis is wider; and the greater the obliquity, the less is the angle. At the upper end of the **trochanteric line** there is often a little tubercle for the attachment of the stronger part of the ilio-femoral ligament.

The **greater trochanter** is under cover of the aponeurotic insertion of the gluteus maximus into the ilio-tibial tract during extension, but it slips under the fleshy part of the muscle during flexion. The highest point or tip of the trochanter is the angle between its upper and posterior borders, and it overhangs the trochanteric fossa.

Sometimes part of the **gluteal tuberosity** is so raised that it makes a prominent excrescence, easily felt in the living person, comparable to the **third trochanter** which is always present on the thigh-bones of some animals. Sometimes the tuberosity is represented by a depression.

The **shaft** of the femur is slightly twisted, making the transverse diameter of the condyles and the long axis of the neck lie in two vertical planes that intersect each other—the neck plane being a little in front of the condylar plane medially. The acute angle between the planes is the **angle of torsion** of the femur. The shaft is also curved, with the convexity forwards, and that partly accounts for the fullness of the front of the thigh; the degree of curvature varies considerably, and is usually most pronounced at the upper part. The **linea aspera** may be a prominent keel; or it may be absent, as it is in apes. Sometimes a small tubercle on the lateral supracondylar line, about two inches above the condyle, marks the lower limit of the lateral intermuscular septum; and above that there is a shallow groove for a muscular artery. The upper and lower parts of the shaft are rather compressed from before backwards; a femur showing an exaggerated degree of compression is called **platymeric**; this condition is more common in the femora of prehistoric races.

The articular surfaces of the **condyles** are spirally curved. Their tibial parts articulate partly with the upper end of the tibia and partly with the semilunar cartilages that lie within the knee joint between the femur and tibia; faint grooves,

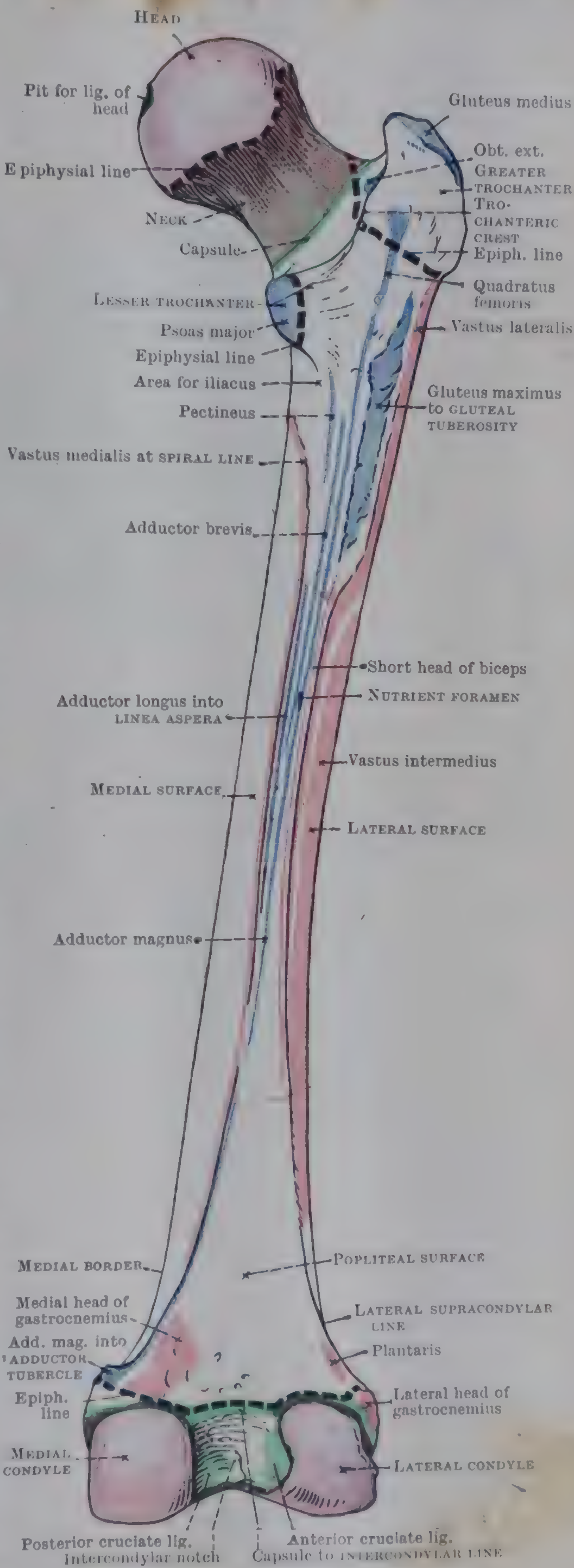


Fig. 262.—Back of Right Femur.

made by the anterior edges of these cartilages, separate the *distal* articular surfaces from the *patellar* surface. The distal surfaces are on the same horizontal plane when the femur is held in its proper oblique position; the lateral condyle is then the one more directly in line with the shaft.

On the distal aspect (Fig. 260) the patellar surface can be seen in front of the intercondylar notch; the two tibial surfaces are separated by the notch. The tibial surface on the *lateral condyle* is relatively broad and is rounded. The same aspect of the *medial condyle* is narrower and curved, with the centre for the curve in the middle of the rounded part of the lateral condyle. Assuming that the tibia is fixed, this indicates a rotation of the femur round a vertical axis passing through the lateral condyle. Actually, medial rotation of the femur on the tibia takes place in the late stages of extension (see p. 387).

The reverse appearance is seen on the posterior aspect of the condyles (Fig. 262). The medial condyle is rounded and the lateral one is narrower and is curved as part of the circumference of a circle, indicating rotation with the medial condyle as centre in the flexed position. The semilunar area for articulation with the patella in extreme flexion of the knee can sometimes be seen on the medial condyle where it bounds the anterior part of the intercondylar notch. The anterior margin of the intercondylar notch is opposite the centre of the lateral condyle; and the floor slopes upwards and backwards to the **intercondylar line**, which separates it from the popliteal surface.

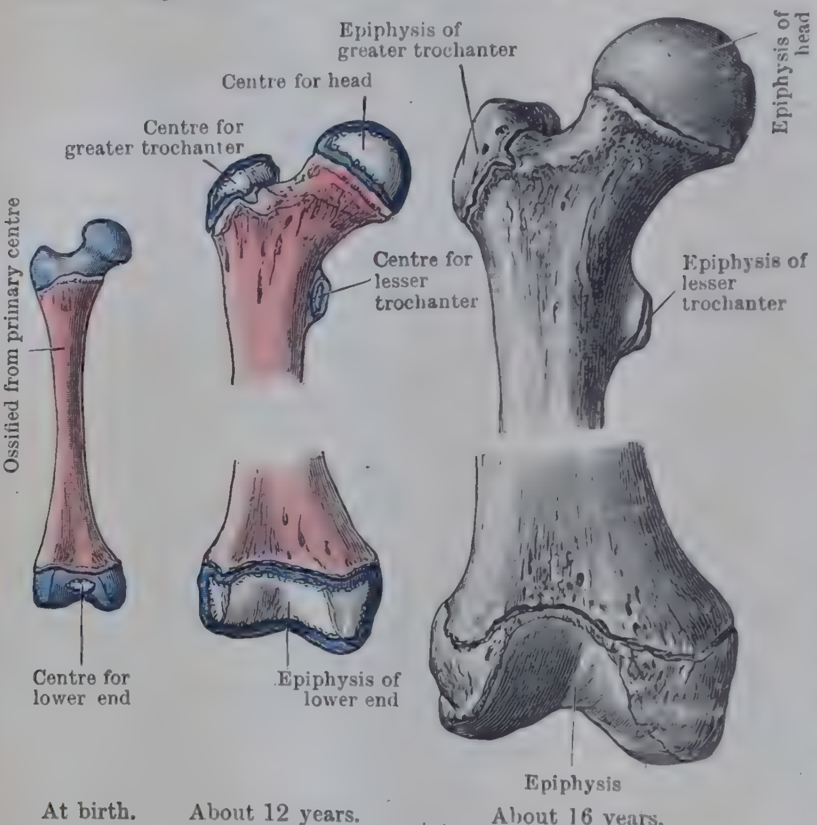


Fig. 263.—Ossification of Femur.

Attachments.—The ligament of the head is attached to the *pit* on the **head**. The capsule of the hip joint is attached to the back of the **neck** a finger's breadth from the trochanter, to the upper and lower borders of the neck near the trochanters, and to the **trochanteric line**; the part of the neck within the capsule is clothed with synovial membrane. The uppermost fibres of the vastus medialis arise from the lower half of the trochanteric line; the uppermost fibres of the vastus lateralis from the upper half of the line and from the front and lateral side of the root of the **greater trochanter**. The gluteus minimus is inserted into the *front* of the greater trochanter and is partly separated from it by a *bursa*; the gluteus medius into its *lateral surface* on a broad, oblique ridge that extends downwards and forwards from the postero-superior angle; the surface in front of the ridge is separated from the gluteus medius by a *bursa*, and another *bursa* intervenes between the gluteus maximus and the surface behind the ridge; the piriformis into the *upper border*; the obturator internus and the gemelli into the *medial surface* above the neck; the obturator externus into the floor of the **trochanteric fossa**; the quadratus femoris into the **trochanteric crest**, into the **quadrate tubercle** and into a strip that runs down from the tubercle for an inch; the psoas major into the **lesser trochanter**; the iliacus into the tendon of the psoas, the lesser trochanter, and the area below and in front of the trochanter.

Part of the gluteus maximus is inserted into the **gluteal tuberosity**, and part of the vastus lateralis arises from its lateral edge; part of the vastus medialis from the **spiral line**. The surface between the spiral line and the gluteal tuberosity gives insertion to four muscles: (1) part of the iliacus (see above); (2) the pectineus into a strip which begins lateral to the back of the root of the lesser trochanter and runs down to the linea aspera; (3) the upper part of the adductor brevis into the same strip, lateral to the pectineus; (4) the uppermost fibres of the adductor magnus between the attachment of the adductor brevis and the gluteal tuberosity.

The **linea aspera** gives attachment to the following structures, named from medial to lateral side: the origin of part of the vastus medialis; the medial intermuscular septum; the insertion of the adductor longus, in the whole length of the line or in the lower two-thirds only; the insertion of the lower part of the adductor brevis, in the upper third of the line; the insertion of a part of the adductor magnus; the posterior intermuscular septum; the origin of the greater part of the short head of the biceps femoris; the lateral intermuscular septum; the origin of part of the vastus lateralis from the upper half of the line, and of part of the vastus intermedius from the lower half.

From medial to lateral side the following structures are attached to the **supracondylar lines**:—Part of the vastus medialis from the upper two-thirds of the **medial** line; the medial septum

PLATE XXI

PLATE XXI.—POSTERIOR RADIOGRAPH OF LEFT KNEE OF YOUNG MAN AGED 22.

The union of the epiphysis of the Femur is not quite complete. Cf. Plate XXIV, Fig. 1, p. 297; and for lateral radiographs of the same knee see Plate XXXIV, p. 371.

PLATE XXII

FIG. 1.—RADIOGRAPH OF PELVIS OF BOY AGED 4.

The pubic and ischial rami are not yet united, and the centre for the epiphysis of the greater trochanter of the femur has not appeared.

FIG. 2.—RADIOGRAPH OF HIP OF BOY AGED 7. (Dr. J. Duncan White.)

The epiphysis of the Lesser Trochanter has not yet appeared.

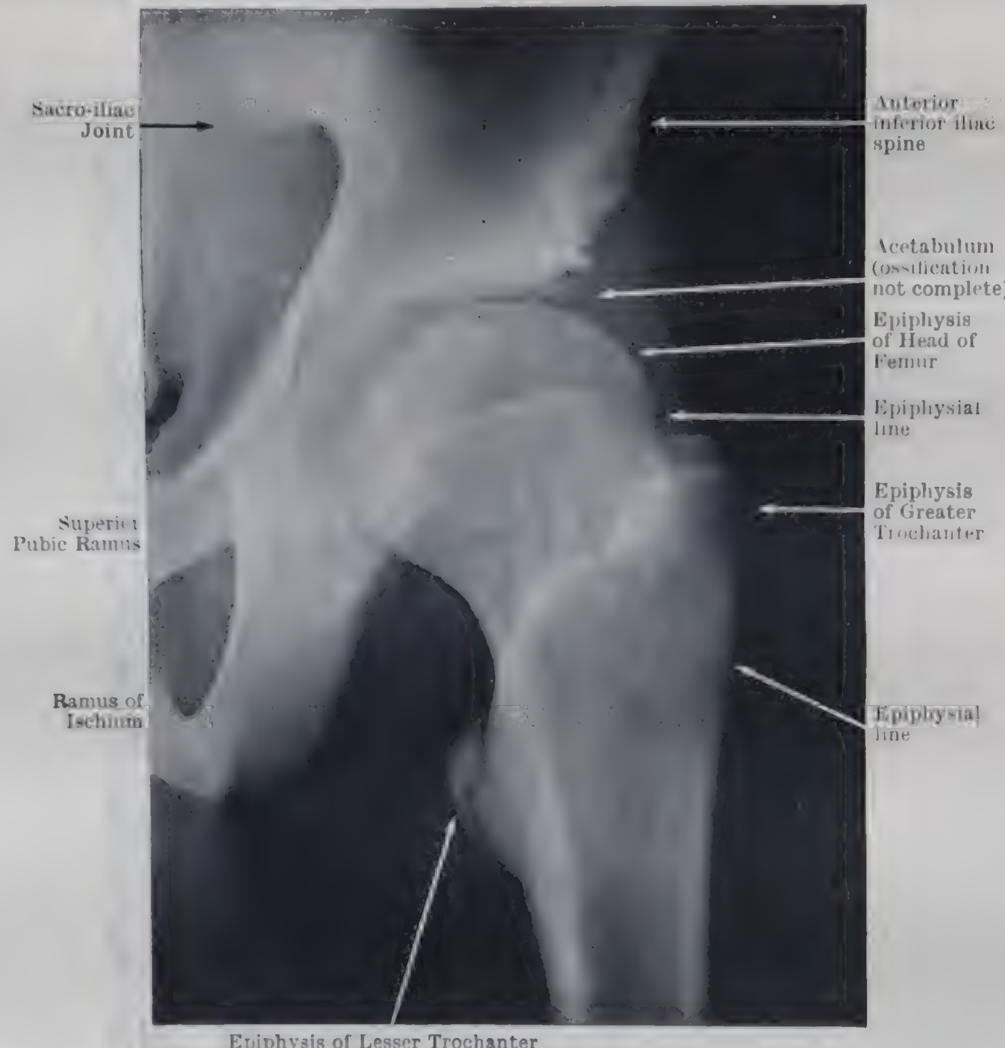


FIG. 1.—RADIOGRAPH OF HIP OF BOY AGED 14.

Note that the edge and floor of the Acetabulum are not yet completely ossified, and that all three epiphyses of the upper end of the Femur are present.

FIG. 2.—RADIOGRAPH OF HIP OF YOUTH AGED 17. (Dr. J. Duncan White.)

All three epiphyses of the Femur are united. Note the continuity of the lines of the lower borders of the Superior Pubic Ramus and the Neck of the Femur (Shenton's line), seen also in Plate XX, p. 289.

PLATE XXIV

Fig. 1.—Posterior Radiograph of Knee of Girl aged 7.
(Dr. J. Duncan White.)

Note the form of the Epiphyses, and compare with Plate XXI, p. 296.

Fig. 2.—Oblique Lateral Radiograph of Slightly Flexed Knee of Girl aged 12. (Dr. J. Duncan White.)

Note the apparent doubling of the femoral epiphysial line, and the extension of the tibial epiphysis to the tubercle—probably ossified in this instance from a separate centre.

[Facing p. 297

and part of the adductor magnus into the whole length, except where interrupted for the passage of the femoral vessels. The lower parts of the short head of the biceps, the lateral septum, and the vastus intermedius from the upper two-thirds of the **lateral** line.

The greater part of the vastus intermedius arises from the upper two-thirds or three-fourths of the **anterior** and **lateral surfaces** of the shaft; the articularis genu muscle (as slender bundles) from the lower part of the anterior surface. The medial surface is covered by vastus medialis, but does not give attachment to any muscle.

The medial head of the gastrocnemius arises from the rough patch on the **popliteal surface** above the medial condyle; the plantaris from a small area above the lateral condyle; the lateral head of the gastrocnemius from an impression on the lateral surface of the **lateral condyle** and the adjoining lower end of the lateral supracondylar line; the tendon of the popliteus from the anterior end of the **popliteal groove**, and when the knee is extended it crosses the lower lip of the groove, which bears therefore a shallow notch near its anterior end. The lateral ligament of the knee is attached to the *lateral epicondyle*; the anterior cruciate ligament to the posterior part of the *lateral wall* of the **intercondylar notch**; the posterior cruciate ligament to the anterior part of the *medial wall*; the medial ligament of the knee to the *medial epicondyle*. The tendon formed by the posterior part of the adductor magnus is inserted into the **adductor tubercle**.

The fascia lata blends with the periosteum of both condyles at the sides of the knee. The posterior ligament of the knee joint is attached to the **intercondylar line**, and the capsular ligament to the bone immediately above the posterior parts of the condyles, to the lateral condyle between the popliteal groove and the epicondyle, and to the medial condyle immediately below the medial epicondyle. There is no definite capsular ligament in front, and the synovial membrane is reflected off the quadriceps on to the femur about a finger's breadth above the patellar surface; but, by means of a wide communication with a large *bursa* that lies under cover of the quadriceps, the cavity of the knee joint extends upwards to a point at least three finger-breadths above the patella. The apex of the infrapatellar synovial fold is attached to the anterior margin of the intercondylar notch.

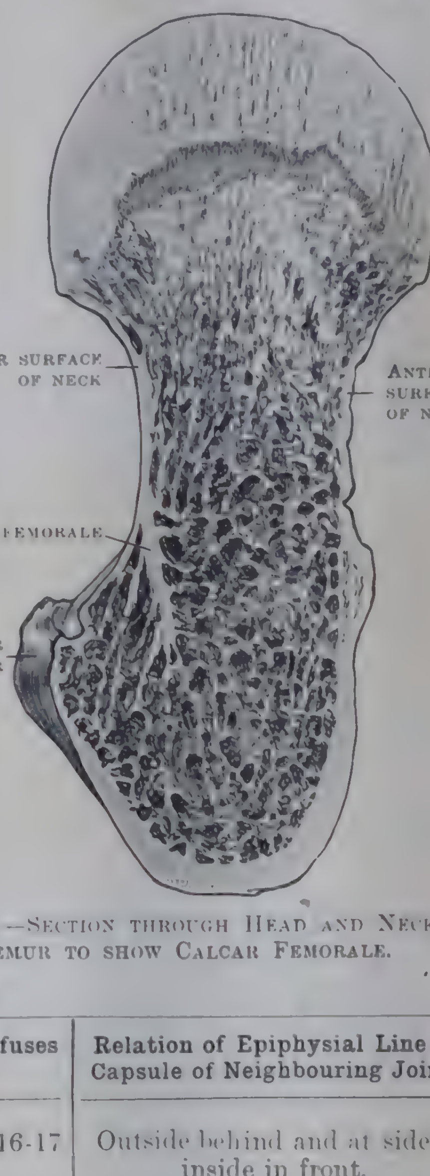


FIG. 264.—SECTION THROUGH HEAD AND NECK OF FEMUR TO SHOW CALCAR FEMORALE.

Ossification (Pls. XXII, XXIII, XXIV).—The **primary** centre for shaft and neck appears at the seventh week of intra-uterine life. At birth the shaft is ossified; ossification extends into the neck after birth.

Secondary Centre.	Appears at	Epiphysis fuses at	Relation of Epiphysial Line to Capsule of Neighbouring Joint.
For lower end	9th month of *intra-uterine* life	**M.** 18; **F.** 16-17	Outside behind and at sides; inside in front.
For head	**M.** ½-1 yr.; **F.** ½ yr.	**M.** 18; **F.** 17	Inside.
For greater trochanter	**M.** 5 yr.; **F.** 4 yr.	**M.** 18; **F.** 16-17	Outside (inside superiorly).
For lesser trochanter	9-11 yr.	**M.** 18; **F.** 16-17	Outside.

The presence of the centre in the cartilage at the lower end in a new-born child found dead is accepted as proof that the child had come to full time. The epiphysial line at the lower end passes through the adductor tubercle, and immediately above the patellar surface, and along the intercondylar line.

Structure.—As in other long bones, the ends are composed of spongy substance enclosed in a shell of compact substance. The shaft is a thick tube of compact bone enclosing a medullary cavity; the cavity begins opposite the lesser trochanter and ends about a handbreadth from the distal articular surface. The walls of the cavity are thickest above the middle of the bone and along the linea aspera. Since the upper end of the femur has become a classical example of bone-architecture (p. 107) its structure is given here in some detail. The following account is based largely on the description given by Dixon (1910) who used stereoscopic radiographs as well as thin sections and dissection of the bone. See also D'Arcy Thompson (1942), Koch (1917) and Murray (1936) for discussion and review of the whole subject, with full historical references.

The compact bone of the shaft gives origin to lamellæ which branch off, diverge and intersect to form the cancellous bone of the neck, the trochanters and the head. Although it is not at first glance obvious, many of these lamellæ are concentrated to form the walls of a curved tube which is an upward continuation of the tubular compact bone of the shaft through the neck to the head of the bone. If the trochanters and intertrochanteric crest are removed carefully it is possible to demonstrate the continuity of this tube from the shaft up into the neck. The part which passes deep to the lesser trochanter to reach the posterior aspect of the neck is termed the **calcar femorale** when seen as a thickened spur in sections through the neck (Fig. 264). Where it lies deep to the greater trochanter it has been referred to as the *lamina femoralis interna*. Lamellæ branch off from the deep and superficial surfaces of the 'tube' as trabeculæ of the adjacent cancellous bone. The arrangement as seen in coronal section is illustrated in Plates II and III (p. 105). The chief systems to be noted are as follows :—

(1) Lamellæ sweep up from the compact bone of the medial and inferior aspects of the shaft and neck and diverge to reach the articular surface of the head—especially the upper weight-bearing part of it. These are obviously subjected to compression from the weight of the body.

(2) Lamellæ spring from the compact bone of the lateral aspect of the shaft, arch across deep to the trochanter and through the upper part of the neck to cross the first series of lamellæ approximately at right angles and so reach the articular surface of the head—mainly the lower part this time. These must be subject to tension when the body weight is applied to the head of the bone.

(3) A series of lamellæ spring from the medial wall of the shaft and arch across to reach the greater trochanter.

(4) Lamellæ also sweep up from the lateral side into the greater trochanter and upper part of the neck of the bone.

The first two of these systems mentioned form the infero-medial and supero-lateral walls of the bent tubular continuation of the shaft. The area enclosed by the first three systems is relatively free of lamellæ and forms a triangle, *trigonum internum femoris*, illustrated by Ward as early as 1838. Many of the lamellæ are arranged spirally as intersecting right and left handed series, an exceedingly efficient arrangement. Dixon found that adult femora could stand compression (applied to the lower end and head of the bone) amounting to between 1800 and 2500 lbs. Weights of this order produced shearing of the neck before fracture from bending stresses took place.

Patella

The **patella** or knee-cap or knee-pan [*patella*, diminutive of *patina* = a pan] lies in the front of the knee and articulates with the femur. It is a small, compressed bone and measures nearly two inches in diameter. The **posterior surface** is largely occupied by an oval *facet* for articulation with the femur; the facet is divided by a blunt ridge into a larger, lateral part, and a smaller, medial part, which correspond to the sloping sides of the patellar surface of the femur. The **anterior surface** is slightly convex and is triangular in outline; the *apex* of the triangle points towards the leg and is on a level immediately above the plane of the knee joint; the base of the triangle is the anterior margin of the *base of the patella*, *i.e.*, its thick, upper border; the *lateral* and *medial borders* are convex.

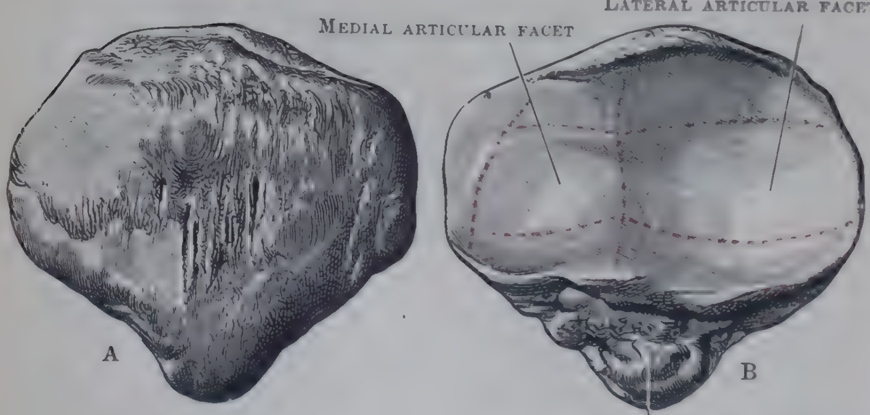


Fig. 265.—Right Patella.
A. Anterior Surface. B. Posterior Surface.

The **patella** is the largest of the *sesamoid* bones; it lies in the tendon of the quadriceps femoris and, playing against the patellar surface of the femur, it increases the leverage of the muscle when it contracts to move the leg. The lower part of the quadriceps tendon is the *ligamentum patellæ*—a strong band that stretches from the patella to the tibia, and on which the body partly rests in the kneeling posture. When the knee is extended and the muscles are relaxed, the patella can be moved from side to side fairly freely, and to some extent also downwards; when the knee

is flexed the quadriceps muscle, including the ligamentum patellæ, is put on the stretch, the patella is jammed hard against the femur and is immovable. The anterior surface has a vertically striated or fibrous appearance. The lateral part of the articular surface is concave in both directions; the medial part is slightly concave from above downwards and is flat or slightly convex from side to side. The vertical ridge lies in the intercondylar notch in extreme flexion. When the cartilage is in place a vertical strip along the medial margin for articulation with the lateral margin of the medial condyle in extreme flexion can be seen; and the rest of the surface is faintly subdivided into six areas (see Fig. 265). The medial, vertical strip can sometimes be seen in the macerated bone.

Attachments.—The three vasti and the rectus femoris are inserted into the upper border; the vastus lateralis and medialis, into the lateral and medial margins also; and these borders give attachment also to the retinacula of the patella. A transverse line or groove divides the upper border into an anterior part for muscular insertion and a posterior part covered with fat and synovial membrane. There is often a well-defined area at the supero-lateral angle for part of the vastus lateralis. Some tendinous fibres of the quadriceps are continued downwards over the front of the patella to the ligamentum patellæ, and, in infancy, they can easily be stripped off the cartilaginous patella. The ligamentum patellæ is attached to the apex and to the adjoining part of the posterior surface, but the greater part of the rough surface below the articular facet is related to fat and the synovial membrane of the knee.

Ossification.—The patella is cartilaginous at birth. Ossification, usually from a single centre, begins about the fifth year and is completed about puberty. Separate epiphysial nodules have been found in the lateral margin of the patella. For the development of the patella in relation to the knee joint, see Walmsley, R. (1940).

Structure and Variations.—The patella is composed of spongy tissue enclosed in a shell of compact tissue, which is thickest in front and at the vertical elevation behind. Small *vascular foramina* are present on the anterior surface. The patella may be absent; its absence is said to be hereditary and transmitted by the female. In one recorded case the patella was divided into a large, upper part and a smaller, lower part embedded in the ligamentum patellæ. The facets on the articular surface are modified in people who habitually squat.

Tibia

The **tibia** or shin-bone [*tibia* = shin-bone] comes next in size after the femur and is between a fourth and a fifth of the length of the body. It is the medial and larger of the two bones of the leg, and it can be felt through the skin in all its length. It is a long bone, having **a shaft** and **two ends**. The most outstanding border of the shaft is the **anterior** border; the lower end is the smaller end; and on the **medial** side of the lower end there is a stout, blunt projection called the *medial malleolus*.

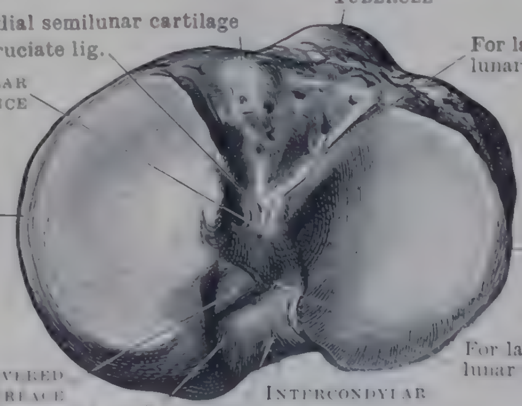


Fig. 266.—Proximal Surface of Right Tibia.

The **upper end** is large and expanded to support the lower end of the femur. Its transverse diameter is the wider and it is bent slightly backwards to overhang the shaft. It includes two imperfectly separated condyles and a tubercle.

The **tubercle** is the low elevation on the front where the upper end joins the anterior border of the shaft; its lower part is rough; its upper part is smooth and rounded and gives attachment to the ligamentum patellæ.

The two **condyles** make up nearly the whole of the upper end; they are separated *posteriorly* by a wide, shallow depression or notch; *anteriorly*, above the tubercle, they are united by a more or less flattened surface concealed behind the ligamentum patellæ. In the **kneeling posture** the body rests on the rough part of the tubercle, the ligamentum patellæ, the front of the two condyles, and the lower part of the patella. The *upper surface* of each condyle is large, oval and smooth; it articulates with the corresponding condyle of the femur; the more central part of the articular area articulates directly with the femur, but the more peripheral part is separated

from the femur by a *semilunar fibro-cartilage.* Between the articular surfaces of the two condyles there is a rough **intercondylar area** which rises near its middle into a prominent **intercondylar eminence.**

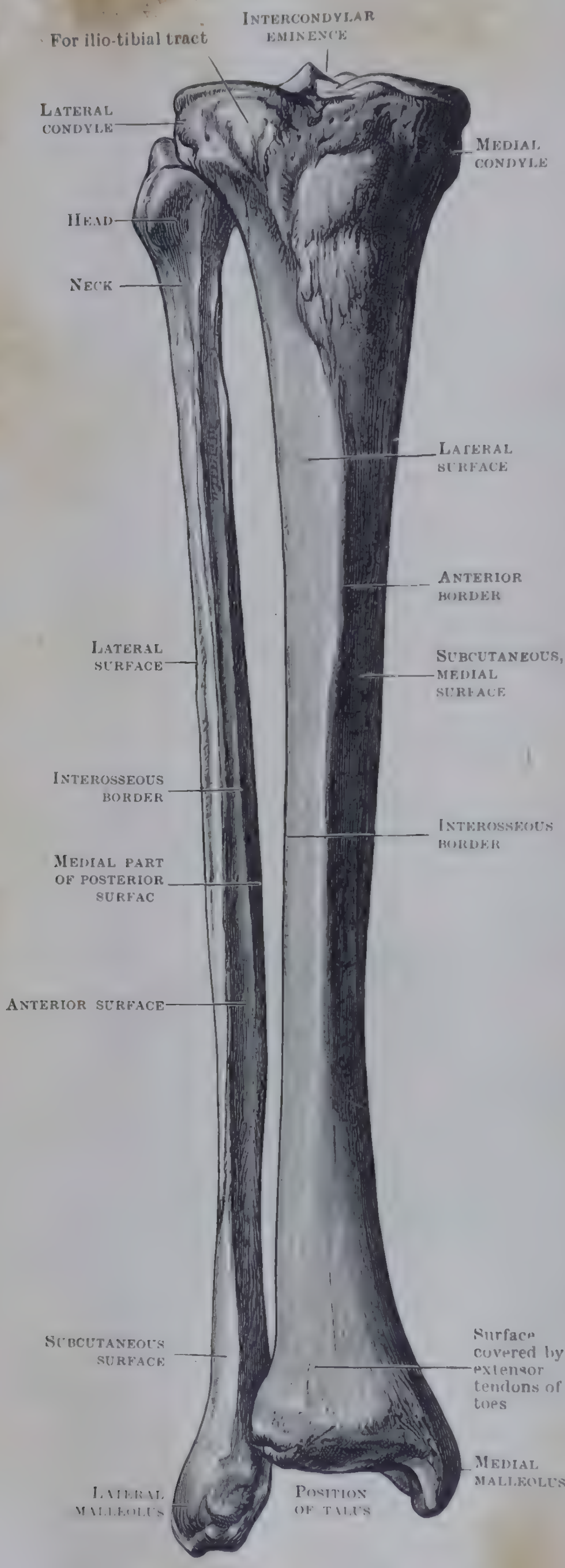


FIG. 267.—RIGHT TIBIA AND FIBULA SEEN FROM IN FRONT.

On the back of the **medial condyle** there is a rough, horizontal groove for the insertion of part of the tendon of the semimembranosus muscle. The **lateral condyle** stands more abruptly away from the shaft than the medial does—so much so that it has a *distal surface.* This distal surface is separated from the lateral surface by a curved ridge to which the fascia of the antero-lateral side of the leg is attached; on the posterior part of the distal surface there is a flat, circular **facet** for articulation with the head of the fibula. On the anterior part of the *lateral surface* there is usually a well-marked impression for the attachment of the posterior part of the *ilio-tibial tract*, a thickened part of the fascia of the thigh. Both the condyles can be felt at the sides of the knee.

The **lower end** of the tibia has five surfaces—anterior, posterior, lateral, medial, and distal.

The **anterior surface** is smooth and rounded, and it can be felt indistinctly through the skin and the tendons that descend from the front of the leg to the foot.

The **medial surface** is subcutaneous, and is continued on to the **medial malleolus**, which is the well-known prominence, both felt and seen, on the medial side of the ankle [*malleollus* = a small hammer]. The distal border of the malleolus is pointed anteriorly and notched posteriorly; it gives attachment to an exceedingly strong fibrous band named, from its shape, the *deltoid ligament* [Δ = the Greek capital letter *delta*]. The lateral surface of the malleolus is smooth and articulates with the medial surface of the talus or ankle-bone.

The **posterior surface** lies deeply under cover of a pad of fat and the tendo calcaneus, the stout sinew felt above the heel. The surface is on the same plane as the back of the malleolus, which can be felt. Where it merges

into the back of the malleolus there is a distinct vertical groove for the tendons of the tibialis posterior and flexor digitorum longus; nearer the lateral side there is an indistinct groove for the tendon of the flexor hallucis longus.

The **lateral surface** is occupied by a wide, triangular depression, the apical part of which extends on to the shaft and is shallow and rough. The basal part is smoother and deeper—being bounded in front and behind by prominent ridges or tubercles. It is called the **fibular notch** because the lower part of the fibula lies in it; the fibula is usually in actual contact with the lower part, but is bound to the upper part by a very short but very thick interosseous ligament.

The **distal surface** is square and smooth, concave from before backwards, slightly convex from side to side, and broader in front than behind; it articulates with and rests upon the upper surface of the talus, the highest bone of the tarsus.

The **shaft** is thinnest about the junction of the middle and lower thirds; it becomes thicker towards the lower end and still more so towards the upper end. It has three borders and three surfaces. The *borders* are anterior, medial, and interosseous; the *surfaces* are posterior, lateral, and medial.

The **anterior border** or shin of the leg is the most prominent of the borders. It begins at the tubercle and extends sinuously to the anterior margin of the medial malleolus; it can be felt from end to end in the living leg. Small notches—the result of accidental impacts—may be felt in it. Its lower third is blunter than the rest of it. The **medial border** is a smooth, blunt margin that extends from near the back of the medial condyle to the back of the medial malleolus; it also can be felt from end to end, but it is best marked in the middle third of the bone. The **interosseous border** is on the lateral side, and is so named because it gives attachment to the interosseous membrane—a strong, fibrous sheet stretched between the tibia and the fibula. It is a

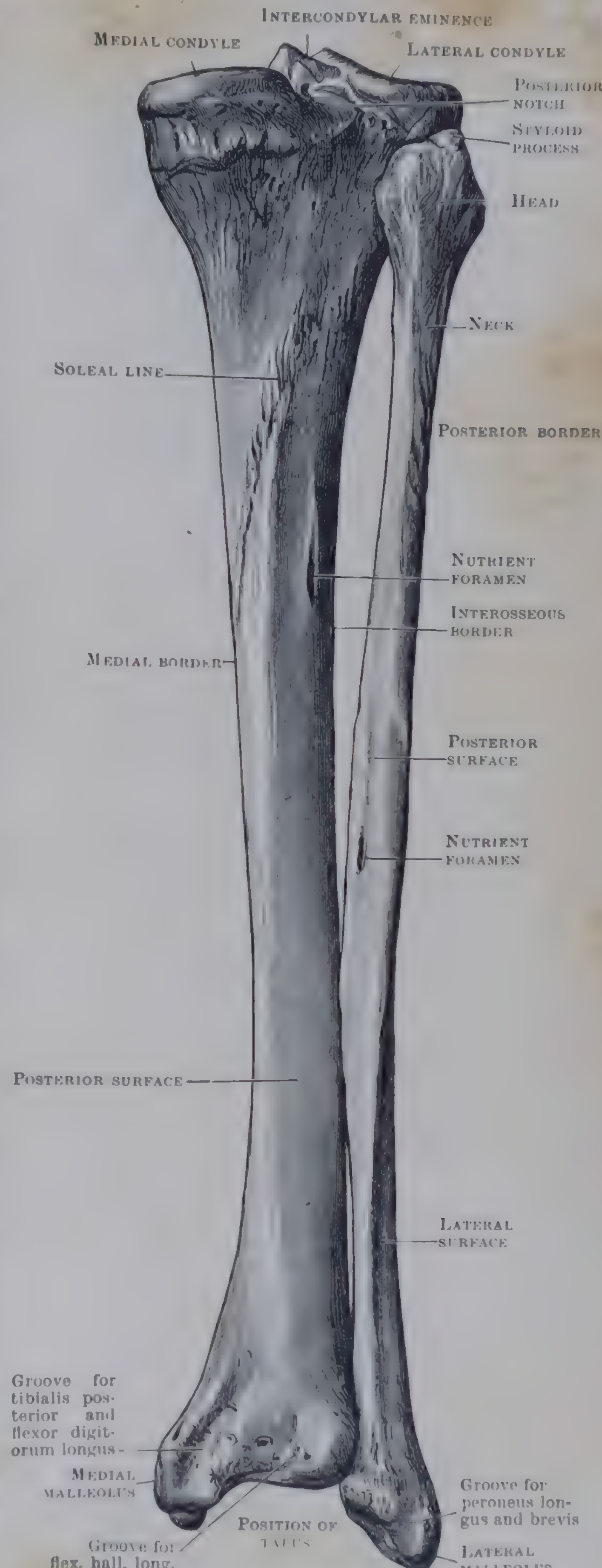


Fig. 268.—Right Tibia and Fibula seen from Behind.

distinct, sharp line, but is not prominent. It extends from the apex of the fibular

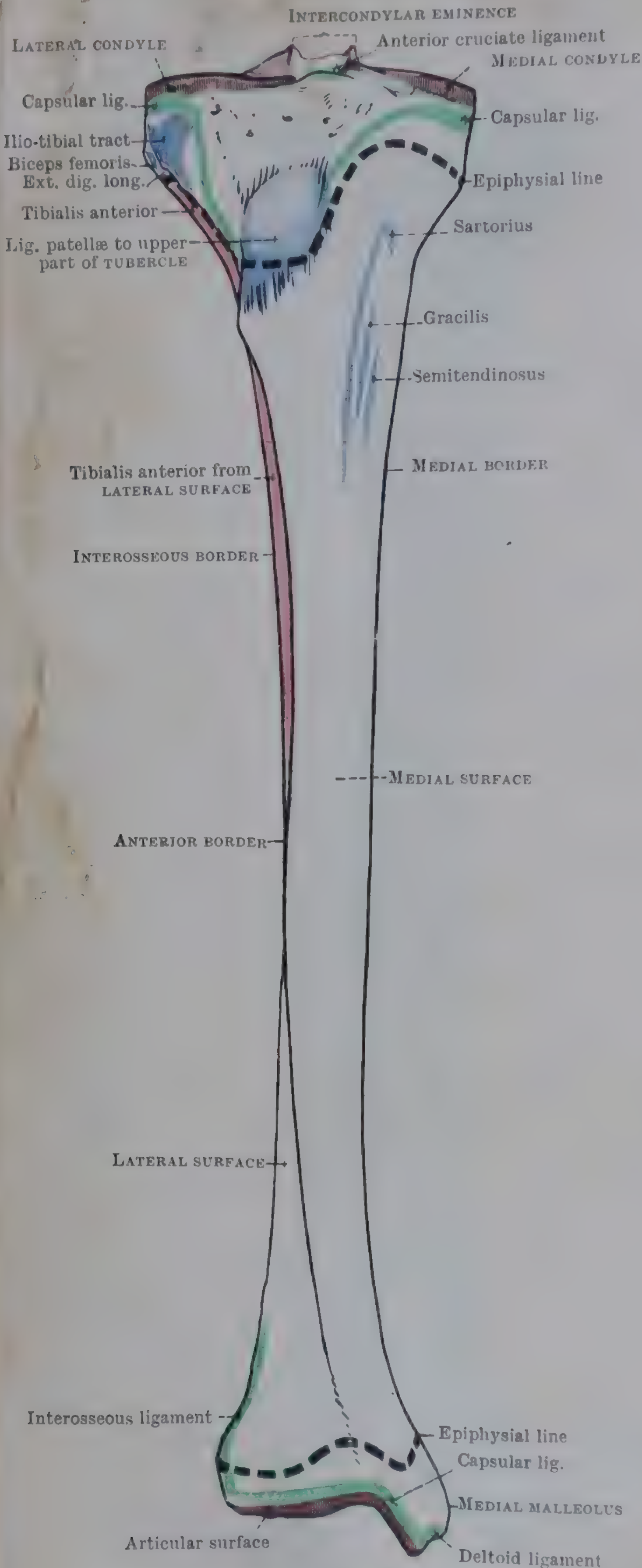


FIG. 269.—ANTERIOR ASPECT OF RIGHT TIBIA.

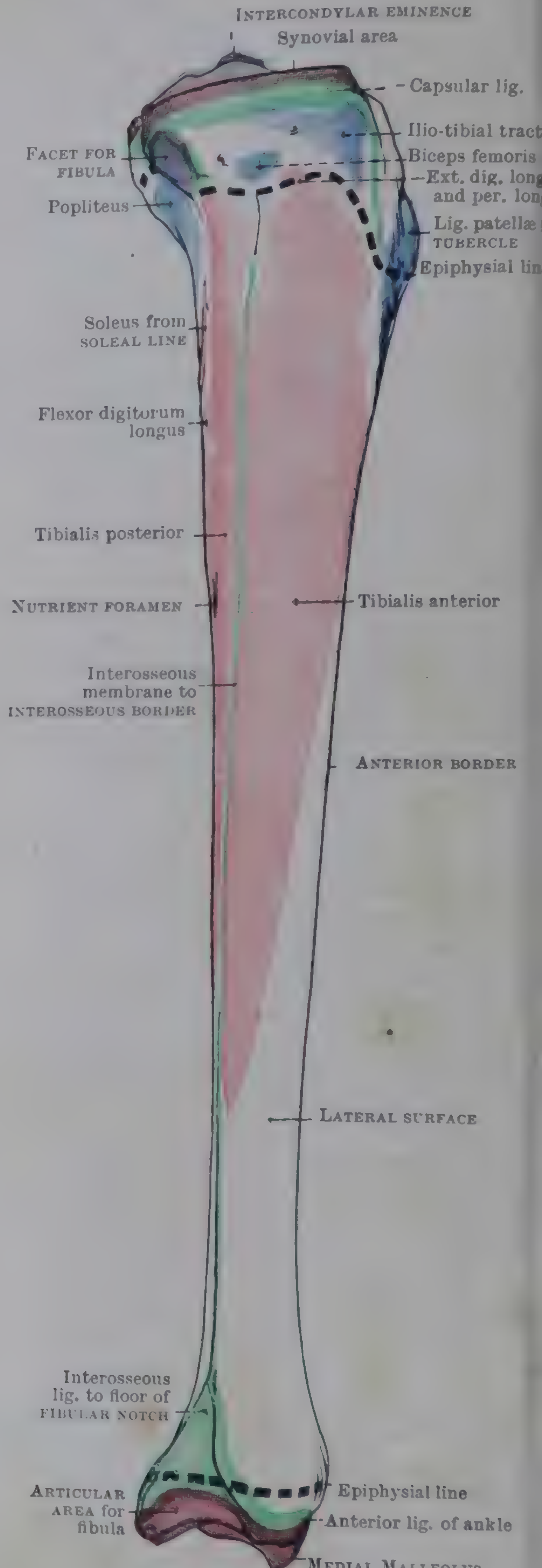


FIG. 270.—LATERAL ASPECT OF RIGHT TIBIA.

notch to the lower part of the lateral condyle some distance in front of the facet for the head of the fibula.

The **medial surface**, between the anterior and medial borders, is smooth and

slightly convex and can be felt through the skin. It is continuous inferiorly with the medial malleolus and its upper part is slightly roughened for the attachment of tendons and ligaments that overlie it. The **lateral surface** is between the anterior and interosseous borders, and, owing to the direction of the lower parts of those borders, it turns forwards to become continuous with the front of the lower end of the tibia. The **posterior surface** is between the medial and interosseous borders; its upper part encroaches on the lateral aspect of the bone owing to the position of the upper part of the interosseous border. The upper third of the posterior surface is crossed by an oblique ridge called the **soleal line** which begins near the facet for the head of the fibula and runs downwards and medially towards the medial border. The line is the chief bony origin of the soleus muscle that lies deeply in the calf; the part of the surface above the line gives insertion to the popliteus muscle which lies in the lower part of the floor of the popliteal fossa. The part of the surface below the soleal line is imperfectly divided into medial and lateral parts by a more or less *vertical line*—which is often ill-defined.

The **nutrient foramen** is near the soleal line and is directed downwards.

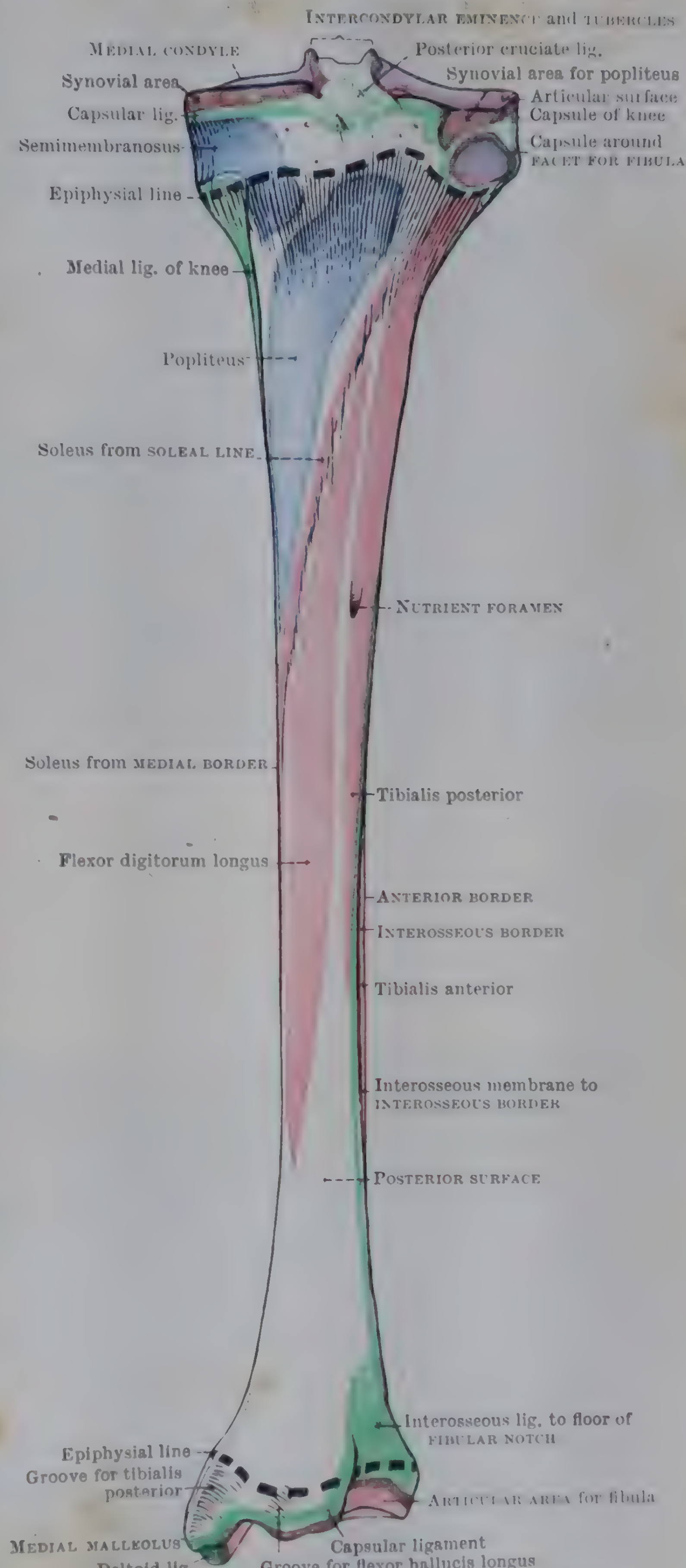


FIG. 271.—POSTERIOR ASPECT OF RIGHT TIBIA.

The articular surface of the **medial condyle** is ovoid, with its long axis antero-posterior; it is concave in each direction. The superior articular surface of the **lateral condyle** is rounder and slightly smaller. It is slightly concave from side to side; from before backwards, its posterior part is convex, but its anterior part varies from slightly convex to slightly concave in different specimens. Its margin is well-defined anteriorly and laterally, but it is rounded off posteriorly—increasing the convexity of the posterior part. The parts of a condylar articular surface that articulate with the semilunar cartilage and with the femur may be indicated by a difference in texture or colour. The sides of

the **intercondylar eminence** stand up prominently as the **intercondylar tubercles**; the articular cartilage extends on to them, and they are separated by a groove that runs obliquely from in front backwards and in a lateral direction. The medial tubercle is the higher and blunter; it sends backwards an oblique ridge that bounds the groove posteriorly and gives attachment to the **posterior horn of the lateral semilunar cartilage.**

On the front of the bone the area above the tubercle, composed of the united anterior surfaces of the two condyles, is covered with fat and is related to the deep infrapatellar bursa, which sometimes also overlaps the upper edge of the tubercle. The **tubercle of the tibia** is divided into two parts—an upper and a lower. The *lower part* is subcutaneous, but is rough; and its upper edge is often raised as a rough ridge that receives the superficial fibres of the ligamentum patellæ; but there may be no ridge, or there may be a depression in place of a ridge. The *upper part* is smooth and rounded, and it is the chief insertion of the ligamentum patellæ; its upper edge is sharply defined and is often bounded by a narrow, shallow, arched groove.

The posterior surface of the **shaft** is variable in contour, but usually its upper part is rounded and its lower part flat. The lower parts of the posterior and lateral surfaces are free from muscular attachments, but are overlain by muscles and tendons.

Attachments. — The capsular ligament of the knee joint is attached to the circumference of the **condyles** a little below the margins of the articular surface; the capsule of the upper tibio-fibular joint to the margins of the **facet for the fibula**; the cruciate ligaments and the horns of the semilunar cartilages to the **intercondylar area** in the following order from before backwards: anterior horn of medial cartilage and anterior cruciate ligament in front of the intercondylar eminence, the horns of the lateral cartilage to the front and back of the eminence, the posterior horn of the medial cartilage and the posterior cruciate ligament behind the eminence. The fascia lata to the sides of both *condyles*; its ilio-tibial tract to the impression on the *lateral condyle*; and the fascia of the leg to the ridge on that condyle. Below that ridge, on the overhanging, distal surface of the condyle, a few fibres of the biceps femoris are inserted in front of the facet for the fibula, and fibres of the peroneus longus, extensor digitorum longus, and tibialis anterior muscles arise. Part of the semimembranosus tendon is inserted into the medial part of the horizontal *groove* on the back of the *medial condyle* and into the rough area below the groove. The ligamentum patellæ is inserted into the smooth, upper part of the **tubercle** of the tibia, and its most superficial fibres run on into the rough part.

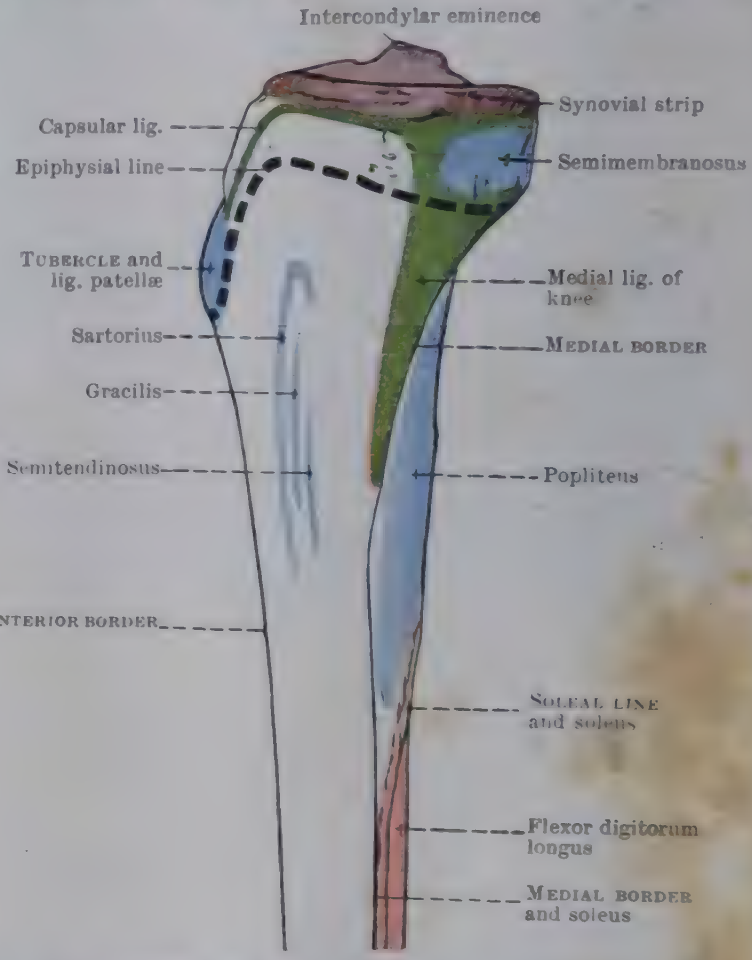


FIG. 272.—MEDIAL ASPECT OF UPPER HALF OF RIGHT TIBIA.

The medial ligament of the knee is attached to a rough patch about two inches long and half an inch wide on the *medial surface of the* **shaft**, immediately in front of the upper part of the medial border. The tendons of the semitendinosus, gracilis, and sartorius, in that order from behind forwards, have linear insertions into the area immediately in front of that rough patch. The tendon of the popliteus, as it emerges from the knee joint, lies in a smooth, shallow, oblique groove on the back of the lateral condyle between the superior and fibular articular surfaces; it then becomes fleshy and widens out to be inserted into the surface above the **soleal line**. Part of the soleus arises from the line and the middle third of the *medial border*; the flexor digitorum longus from the upper two-thirds of the *medial area* of the **posterior surface**; part of the tibialis posterior from the *lateral area*; and the fascia that covers the tibialis posterior is attached to the *vertical line*. The interosseous membrane to the *interosseous border*; the fascia of the leg to the *medial* and *anterior borders*; the superior extensor retinaculum to the lower part of the anterior border. The inferior extensor retinaculum is attached to the *anterior* border of the medial malleolus; the deltoid ligament to the *distal* border; the flexor retinaculum to the *posterior* border. The posterior ligament of the ankle joint and transverse tibio-fibular ligament to the *posterior* border of the **lower end**; the anterior ligament to the *anterior* border. The interosseous tibio-fibular ligament to the floor of the **fibular notch**; the anterior inferior and posterior inferior tibio-fibular ligaments to the anterior and posterior *margins* of the lower part of the notch.

FIG. 1.—POSTERIOR RADIOGRAPH OF ANKLE AND TARSUS OF YOUNG MAN AGED 22. (Dr. J. Duncan White.) Note that the superimposition of the shadows of the tarsal bones makes it difficult to distinguish them.

FIG. 2.—LATERAL RADIOGRAPH OF THE SAME ANKLE AND TARSUS. (Dr. J. Duncan White.) Cf. Plate XXVII, p. 320, noting the change in the relation of the articular surfaces of Tibia and Talus during movements of the Ankle.

[Facing p. 304

PLATE XXVI

Fig. 1.—Posterior Radiograph of Ankle of Girl aged 12.

Cf. Plate XXV, Fig. 1, p. 304, and note the relation of the epiphyses of Tibia and Fibula to the Malleoli and to the Ankle Joint.

Fig. 2.—Lateral Radiograph of the same Ankle and Foot (Girl aged 12).

Cf. Plate XXV, Fig. 2, and note that the epiphysis of the Calcaneum is almost united.

[Facing p. 305

Ossification (Pls. XXIV, p. 297, XXVI).—The **primary** centre appears at the seventh week of intra-uterine life. At birth only the ends are cartilaginous.

The *upper* epiphysial centre appears shortly after birth and sometimes shortly before birth.

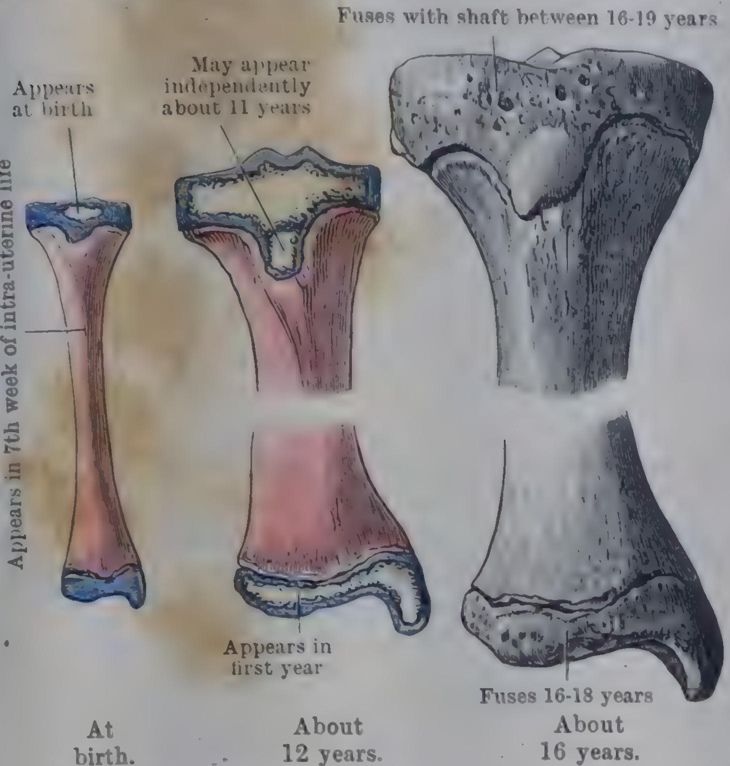


Fig. 273.—Ossification of Tibia.

The *epiphysial line* extends downwards in front to include the greater part of the tubercle. The downward spread of ossification to include the tubercle begins at the end of the tenth year; and that is the last part of the epiphysis to unite with the shaft. The medial malleolus is cartilaginous till the eighth year, when ossification begins to extend into it from the lower epiphysis. Occasionally there are additional epiphysial centres for the tubercle and the medial malleolus.

Structure and Variations.—The structure is like that of the other long bones. The medullary cavity falls short of each end by two or three inches. The cavity is narrow in the middle, for its walls are thickest there. The posterior wall is thicker than the side-walls, and the anterior wall is thicker still, owing to the heaping up of dense bone at the shin. The compact bone is much thicker in the tubercle and the intercondylar eminence than elsewhere at the upper end. The **nutrient canal** extends through the compact bone obliquely for two inches before it reaches the medullary cavity.

Tibiæ that show compression from side to side are called **platyknemic**; the condition is more common in prehistoric and savage people than among modern Europeans. Exaggerated *retroversion* of the upper end is said to be due to the habit that some people have of walking with the

Secondary Centre.	Appears at	Epiphysis fuses at	Relation of Epiphysial Line to Capsule of Neighbouring Joint.
For upper end	Birth	M. 18–19; F. 16–17	Outside.
For lower end	6 mo.–1 year	M. 18; F. 16	Outside.

knees slightly bent. The anterior margin of the lower end is often grooved transversely for the attachment of the anterior ligament of the ankle. In people who habitually squat rather than sit there may be a 'pressure' facet on that margin.

Fibula

The **fibula** or splinter-bone is the lateral and smaller bone of the leg. It is almost as long as the tibia, is very slender, and has slightly expanded ends. In some animals it is pointed at one end—hence its name [*fibula* (from *figibula*) = a pin or skewer; the equivalent word in Greek is περόνη (peronē), hence the names *peroneus* and *peroneal* given to muscles, vessels, and nerves related to the fibula].

The fibula has a **shaft** and **two ends**. It gives attachment to muscles and is so covered that it is not easily felt except at the ends. Its lower end assists in the formation of the ankle joint, but its upper end fails to reach the femur and lies 1½ inches behind and below the most prominent part of the lateral condyle of the tibia, articulating with the inferior surface of the condyle. The **upper** end is knob-like; the lower end is compressed from side to side and triangular in outline; on the **medial** side of the lower end there is a large, nearly flat, triangular facet; the **posterior** aspect can be recognized from the fact that there is a pit *behind* the lower part of the facet.

The **upper end** is the *head* of the fibula. The anterior, posterior, lateral, and medial surfaces of the **head** are identified more easily after the surfaces of the shaft

and lower end have been recognized; the medial part of the *proximal surface* bears a *facet* of considerable size for articulation with the lateral condyle of the tibia; a conical projection, the **styloid process**, stands up from the junction of the *lateral* and *posterior* surfaces. The head is felt as a hard knob well back on the lateral side of the leg at the level of the tubercle of the tibia. If the finger is passed round to its posterior surface, a big nerve, called the *lateral popliteal nerve*, can be felt and rolled between the finger and the bone; it is felt most easily when the knee is bent to a right angle to relax the muscles. The part of the shaft immediately adjoining the head is the **neck** of the fibula, and it also can be felt; the nerve inclines downwards and forwards from the back of the head and ends on the lateral side of the neck, and it is most liable to injury there.

The **lower end** is the *lateral malleolus*, the outstanding prominence on the lateral side of the ankle. It articulates with the lateral surface of the lower end of the tibia, and projects downwards beyond the tibia to articulate with the lateral surface of the talus; the talus therefore fits between the two malleoli.

The **lateral malleolus** has four surfaces—lateral, medial, anterior, and posterior. The **lateral surface** is subcutaneous. The **medial surface** bears a large, almost flat, articular *facet*; the malleolus projects so far beyond the tibia that only the upper edge of the facet articulates with the tibia; the remainder articulates with the talus. The pit behind and below the facet is the *malleolar fossa*, and is big enough to accommodate the tip of the little finger. The rough mark on the shaft, immediately above the facet, fits into the fibular notch of the tibia and is bound to its floor by an interosseous ligament. The **anterior surface** is narrow from side to side, convex from above downwards, and slightly roughened. The **posterior surface** is wider and flatter than the anterior; the width of its lower part is greatly reduced, owing to the malleolar fossa; the tendon of the peroneus brevis lies on it and often grooves it longitudinally, and the tendon of the peroneus longus lies on that of the brevis.

The **shaft** of the fibula, though slender, is strongly marked by grooves and ridges which vary in size according to the strength of the muscles and fascial sheets which have been attached to them. It has three borders and three surfaces, one of which—the posterior surface—is divided into two by an outstanding medial crest resembling a border. In addition, there is a smooth **triangular subcutaneous area** which is the upward continuation of the lateral surface of the malleolus on to the lower part of the shaft. This triangular area is continuous at its apex with the anterior border of the shaft and, since it also indicates the lateral side and inferior end, it provides sufficient information to place the bone in its proper position as well as leading to identification of all its parts. The area is about two inches in length and, along with the malleolus, is easily identified through the skin.

The **anterior border** of the shaft runs from the apex of the triangular subcutaneous area up to the neck as a sharp, even line. The **lateral surface**, for the peroneal muscles, lies lateral to the anterior border and is prolonged downwards behind the triangular area to become continuous with the posterior surface of the malleolus. It is limited posteriorly by the **posterior border** which runs from the medial margin of the posterior surface of the malleolus up to the neck of the bone, usually as a distinct edge. The **anterior surface**, for extensor muscles and peroneus tertius, lies medial to the anterior border and is very narrow, or even linear, at its upper part It usually widens to about a quarter of an inch towards its lower end. The anterior surface is in front of the interosseous membrane and so is limited medially by the **interosseous border**. This border gives attachment to the membrane but is never strongly marked and approaches close to the anterior border in its upper part. Its lower end is easier to find and runs into the rough triangular patch for the interosseous ligament, situated above the medial surface of the malleolus. The remainder of the shaft, between the posterior and interosseous borders, is named **posterior surface** because it is behind the interosseous membrane. It is divided by a prominent *medial crest* into a flat or slightly convex area, for the flexor hallucis and soleus muscles, situated lateral to the crest and a concave area between the crest and the interosseous border, for tibialis posterior muscle. The area for tibialis posterior is frequently divided by an oblique ridge beginning at the interosseous border near the neck and running downwards and backwards. It gives attachment to a fascial septum in the muscle and may be mistaken for part of the medial crest. The medial crest begins at the neck and runs down the shaft to join the interosseous border three or four inches above the lower end. It is here that the crest is most easily identified and in many fibulæ it is the most prominent ridge on the bone. Below the crest the posterior surface inclines on to the medial aspect of the bone behind the interosseous membrane.

The **nutrient foramen** is usually on the posterior surface, about the junction of the upper and middle thirds, and is directed downwards ; it may be near the lower third.

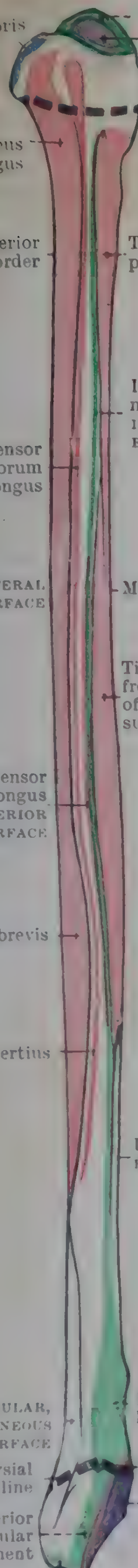


Fig. 274.—Anterior Aspect of Right Fibula.

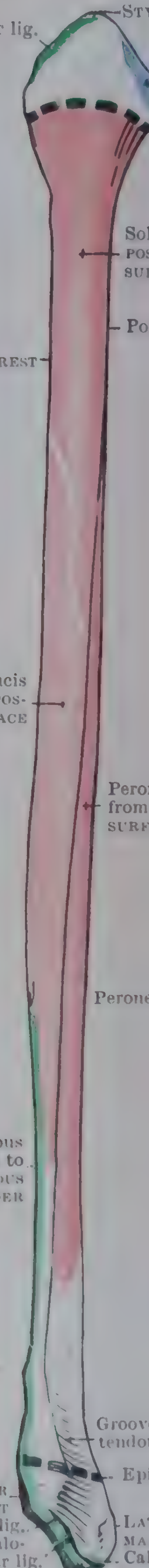


Fig. 275.—Posterior Aspect of Right Fibula.

Attachments.—The tendon of the biceps is inserted into the **head**—the main slip on the lateral side of the styloid process, and a small slip farther forwards. The lateral ligament of the

knee is attached to the head between the slips of the biceps tendon; the capsular ligament of the superior tibio-fibular joint to the margins of the *facet*; the deep fascia to the *lateral side* of the

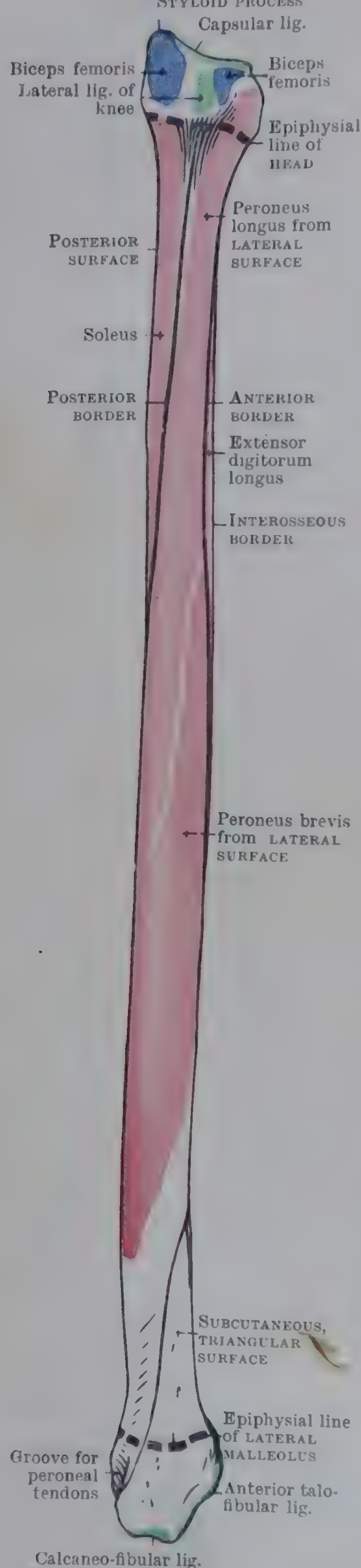


FIG. 276.—LATERAL ASPECT OF RIGHT FIBULA.

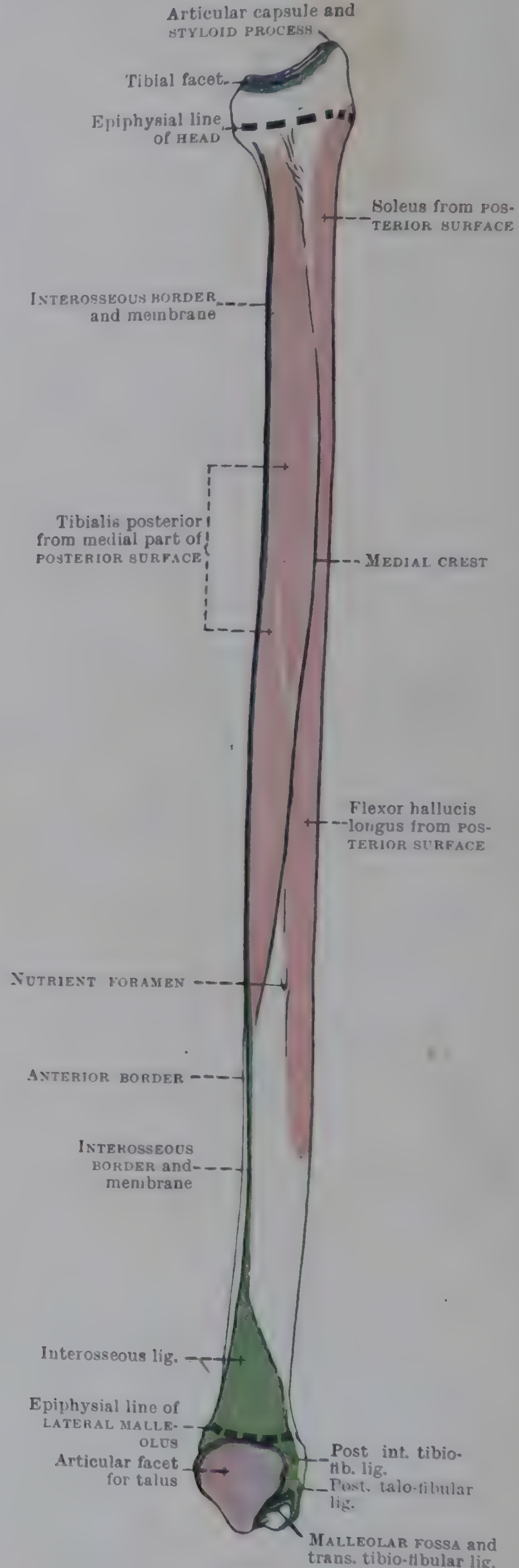


FIG. 277.—MEDIAL ASPECT OF RIGHT FIBULA.

head. The muscles that arise from the upper part of the shaft take origin also from the adjoining surfaces of the head.

The peroneus longus arises from the head and the upper two-thirds of the *lateral surface* of the **shaft**; the peroneus brevis from the lower two-thirds, overlapping the longus anteriorly in the middle third. Part of the tibialis posterior from the head and the part of the *posterior surface* between the medial crest and the interosseous border; part of soleus from the head and the upper third of the remainder of the surface, and the flexor hallucis longus from the lower two-thirds. The extensor digitorum longus from the head and the upper two-thirds of the *anterior surface*; the peroneus tertius from the lower third; and, medial to those two, the extensor hallucis longus from the middle three-fifths. The interosseous membrane is attached to the *interosseous border*; the fascia over the tibialis posterior to the *medial crest*; the posterior intermuscular septum to the *posterior border*; the anterior intermuscular septum to the greater part of the *anterior border*; the deep fascia of the leg to the *margins of the subcutaneous surface* (including the superior extensor retinaculum attached to its anterior margin); the interosseous ligament to the rough area above the facet at the lower end.

The anterior inferior and posterior inferior tibio-fibular ligaments are attached to the **lateral malleolus** at the anterior and posterior margins of its articular facet; the anterior talo-fibular ligament to the *anterior surface* of the malleolus near its tip; the calcaneo-fibular ligament to the *tip*; the posterior talo-fibular ligament and the transverse tibio-fibular ligament to the floor of the **malleolar fossa**; the superior peroneal retinaculum to the margins of the *posterior surface* of the malleolus.

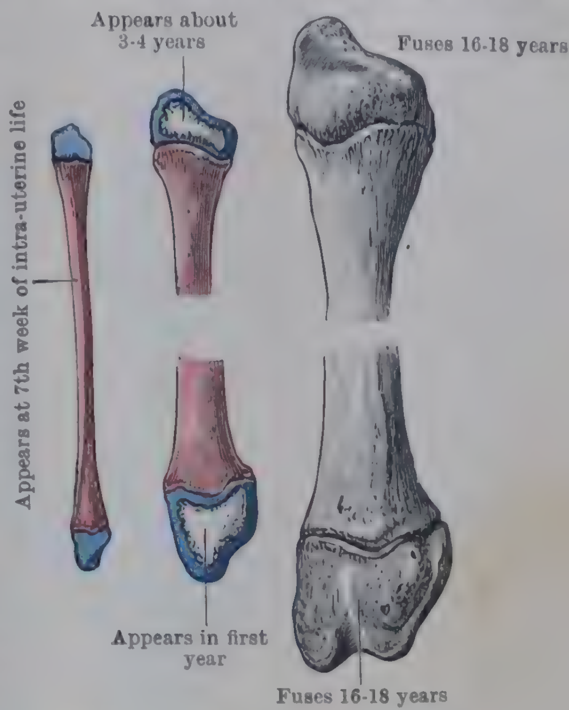


Fig. 278.—Ossification of Fibula.

Ossification (Pls. XXIV, p. 297, XXVI, p. 305).—The **primary** centre appears at the seventh week of intra-uterine life. Only the ends are cartilaginous at birth.

At the third month of intra-uterine life the fibula is nearly half as thick as the tibia, and its lower end is either at the same level as the tibial malleolus or only a very little lower. At birth it is still, compared with the tibia, much thicker relatively than in the adult; its lower end has not yet reached the adult level and does not do so until ossification has begun in it. The fibular malleolus reaches lower than the tibial in only a few vertebrates besides Man, *e.g.*, elephant, leopard, walrus; and Man vies with the Elephant in that respect. Its importance in the construction of the ankle joint accounts for its downward extension, and probably accounts also for ossification beginning in it sooner than in the upper end.

Secondary Centre.	Appears at	Epiphysis fuses at	Relation of Epiphysial Line to Capsule of Neighbouring Joint.
For lower end	**M.** 1 yr. **F.** 1 yr.	**M.** 18; **F.** 16	Medial part inside, lateral part outside.
For upper end	**M.** 3-4 yr. **F.** 3 yr.	**M.** 18; **F.** 16	Outside.

Structure and Variations.—The structure is like that of other long bones. The medullary canal extends from the neck to a point about three inches from the tip of the malleolus; its lateral wall is thicker than the medial. The *nutrient canal* is one inch in length.

The fibula is occasionally absent or incompletely developed. The facet on the head may be double or may be absent.

Tarsus

The term **tarsus** originally included nearly the whole foot [ταρσός (tarsos) = the part of the foot between the toes and the heel], but it is now applied only to the posterior half of the foot, the skeleton of which consists of seven tarsal bones.

The **tarsal bones** are closely bound together by ligaments. They are arranged in two groups—a posterior group consisting of two bones related vertically to each other, the **talus** on top and the **calcaneum** or "heel-bone" below it. The anterior group is more or less horizontal and comprises five bones; four are placed side by side—three **cuneiform** bones and, lateral to them, the **cuboid** bone. The fifth is the **navicular** which is placed between the talus and the three cuneiforms (Fig. 279).

All the tarsal bones are conveniently described as having six surfaces—anterior, posterior, superior, inferior, lateral, and medial.

Sufficient knowledge of the characters of the individual bones is necessary to give a clear understanding of the structure and mechanism of the foot.

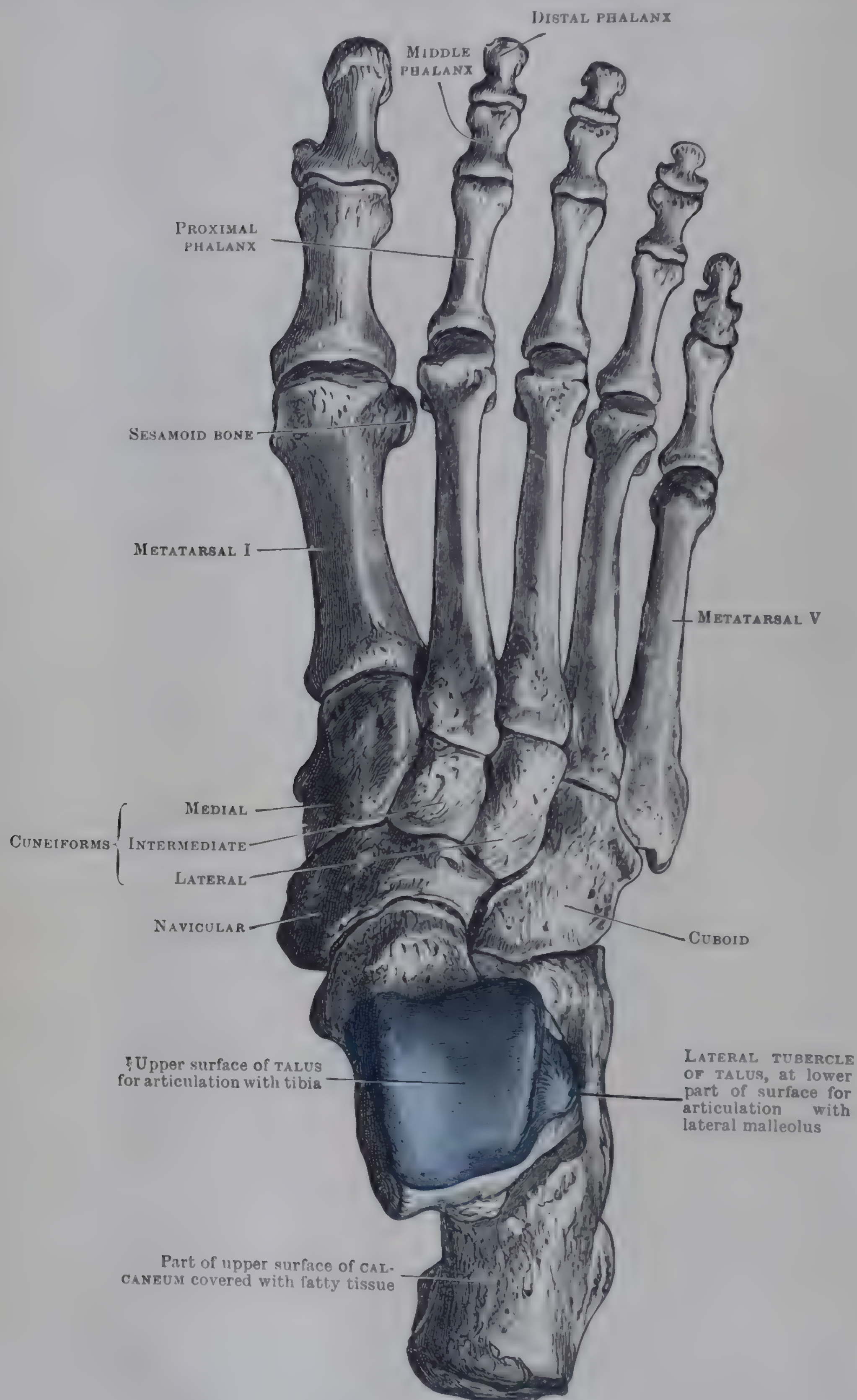


Fig. 279.—Upper or Dorsal Surface of Bones of Right Foot.

Calcaneum

The **calcaneum** is the heel-bone [*calcaneum* (allied to calx) = the heel]. It is the largest of the tarsal bones, being nearly three inches in length and about half of that in thickness.

The *anterior* and *posterior surfaces* are the ends of the bone. The anterior surface is smooth and concavo-convex, to articulate with the cuboid bone: the posterior surface is rough, and the tendo calcaneus is inserted into a specially roughened strip across the middle of the surface.

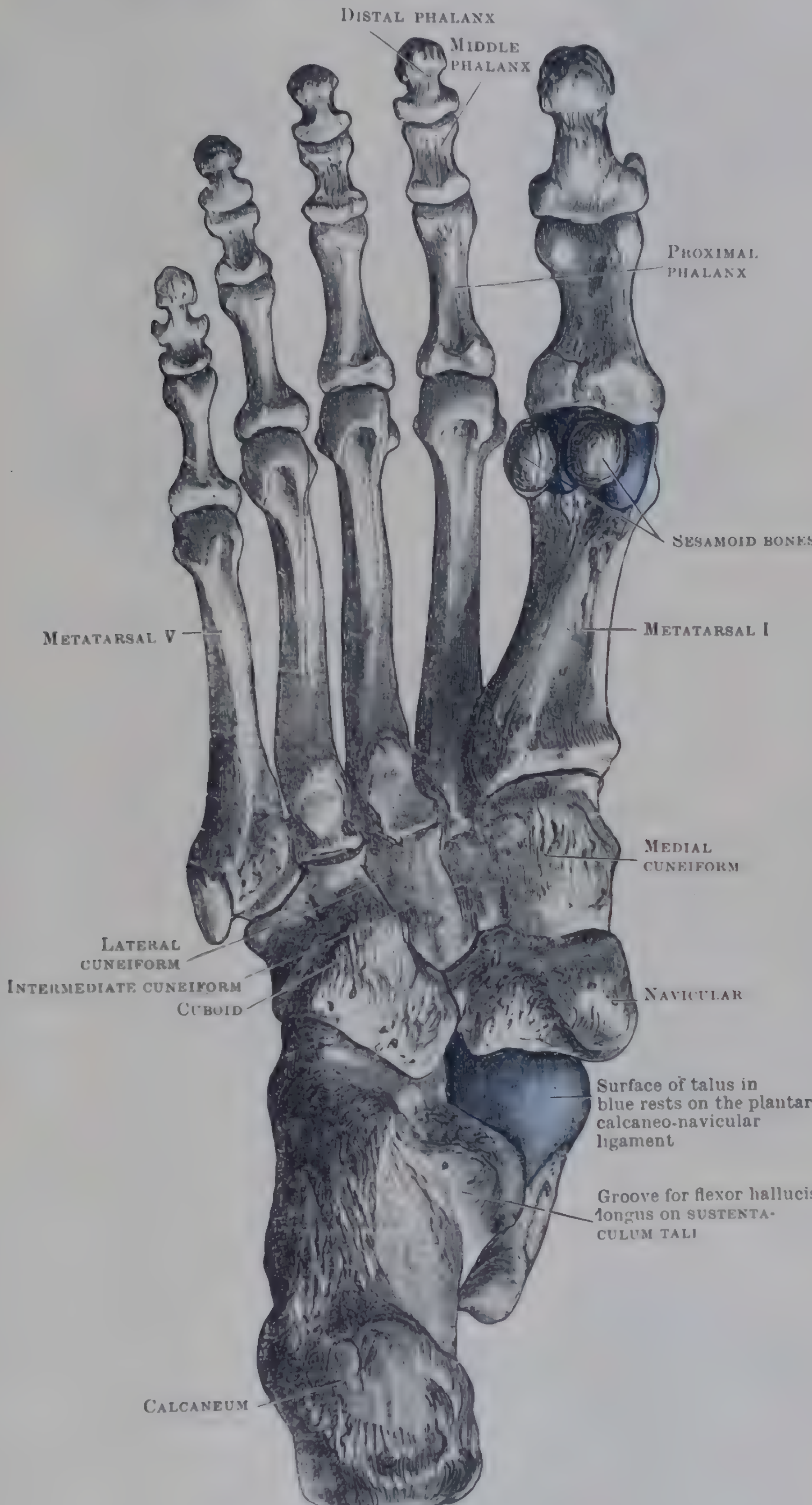


FIG. 280.—LOWER OR PLANTAR SURFACE OF BONES OF RIGHT FOOT.

The *superior surface* is distinguished from the others because it has a large, oval facet about its middle for articulation with the body of the talus. In front of the facet there is a groove for the attachment of an interosseous ligament between the talus and calcaneum (p. 394). In front of the lateral part of that groove there is

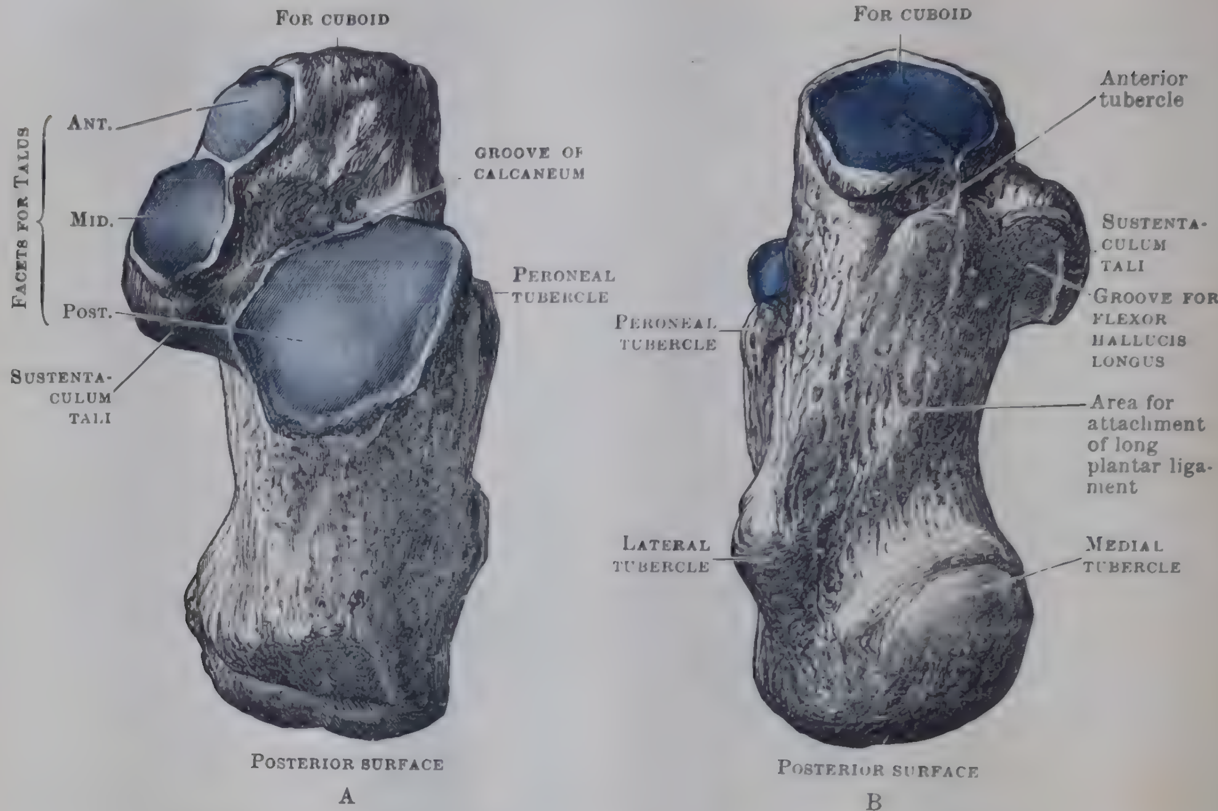


Fig. 281.—Right Calcaneum. A, seen from above; B, seen from below.

a rough, fairly flat, quadrilateral area, and at the anterior and medial corner of the area there is usually a small facet for articulation with the head of the talus. In front of and medial to the medial part of the groove, there is a projecting shelf of bone called the **sustentaculum tali** because part of the talus rests on it; the upper surface of the sustentaculum is smooth for articulation with the talus; its lower surface is grooved by the tendon of the flexor hallucis longus as it runs forwards into the sole of the foot. The medial border of the sustentaculum is thick and rough and can be felt in the living body as an ill-defined bony resistance a finger's breadth below the medial malleolus. The tendon of the flexor digitorum longus muscle lies on the medial border of the sustentaculum.

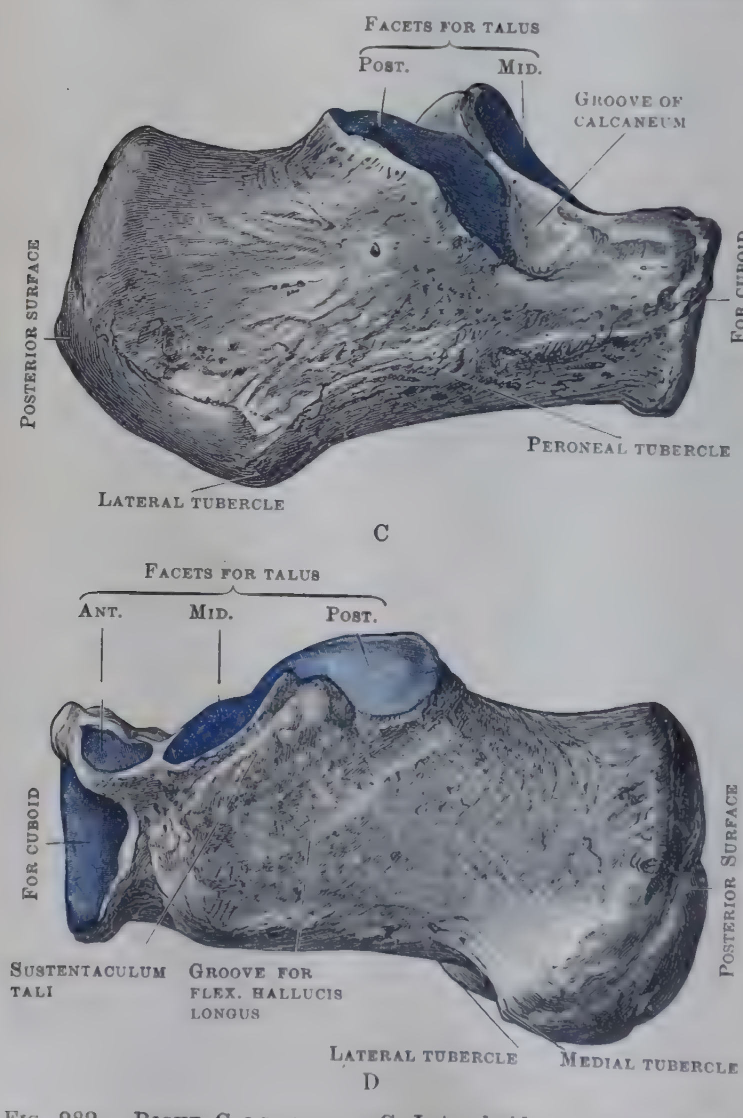


Fig. 282.—Right Calcaneum. C, Lateral side; D, Medial side.

The *inferior surface* is rough. At its anterior part there is a low, rounded eminence called the **anterior tubercle** of the calcaneum. At its most posterior part there are two blunt, rounded prominences called the **lateral** and **medial tubercles** of the calcaneum; the medial tubercle is the larger of the two. When the

calcaneum is laid on the table it rests on the three tubercles. When the sole is on the ground the long axis of the calcaneum is directed forwards, upwards and slightly sidewards; the bone rests on the backs of the lateral and medial tubercles, *i.e.*, on the lower, sloping part of the posterior surface; and the anterior part of the bone is raised up from the ground.

The *medial surface* is markedly concave owing to the projection of the medial tubercle and the sustentaculum. The *lateral surface* is slightly convex and is rough. On the anterior half of the surface, in some specimens, there is a small but well-marked **peroneal tubercle**. The tendons of the peroneus longus and brevis cross the surface obliquely—the longus below the tubercle, the brevis above it—and produce shallow grooves on the bone. Except for the strips covered by those two tendons, the whole of the lateral surface is subcutaneous and can be felt in the living foot.

The **anterior surface** is concave from above downwards and convex sideways; its margins are sharp, except medially. The **posterior surface** widens from above downwards; the upper of its three areas is crescentic in outline; the intermediate is rough for tendo calcaneus insertion; the lower has a striated appearance. The wide, saddle-shaped area behind the large facet on the **superior surface** is covered with the fatty, fibrous tissue that lies deep to the tendo calcaneus; and it varies in length with the degree of projection of the heel. The **inferior surface** is slightly concave from behind forwards and is convex from side to side. The *anterior tubercle* fades away posteriorly, but ends abruptly in front near the anterior margin, and it is separated from that margin by a shallow groove or notch. The **lateral surface** is widest at the posterior end; and its anterior third is much narrower than the rest of it. The *peroneal tubercle* is variable in position, but is usually a little below the lateral end of the rough groove of the upper surface. The wide groove or concavity that occupies the **medial surface** is oblique from above downwards and forwards; it is bridged across by the flexor retinaculum which converts it into a tunnel. The margin of the *sustentaculum tali* is sometimes grooved by the tendon of the flexor digitorum longus.

Attachments.—The tendo calcaneus is inserted into the rough strip across the middle of the *posterior surface* and is separated from the upper part of the surface by a *bursa*; the lower part of the surface is covered with the fatty pad on which the heel rests. The calcaneo-fibular ligament is attached to the middle of the *lateral surface*; the inferior peroneal retinaculum to the margins of the grooves which lodge the peroneal tendons. The flexor retinaculum and the plantar aponeurosis are attached to the **medial tubercle**, and parts of the abductor hallucis and flexor digitorum brevis arise from it; the abductor digiti minimi from both **medial and lateral tubercles**. The short plantar ligament is attached to the **anterior tubercle** and the groove in front of it; the long plantar ligament to the wide area on the *inferior surface* behind the anterior tubercle; the lateral head of the flexor accessorius arises from the lateral edge of that area, and the medial head from the *medial surface*. The deltoid ligament and the plantar calcaneo-navicular ligament are attached to the medial margin of the **sustentaculum tali**, and a slip from the tendon of the tibialis posterior is inserted into it.

The following structures, after they leave the back of the leg and turn forwards into the sole of the foot, are related to the sustentaculum tali: the tendon of the tibialis posterior lies above it, between it and the medial malleolus; the tendon of the flexor hallucis longus lies on its lower surface; the tendon of the flexor digitorum longus lies along its medial margin; the posterior tibial vessels and nerve lie between the tendons of the flexor digitorum and flexor hallucis.

The capsular ligament of the talo-calcanean joint is attached to the margins of the large, oval *facet* on the *upper surface*; the groove in front of the facet gives attachment to the interosseous talo-calcanean ligament; the rough flat area in front of the lateral end of the groove gives attachment to the stem of the bifurcated ligament, the stem of the inferior extensor retinaculum, and some fibres of origin of the extensor digitorum brevis (Fig. 347, p. 394): and the dorsal calcaneo-cuboid ligament is attached to the upper and lateral margins of the *anterior surface*.

Structure.—For the architectural features of the calcaneum, see p. 108, and Pl. II, p. 104.

Talus

The **talus**, ankle-bone or witch-bone, is next to the calcaneum in size, and it has large, smooth articular facets on several of its surfaces. It rests on the upper surface of the calcaneum, directly below the lower end of the tibia: it is held between the two malleoli, and with them and the lower end of the tibia it forms the *ankle joint* [*talus* = the ankle-bone].

The bulkier part of the talus is the *body*; the smooth and rounded end is the anterior part of the bone and is called the *head*; the rough, slightly constricted part between the head and the body is the *neck*.

The *superior surface* of the **body** is a large face for articulation with the lower end of the tibia. It is convex from before backwards, slightly concave from side

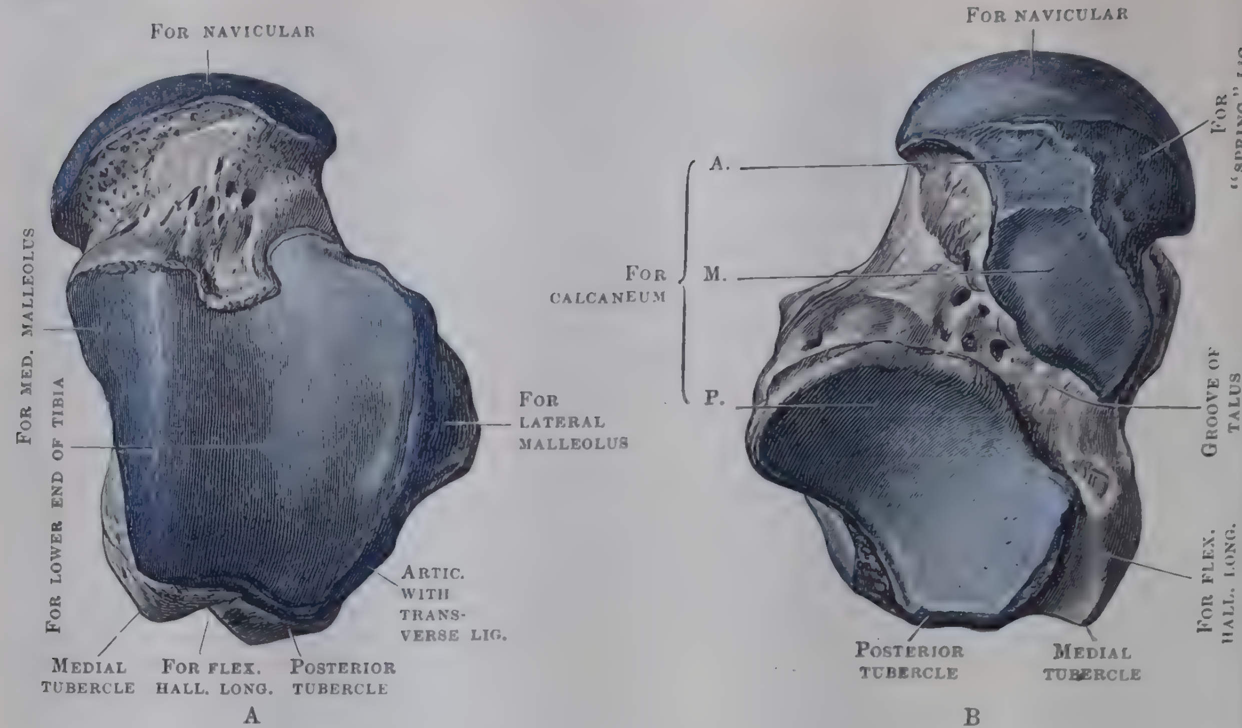
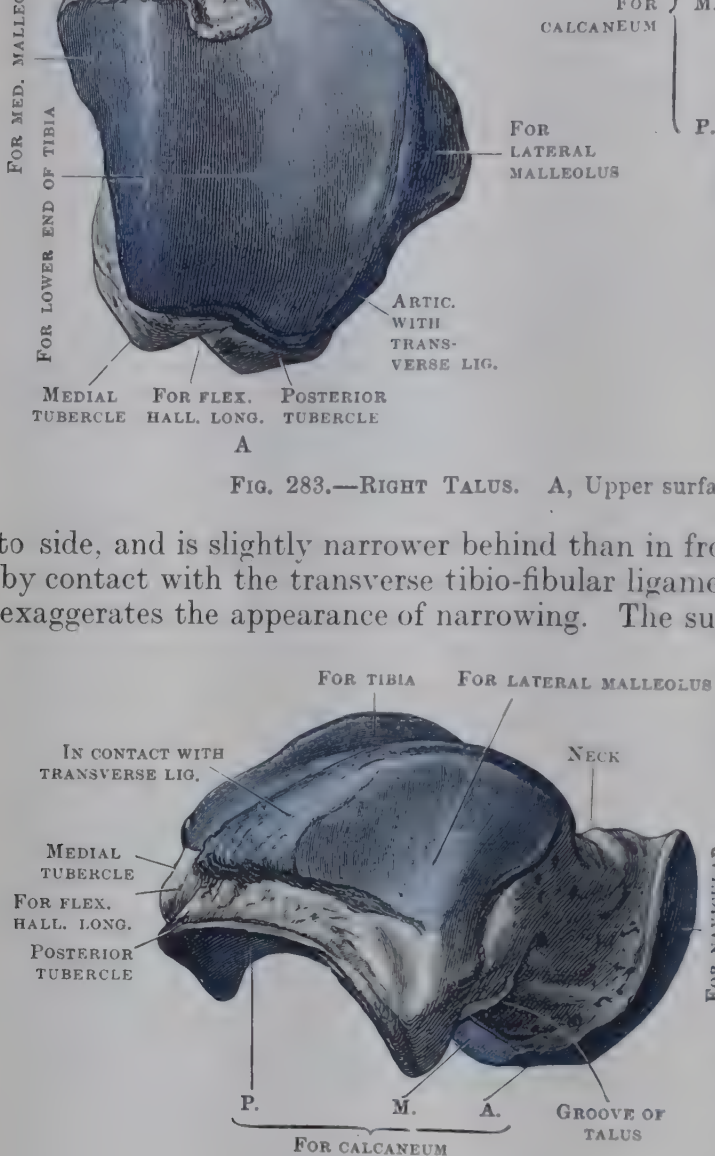


Fig. 283.—Right Talus. A, Upper surface; B, Lower surface.

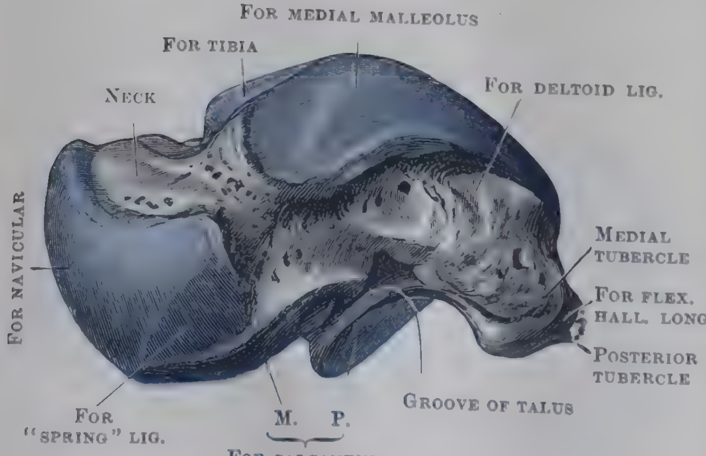
to side, and is slightly narrower behind than in front. The lateral border is bevelled by contact with the transverse tibio-fibular ligament to form a triangular area which exaggerates the appearance of narrowing. The superior and lateral surfaces and the articular part of the medial surface are sometimes, together, called the **trochlea** of the talus. The *inferior surface* has two facets with a deep groove between them. The one farther back is large, concave, and oval, with the long axis oblique, and it articulates with the large, oval facet on the upper surface of the calcaneum. The one in front is on body, neck, and head; it articulates with the sustentaculum tali and with the facet on the anterior part of the upper surface of the calcaneum; it varies in its extent, and the part on the head may be separate from the rest.

The *medial surface* can be distinguished from the lateral surface because it is nearly all rough and is flush with the medial side of the neck. Near the upper margin there is a comma-shaped facet for articulation with the medial malleolus.

The *lateral surface* stands away from the neck, and it is nearly all occupied by a large facet for articulation with the lateral malleolus. The posterior part of the facet is united to the upper surface by the triangular facet mentioned above.



Lateral side.



Medial side.

Fig. 284.—Right Talus.

The *posterior surface* is very small. It is crossed by a fairly broad, oblique groove that lodges the tendon of the flexor hallucis longus. When the talus and calcaneum are placed together properly, that groove is continuous with the groove for the same tendon on the lower surface of the sustentaculum tali. The projection on the lateral side of the groove is the **posterior tubercle** of the talus, and the rough prominence on the medial side is the **medial tubercle**.

The *anterior surface* is the convex, smooth surface of the **head**; it articulates with the navicular bone. The facet on the lower surface of the head for articulation with the anterior part of the upper surface of the calcaneum is usually continuous with the facet that articulates with the sustentaculum tali. The lower part of the medial side of the head articulates, not with a bone but with the plantar calcaneo-navicular or "spring" ligament, which stretches between the sustentaculum tali and the plantar surface of the navicular bone; a faint ridge often marks off that area from the rest of the articular surface of the head.

When the talus and calcaneum are placed together, the grooves which give attachment to the interosseous ligament (p. 394) form a tunnel called the **canalis tarsi** which expands at its antero-lateral end to form the **sinus tarsi** (Wood Jones, 1944). The head of the talus looks in a medial direction as well as forwards. The articular facet on the lateral surface of the body is concave from above downwards; at its lower angle the bone projects laterally to form the **lateral tubercle**. On the medial surface, below the tail of the articular comma, there may be a circular or oval impression for the attachment of part of the deltoid ligament.

Inversion is the movement whereby the medial border of the foot is lifted up, the lateral border is depressed, and the sole looks towards the median plane. **Eversion** is the reverse movement whereby the lateral border of the foot is lifted up. Movement at the ankle joint is almost entirely flexion and extension, taking place between the tibio-fibular socket and the body of the talus, and the anterior part of the body is uncovered by the tibia in full extension. Inversion and eversion are movements of the rest of the foot below the talus and round the head of the talus, which is partially uncovered in full inversion (p. 398). When the foot is extended so that it is almost in line with the leg, and is inverted, the head of the talus can be both felt and seen as a distinct prominence about an inch in front of and below the ankle joint, and the body of the talus also may be felt near the lateral malleolus.

Attachments.—The anterior ligament of the ankle joint and the dorsal talo-navicular ligament are attached to the *upper surface* of the **neck**; the anterior talo-fibular ligament to the *lateral surface*; a part of the deltoid ligament to the *medial surface* of both neck and **body**; the capsular ligament of the talo-calcanean joint to the margins of the large, oval facet on the *lower surface* of the body; the interosseous ligament to the floor of the *groove* in front of that facet; the posterior ligament of the ankle joint to the upper part of the *posterior surface*; the posterior talo-fibular ligament to the **posterior tubercle**. No muscle or tendon is attached to the talus.

Cuboid Bone

The **cuboid** bone may be picked out from the other smaller tarsal bones because of its more cubical shape and the ridge and groove on its inferior surface. It lies in the lateral margin of the foot in front of the calcaneum.

The *anterior* and *posterior surfaces* can be distinguished from the others because they are both wholly articular. The posterior surface is concavo-convex, slopes from behind forwards and sidewards, and articulates with the calcaneum. The anterior surface is nearly flat; it slopes backwards from medial to lateral side, but its slope is not so great as that of the posterior surface; a faint vertical ridge divides it into two parts which articulate with the bases of the fourth and fifth metatarsal bones.

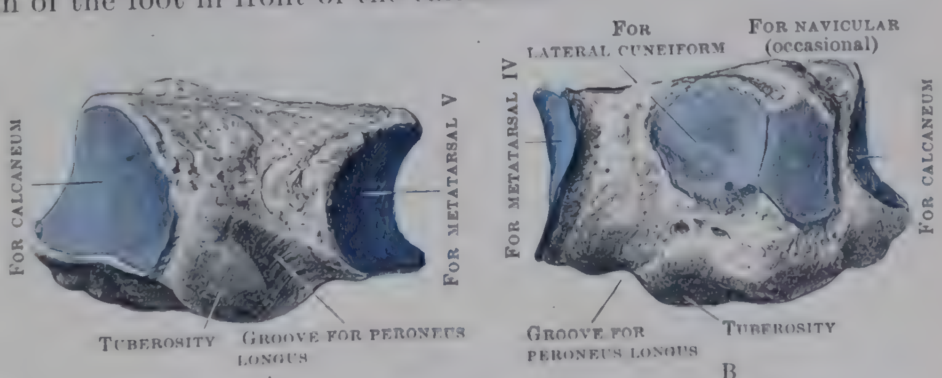


FIG. 285.—RIGHT CUBOID BONE. A, Lateral Side; B, Medial Side.

The *superior surface* is distinguished from the others because it is nearly flat and is rough—having no articular facet. Owing to the slope of the dorsum of the foot from medial to lateral border, the upper surface of the cuboid is flush, not with the upper surface of the calcaneum but with the lateral surface when the bones are placed together properly. The *inferior surface* is rough and uneven. Close to its anterior margin it is crossed by a fairly deep groove which lodges the tendon of the peroneus longus as it crosses the sole of the foot; the posterior boundary of the groove is a broad, prominent ridge, the lateral end of which is called the **tuberosity.**

The *lateral surface* is the smallest of all the surfaces, owing to the slope of the other surfaces, and it looks downwards as well as in a lateral direction. It is occupied by the tuberosity and the lateral end of the groove seen on the plantar surface. On the antero-lateral aspect of the tuberosity there is often a smooth facet produced by contact with a sesamoid bone or cartilage which lies in the substance of the peroneus longus tendon as the tendon turns into the sole. The *medial surface* is large and rather uneven; about its middle there is a facet for articulation with the lateral cuneiform bone; and, behind that facet and continuous with it, there may be another, smaller facet for articulation with the navicular bone.

The long peroneal tendon traverses the whole length of the groove on the lateral and lower surfaces; and the groove is lined throughout with the synovial sheath of the tendon. The facet for the peroneal sesamoid is, however, not in line with the groove. The tendon, as it enters the groove, expands, so that the part of it which contains the sesamoid articulates with the facet while its upper edge lies in the groove. The sesamoid glides obliquely on the facet during the movements of eversion and inversion; during inversion the tendon is partly drawn off the facet and then occupies the lateral end of the groove more completely.

Attachments.—Dorsal, plantar, and interosseous ligaments that bind the **cuboid** to neighbouring bones are attached to the rough parts of its surfaces. The long plantar ligament is attached to both *lips* of the **groove** on the *plantar surface* and holds the peroneus longus tendon in place. A slip from the tendon of the tibialis posterior is inserted into the medial part of the groove; and a slip of the flexor hallucis brevis arises from the medial part of the area behind the ridge.

Navicular Bone

The **navicular bone** is readily identified because one of its two large surfaces is markedly concave—hence its name, from a fancied resemblance to a boat. It lies in the medial side of the foot in front of the talus; and it is compressed from before backwards.

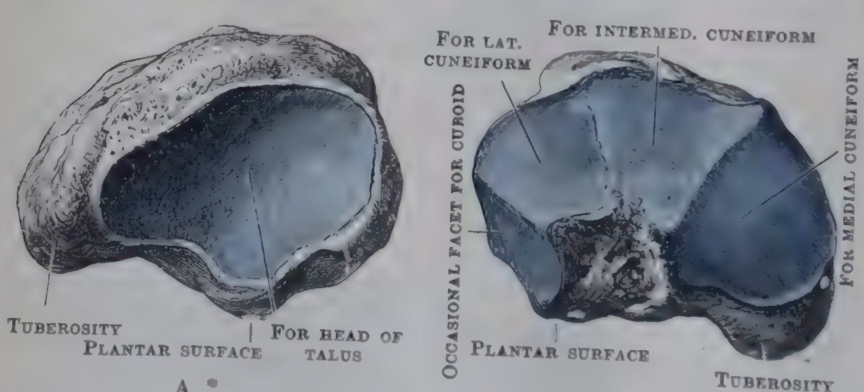


Fig. 286.—Right Navicular Bone.
A, Posterior aspect; B, Anterior aspect.

The *posterior surface* is the large, smooth, concave surface, and it articulates with the head of the talus. The *anterior surface* also is smooth, but it is slightly convex, and is mapped out by faint ridges into three areas for articulation with the three cuneiform bones. The *superior surface* is rough and is convex in its longer measurement. The *inferior surface* also is rough, but it is much smaller than the dorsal surface and is very uneven.

The *medial surface* is modified into a rough projection called the **tuberosity** of the navicular bone. This tuberosity is an important landmark and can be felt on the medial side of the foot about an inch below and in front of the medial malleolus. When shoes are worn the tuberosity is felt at the edge of the shoe. Close to the tuberosity, on the plantar surface, there is a shallow, oblique groove that lodges the smaller, deeper part of the tendon of the tibialis posterior as it

runs forwards in the sole. The *lateral* surface is not marked off from the superior surface by any definite line; it is small and usually rough, but it may be faceted to articulate with the cuboid bone.

Attachments.—Dorsal and plantar ligaments are attached to the rough parts and bind the **navicular** bone to adjacent bones. The most important is the plantar calcaneo-navicular ligament (or "spring" ligament), which stretches from its *plantar surface* to the sustentaculum tali. The anterior fibres of the deltoid ligament are attached to the **tuberosity**, which receives also a great part of the tendon of the tibialis posterior.

Cuneiform Bones

The three **cuneiform** bones are wedge-shaped [*cuneus* = a wedge]. They lie side by side in front of the navicular bone and link it with the medial three metatarsal bones. Their anterior and posterior surfaces are occupied by smooth articular facets. The medial cuneiform is the largest and most important; the intermediate one is the smallest and is the most definitely wedge-shaped.

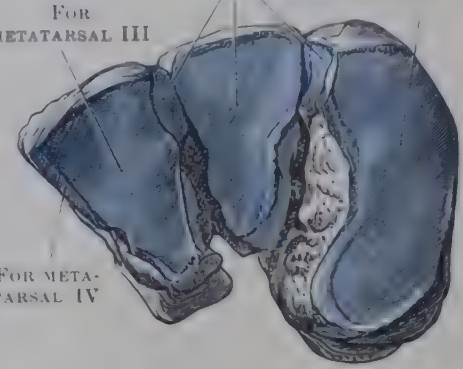


Fig. 287.—Anterior aspect of Cuneiform Bones of Right Foot.

The **medial cuneiform** lies in the medial side of the foot and is the bone felt in front of the tuberosity of the navicular bone. The *anterior surface* is kidney-shaped in outline, the concave edge being its lateral margin; it articulates with the base of the first metatarsal bone. The *posterior surface* is concave and pear-shaped, with the stalk of the pear upwards; it articulates with the navicular bone. The *lateral surface* is uneven and slightly concave; it has facets near its posterior and upper margins for articulation with the intermediate cuneiform and with the medial side of the base of the second metatarsal bone. The *medial surface* is the largest of the surfaces and is rough, and, in conformity with the shape of the medial side of the foot, it is convex from above downwards. At the most anterior and lowest part there is a smooth impression, resembling a facet, for the insertion of the tendon of the tibialis anterior, under which a bursa may lie. The *inferior surface* is rough and is the base of the wedge. The *superior surface* is reduced to a border—the edge of the wedge—between the lateral and medial surfaces, and it slopes downwards and backwards, because the posterior surface is smaller than the anterior.

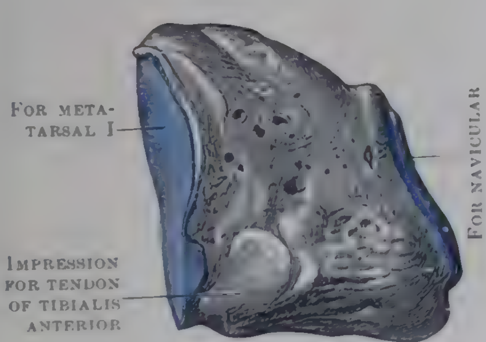


Fig. 288.—Right Medial Cuneiform (Medial Side).

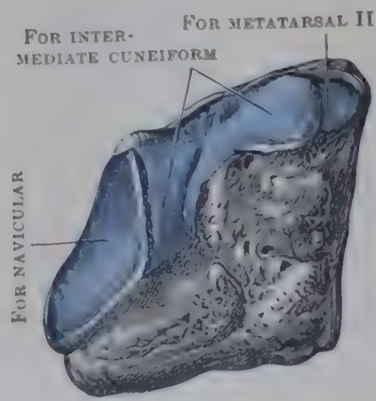


Fig. 289.—Right Medial Cuneiform (Lateral Side).

The **intermediate cuneiform** is the smallest of the tarsal bones. Its *superior surface* is square in outline, rough and slightly convex, and is the base of the wedge. The *inferior surface* is reduced to a rough border between the medial and lateral surfaces, and is the edge of the wedge. The *anterior* and *posterior surfaces* are triangular in outline: the anterior is slightly convex and articulates with the base of the second metatarsal bone; the posterior is slightly concave and articulates with the navicular bone. The *medial surface* has a facet along its upper border and another along its posterior border, both for articulation with the medial

cuneiform and usually confluent to form a single L-shaped facet. The rest of the surface is rough. The *lateral surface* has a facet along its posterior border for articulation with the lateral cuneiform, and the rest of it is rough. The facet along the upper border distinguishes the medial surface from the lateral surface; the facets along the posterior borders enable one to distinguish the posterior surface from the anterior, if that has not been done already.

The **lateral cuneiform** is larger than the intermediate cuneiform—if both specimens are from the same skeleton. If they are not, a large intermediate cuneiform can be identified by its square superior surface.

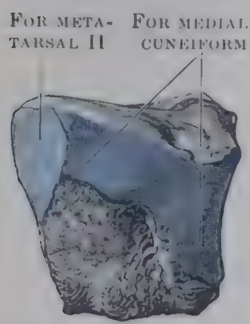


Fig. 290. — Right Intermediate Cuneiform (Medial Side).

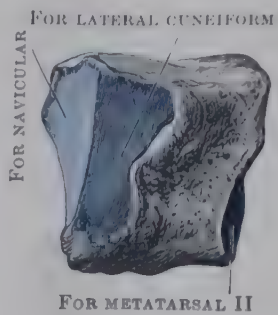


Fig. 291. — Right Intermediate Cuneiform (Lateral Side).

The *superior surface* of a lateral cuneiform is oblong in outline, rough and nearly flat, and is the base of the wedge; its anterior part turns medially, so that its long axis is slightly bent and its lateral border is angulated. The *inferior surface* is reduced to a rough, thick border between the medial and lateral surfaces, and is the edge of the wedge. The *anterior surface* is covered with a facet for articulation with the base of the third metatarsal bone, and is nearly triangular in outline. The upper and larger part of the *posterior surface* is covered with a quadrangular facet for articulation with the navicular bone, and the small, lower part is rough. The *medial surface* has a narrow facet along its posterior border for articulation with the intermediate cuneiform, and usually two small facets along its anterior border for articulation with the lateral side of the base of the second metatarsal bone; the rest of the surface is rough. The *lateral surface* is usually wider from before backwards than the medial surface; and it has a small facet at its anterior border for articulation with the medial side of the base of the fourth metatarsal bone. It has also a large facet in its upper posterior corner; that facet distinguishes the lateral surface from the medial surface, distinguishes the lateral cuneiform from the intermediate, and enables one to identify the posterior surface, for it lies close to the posterior border; it articulates with the cuboid bone. The rest of the lateral surface is rough.

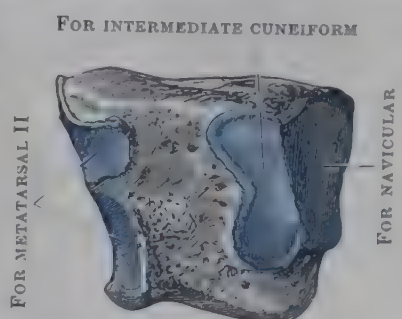


Fig. 292.—Right Lateral Cuneiform (Medial Side).

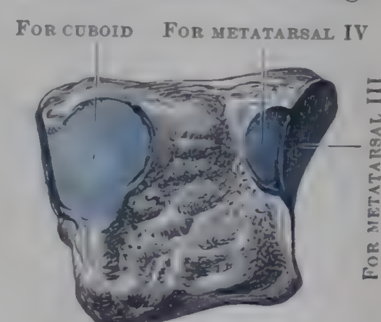


Fig. 293.—Right Lateral Cuneiform (Lateral Side).

When the three cuneiform bones are fitted together, their posterior surfaces are nearly flush, for they all articulate with the front of the navicular bone. The intermediate cuneiform is shorter than the other two; a gap is left, therefore, between the medial and the lateral and in front of the intermediate one. (See Fig. 279.) The base of the second metatarsal bone fits into the gap. This metatarsal bone, therefore, articulates posteriorly with the intermediate cuneiform, and at the sides with the medial and the lateral—an arrangement which increases the stability of the foot, but adds to the difficulty of amputating the foot at the tarso-metatarsal joints. The intermediate and lateral cuneiform bones are placed edge downwards and are of less depth than the first; the plantar surfaces of the cuboid bone and the medial cuneiform are therefore not far apart.

Attachments.—The three **cuneiform** bones are united to one another and to adjacent bones by dorsal, plantar, and interosseous ligaments. A large part of the tendon of the tibialis posterior is inserted into the posterior part of the *inferior surface* of the **medial** cuneiform, and it sends slips to the inferior surfaces of the **other two**. The greater part of the tendon of the tibialis anterior is inserted into an impression situated low down and far forward on the *medial surface* of the **medial** cuneiform, and the smaller part of the peroneus longus tendon is inserted into an impression at

the corresponding point on its *lateral surface.* The medial cuneiform, therefore, receives parts of the tendons of the tibialis anterior, tibialis posterior, and peroneus longus, while the intermediate and lateral cuneiform bones get only slips from the tibialis posterior.

Metatarsus

The **metatarsus** is in front of the tarsus and is the skeleton of the anterior or distal half of the foot proper [μετά (meta) = next after]. It consists of five separate **metatarsal bones**—one corresponding to each toe. They are named by number—*first*, *second*, etc., beginning with the one for the big toe. Each metatarsal is a miniature long bone, having a **shaft** and **two ends**. They are slightly concave lengthwise on the inferior or plantar surface; the rounded end is the **anterior** or distal end and is called the *head*; the **posterior** end is larger and forms the *base*.

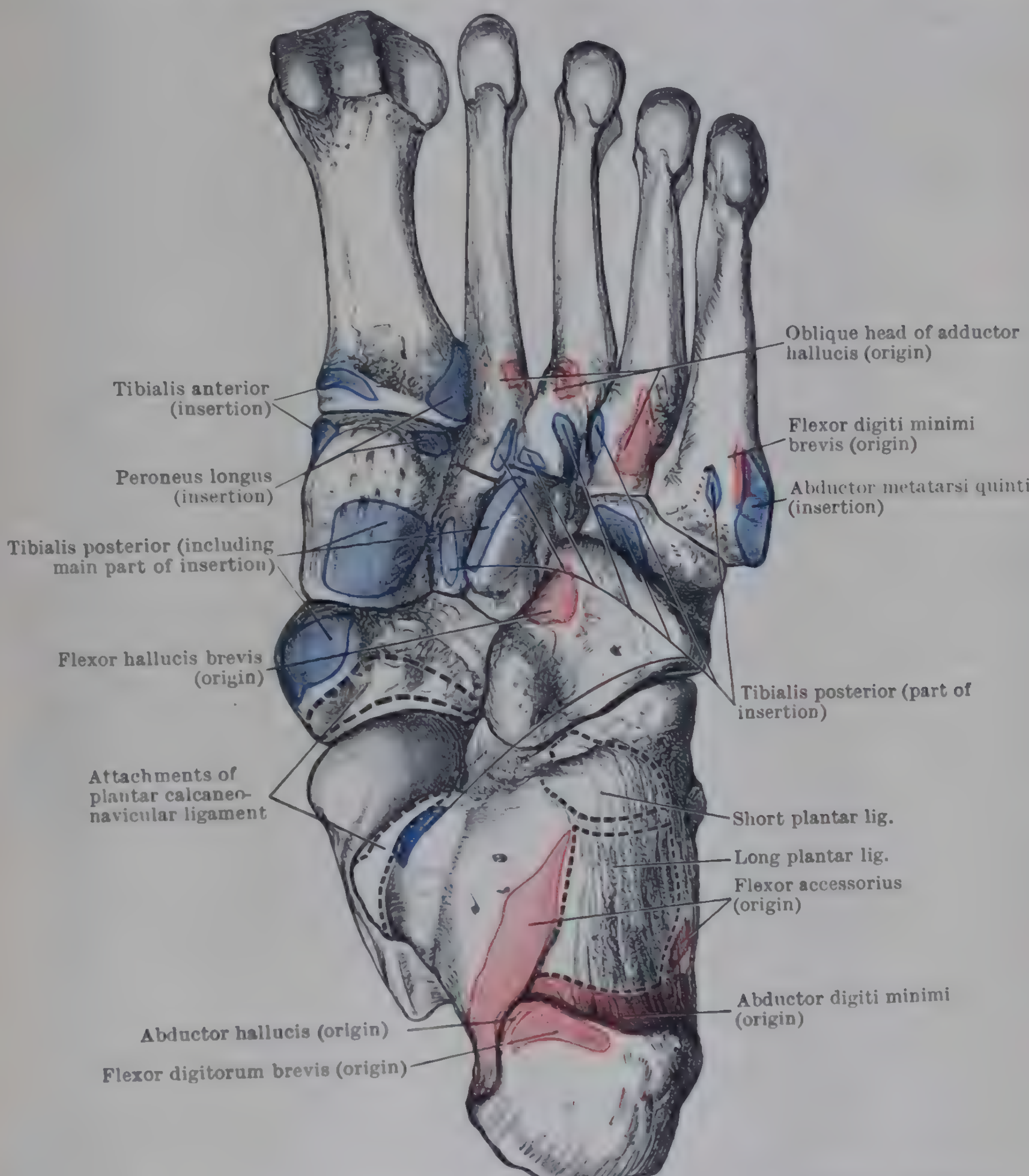


Fig. 294.—Muscle Attachments to Left Tarsus and Metatarsus (Plantar Aspect).

The corresponding bones of the hand are *metacarpal bones*. The metatarsal bones are more flattened from side to side than the metacarpals and, except in the case of the first, the shaft tapers to a narrow head. A metacarpal has on its dorsal surface a long, flat, triangular area, the base of which is at the wide, rounded head of the bone. Metatarsal bones have no such area. The metatarsals are about three inches long, and they are rather longer than the metacarpals if the bones are from

the same skeleton. The first metatarsal and metacarpal bones each have their own special characters.

The bases of the metatarsal bones are firmly bound to the tarsus by ligaments, and their *posterior surfaces* articulate with the tarsus, forming *tarso-metatarsal joints.* The bases of the lateral four are tightly bound to each other and articulate *side by side,* forming *intermetatarsal joints*; the base of the first sometimes articulates with that of the second but is usually free.

FIG. 295.—RIGHT FIRST METATARSAL BONE (Plantar Aspect).

The **heads** articulate with the proximal row of phalanges, forming *metatarso-phalangeal joints.* The sides of the heads have grooves and tubercles for the attachment of the collateral ligaments of these joints. The articular part extends much farther on to the plantar surface than on to the dorsum, because when the toe is *flexed* (*i.e.,* moved towards the sole) the base of the phalanx articulates with the plantar surface of the head of the metatarsal; when the toe is *extended* it is in a straight line with the metatarsal, and the base of the phalanx articulates with the distal surface of the head. *Dorsiflexion* or *hyperextension* is the movement of bending the toe upwards out of line with the metatarsal; the degree to which it is possible varies in different people but is never great, and the articular surface of the head extends, therefore, very little on to the dorsum.

The **first metatarsal bone** can be felt in all its length in the medial side of the foot. Its **base**—looked at end-on—is kidney-shaped, with the long axis vertical, and the notched or concave side is the *lateral* side. It articulates with the medial cuneiform bone. The **head** is slightly compressed from above downwards, and it has two well-marked grooves on its lower or *plantar* surface for articulation with two sesamoid bones. The **shaft** is three-sided with dorsal, plantar, and lateral surfaces which can be identified by reference to the head and base.

The **fifth metatarsal bone** is easily distinguished from the others because it is compressed from above downwards, has a relatively small **head**, and has a large **tubercle** on the *lateral* side of the **base**. The bone can be felt in its whole length in the lateral border of the foot, and the tubercle makes the prominence—seen as well as felt—about midway between the heel and the little toe. The posterior surface of the base articulates with the cuboid.

A line drawn from the base of the first metatarsal to the tubercle of the fifth slants backwards, and corresponds fairly closely to the position of the tarso-metatarsal joints. These joints and the posterior surfaces of the bases of the lateral four metatarsals therefore slope backwards from medial to lateral side; consequently, the lateral surface of a metatarsal is longer than the medial surface and can be distinguished at a glance.

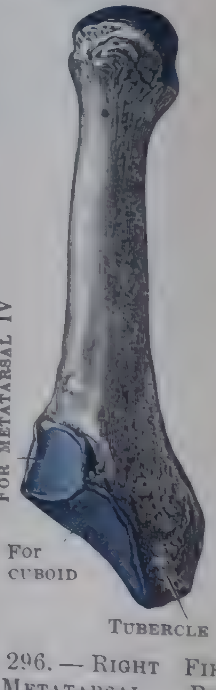


FIG. 296.—RIGHT FIFTH METATARSAL BONE (Dorsal Aspect).

The **second** and **third metatarsal bones** are very much alike. They are compressed from side to side in all their length; the posterior surface of the base is nearly triangular in outline and articulates with a cuneiform bone. But they can be distinguished if the *lateral* surface of the base is examined: the lateral surface of the **second** has two facets—an upper and a lower—separated by a horizontal groove, and one or both of the facets are double; for the base of the second metatarsal fits in between the lateral and medial cuneiform bones, articulating with them, and the lateral surface articulates also with the base of the third metatarsal.

The **head** and **shaft** of the **fourth metatarsal bone** resemble those of the second and third, but the base is more irregular, is more cuboidal in shape, and its posterior surface, which

PLATE XXVII

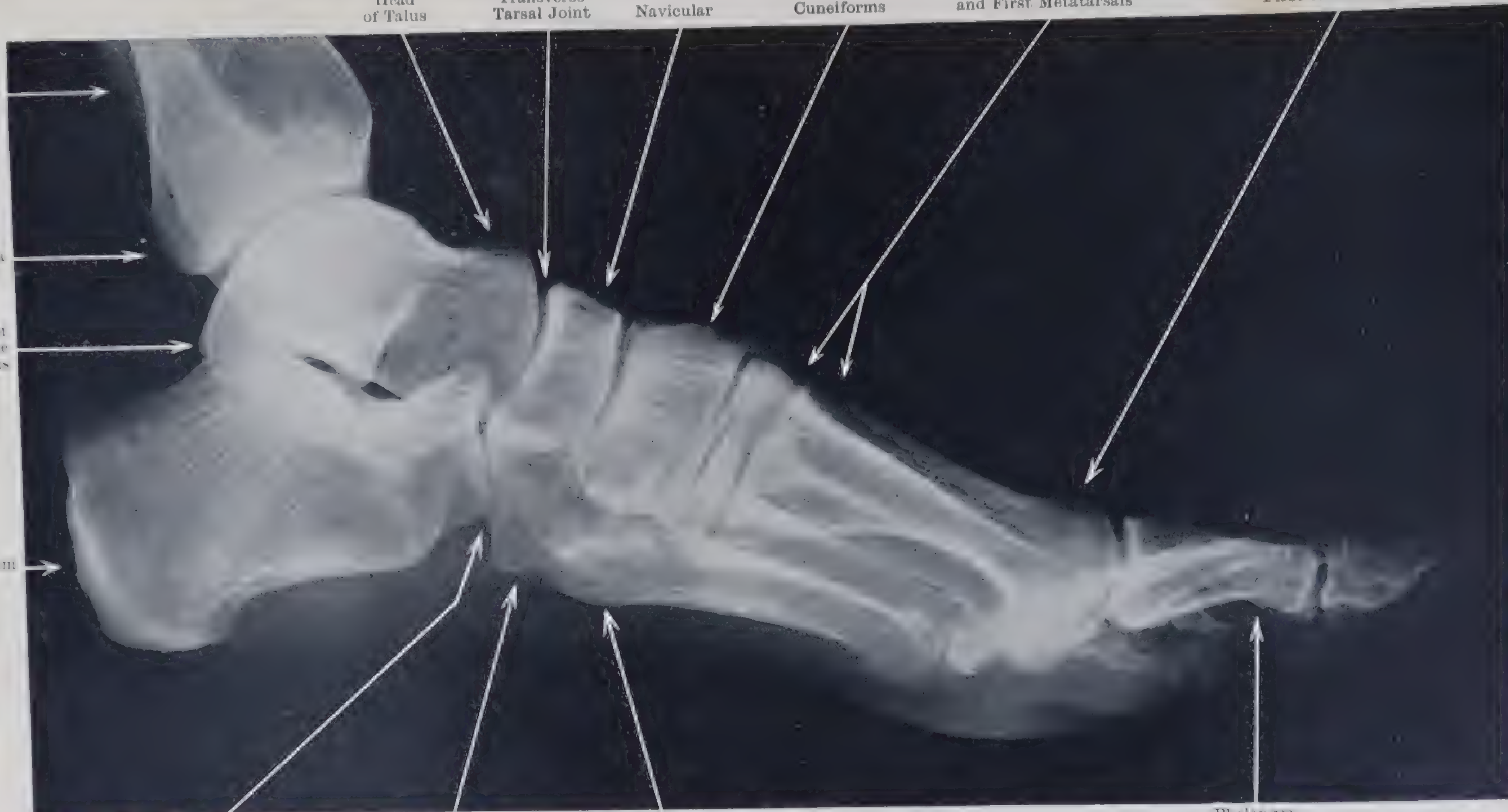


PLATE XXVII.—LATERAL RADIOGRAPH OF FOOT OF GIRL AGED 17. (Dr. J. Duncan White.)

Note how the Medial Cuneiform overlaps the base of the Second Metatarsal. For the change in the relative position of the articular surfaces of Tibia and Talus during movements of the Ankle, compare Plate XXV, Fig. 2, p. 304.

[Facing p. 320

PLATE XXVIII

FIG. 1.—RADIOGRAPH OF FOOT OF FULL-TIME FŒTUS.

Cf. Plate XVIII, Fig. 1, p. 273, and note (1) the presence of centres of ossification for tarsal bones, (2) that the Phalanges of the Foot are less advanced than those of the Hand.

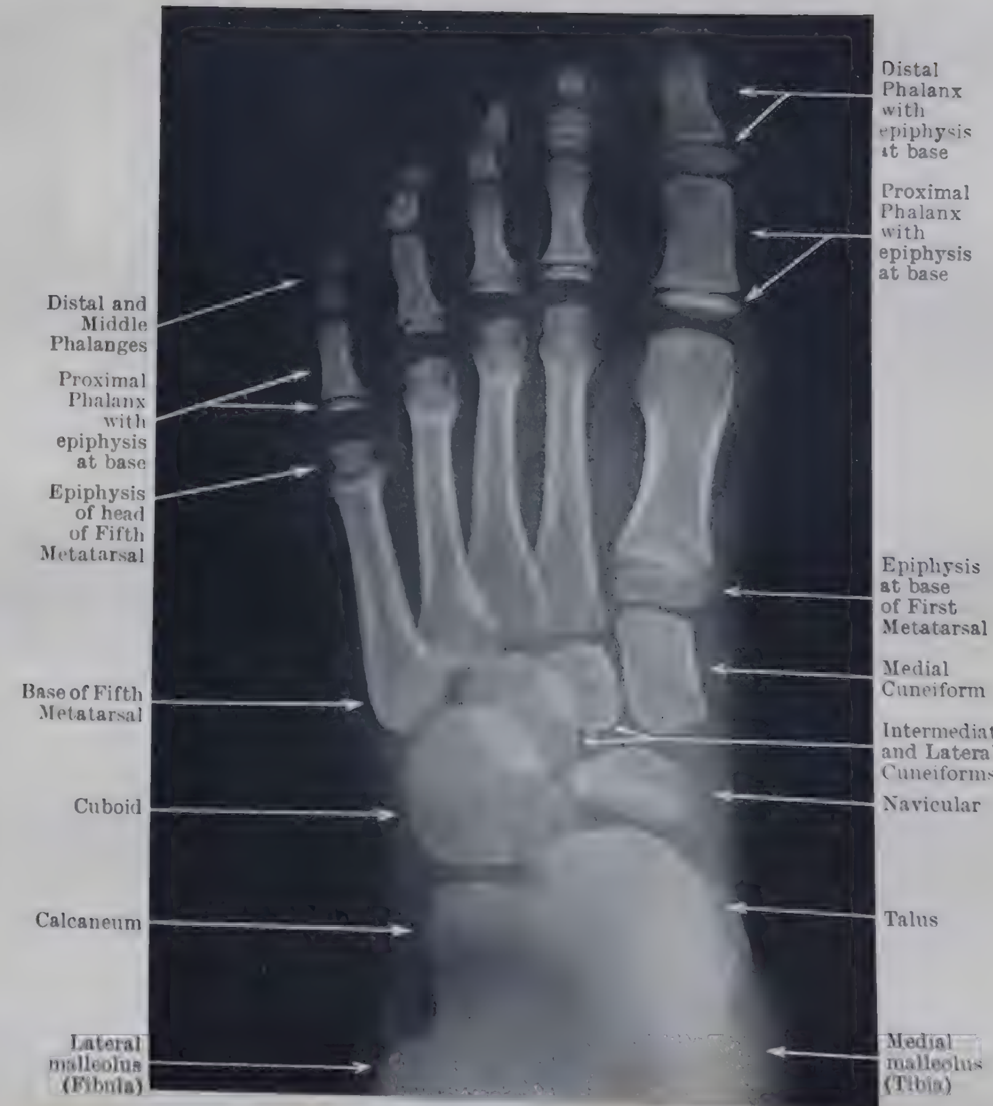


FIG. 2.—RADIOGRAPH OF FOOT OF BOY AGED 7. (Dr. J. Duncan White.)

Cf. Plate XVIII, Fig. 2, noting that the Tarsus is more advanced in ossification than the Carpus, but that the Phalanges of the Toes are less advanced than those of the Fingers.

[Facing p. 321]

articulates with the cuboid, is more nearly square in outline. The *lateral surface* of the **base** has a large facet bounded by an oblique groove; in that respect it resembles the lateral surface of the third, but the medial surfaces are quite different: the *medial surface* of the **third** has two small facets, an upper and a lower; the *medial surface* of the **fourth** has a large facet which is usually divided, for it articulates not only with the base of the third metatarsal but also with the lateral surface of the lateral cuneiform bone.

The articular surface of the head is bounded, on the sides and superiorly, by a groove—better marked in the smaller metatarsals than in the first. On each side the upper part of the groove is bounded posteriorly by a smooth tubercle. The edge of the plantar part of the articular surface is notched in the middle. The boundaries of the notch end posteriorly as pointed tubercles. The groove on the first for the medial sesamoid is usually the wider (Fig. 294.)

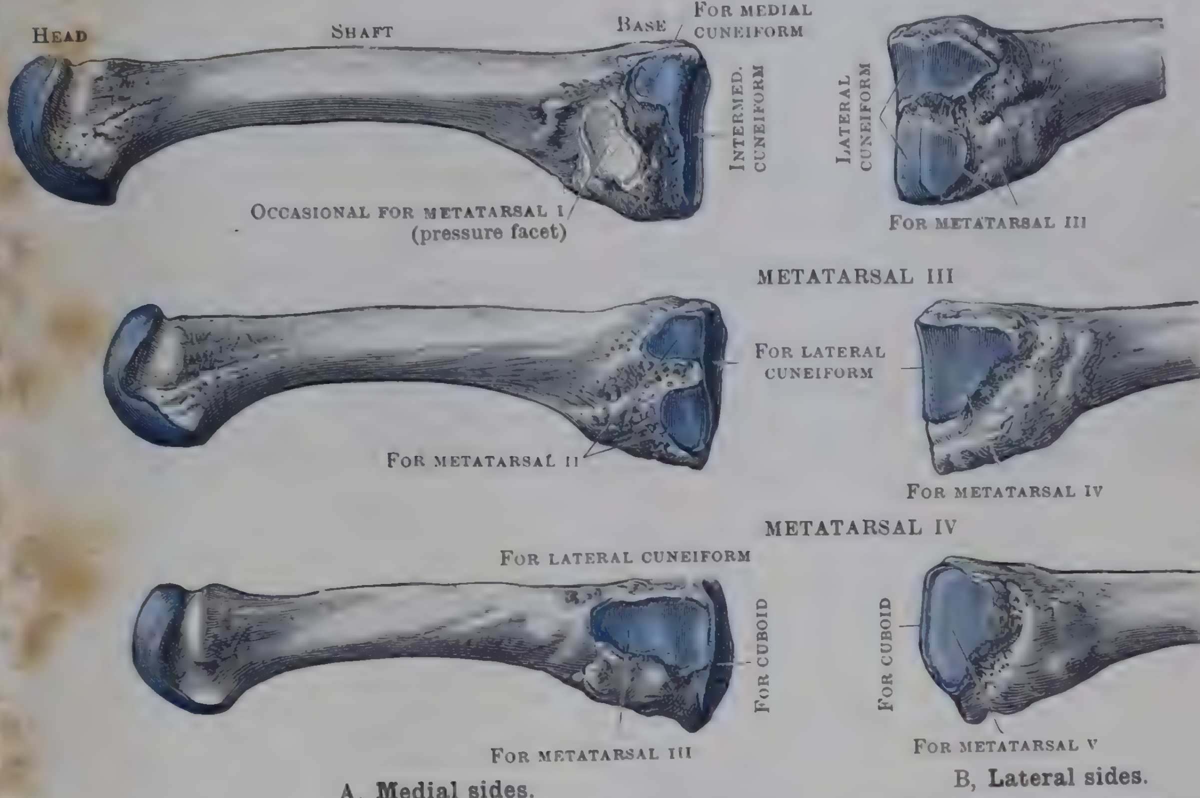


FIG. 297.—VIEW OF BASES AND SHAFTS OF SECOND, THIRD, AND FOURTH METATARSAL BONES OF RIGHT FOOT. NOTE THAT THE SECOND IS THE LONGEST.

Attachments.—In the case of *each metatarsal*, collateral ligaments pass from the sides of the **head** to the sides of the base of the proximal phalanx, and the plantar ligament closes in the metatarso-phalangeal joint below, being attached loosely to the plantar surface of the metatarsal immediately behind the head, and firmly to the plantar surface of the base of the phalanx; the extensor tendon either takes the place of a dorsal ligament or is fused with it. Dorsal, plantar, and interosseous ligaments bind the **bases** to one another and to the tarsus.

Slips of the long plantar ligament are attached to the plantar surfaces of the **bases** of the *second, third*, and *fourth* metatarsals; slips of the tibialis posterior tendon are inserted into these bases, and the oblique head of the adductor hallucis arises from them. One head of a dorsal interosseous muscle arises from each side of the **shaft** of each of these three bones, and the first and second plantar interosseous muscles arise respectively from the third and fourth.

The smaller part of the tendon of the tibialis anterior is inserted into an impression on the medial side of the **base** of the *first* metatarsal bone near the sole, and the greater part of the peroneus longus tendon into a smooth impression on the prominent, lowest part of the lateral side; one head of the first dorsal interosseous muscle arises from the lateral surface of the **shaft**.

The peroneus brevis and tertius are inserted into the dorsum of the **base** of the *fifth* metatarsal; part of the flexor digiti minimi brevis arises from the plantar surface. The abductor metatarsi quinti (when present) and a strong band of the plantar fascia are inserted into the *tubercle*. The third plantar interosseous muscle arises from the plantar surface of the **shaft**, and one head of the fourth dorsal interosseous from the medial surface.

Phalanges of Toes

Each **phalanx** is a miniature long bone, possessing a **shaft** and **two ends** [φάλαγξ (phalanx) = a round log or roller]; the **proximal** or posterior end is the larger end and is the *base*; the **distal** end is the *head*. The proximal phalanx of a

toe is about the same length as the middle phalanx of a finger, but it can be picked out from among phalanges of fingers because its base is larger, and its shaft is relatively more attenuated; the proximal phalanx of the big toe, on the contrary, is thicker than any other phalanx. The middle and distal phalanges of the toes are so short that they cannot be mistaken either for the proximal phalanges of toes or for the phalanges of fingers.

The **proximal phalanx** of a toe is a little more than an inch in length, and it is slightly concave lengthwise on its inferior or *plantar surface.* The **base** is expanded and is concave on its proximal surface for articulation with the head of the metatarsal. The **shaft** is thin—being compressed from side to side near the base, and from above downwards near the head. The **head** is pulley-shaped and articulates with the base of the middle phalanx; the articular part extends on to the plantar surface but scarcely at all on to the dorsum, for dorsiflexion is a limited movement, while flexion is free, and the middle joint of the toes in many people who have worn boots since infancy is in a permanent position of flexion.

Fig. 298.—Phalanges of a Toe (Plantar Aspect).

The **middle phalanx** is very short—usually less than half an inch in length—and it may be a mere nodule of bone. The **base** articulates with the head of the proximal phalanx and is therefore the reverse of a pulley: it has two concave smooth areas with a low, vertical, smooth ridge between them. The **shaft** is convex on its dorsal surface and either flat or concave on its plantar surface; but it may be difficult to distinguish the surfaces if the phalanx is stunted. The articular part of the **head** is a shallow pulley, and as it extends some distance on to the plantar surface it is a guide to the surfaces.

The **distal phalanx** also is very small. The **base** articulates with the head of the middle phalanx and is relatively expanded. The **shaft** is constricted; the **head** is expanded and is very rough on its plantar surface.

The **big toe** has only two phalanges. The **proximal** resembles the proximal phalanx of the other toes and the **distal** resembles the distal; but they are much larger in every way than the phalanges of other toes. In an adult big toe the medial side of the base of a phalanx is larger than the lateral side, and the big toe inclines therefore towards the other toes; the inclination is not an abnormality due to wearing pointed boots, but it may be exaggerated by the use of boots that do not fit.

Owing to the slant of the joints between the tarsus and metatarsus and to the fact that the toes are progressively shorter from the second to the fifth, the nail of the little toe is about the level of the root of the big toe. The root of the little toe or fifth metatarso-phalangeal joint is the yielding prominence on the lateral border of the widest part of the foot; it usually bulges out the side of the shoe a little in front of the middle, and, being so far back, it is apt to be mistaken for the base of the metatarsal bone if the foot is shod.

Attachments.—The plantar and the collateral ligaments of the metatarso-phalangeal joints and interphalangeal joints are attached to the **bases** and the **heads**; the fibrous flexor sheaths are attached to the margins of the **shafts** of the proximal and middle phalanges and to the base of the distal phalanx in front of the insertion of the long flexor tendon.

The abductor hallucis is inserted into the medial side of the **base** of the **proximal phalanx** of the *big toe*; the adductor hallucis into the lateral side; the flexor hallucis brevis into both sides; the medial tendon of the extensor digitorum brevis into the dorsum. The flexor brevis and abductor digiti minimi are inserted into the lateral side of the base of the proximal phalanx of the *little toe.*

The **base** of the **distal phalanx** of the *big toe* receives the insertion of the tendons of the long flexor and extensor on the plantar and dorsal surfaces respectively. A tendon of the flexor digitorum brevis is inserted into the margins of the **shafts** of the **middle phalanx** of each of the *other toes*, and a slip of the extensor expansion into the dorsum of its base. The **base** of each **distal phalanx** gives insertion to a tendon of the flexor digitorum longus on its plantar surface, and to the rest of the extensor expansion on its dorsal surface.

Columns of the Foot.—The bones of the foot as a whole can be separated into two columns. The **lateral column** consists of the calcaneum, the cuboid, the fourth and fifth metatarsal bones, and the phalanges of the corresponding digits. The **medial column** consists of the talus, the navicular, the three cuneiform bones, the medial three metatarsal bones, and the phalanges of the corresponding digits.

Arches of the Foot.—The bones of the tarsus and metatarsus are arranged in the form of a half-dome with longitudinal and transverse arches; the foot therefore

rests posteriorly on the lower part of the back of the calcaneum, anteriorly on the heads of the metatarsal bones, and at the lateral border slightly on the fifth metatarsal bone, while at the medial border it is raised well away from the ground.

The dome and its arches conform to the shape of the bones with which the framework of the foot is built, and they are maintained by the ligaments that bind the bones together and by the muscles, tendons, and fasciæ of the foot. Their chief supports are the muscles, particularly the tendons of the tibialis posterior and peroneus longus which cross the sole obliquely from opposite sides.

The advantages given by the arches of the foot are that the weight of the body is distributed over the foot (compare the use of arches above windows in the wall of a big building), sufficient rigidity and strength are provided to allow the foot to be used as a lever, and a space is provided in which the soft parts of the sole of the foot may lie free from pressure. The arches are modified by the presence of joints which allow a small range of movement, controlled by the muscles and limited in range by ligaments. This control of the joints by the muscles provides elasticity and spring to the foot and serves to absorb shocks such as are received in running or jumping.

If, for any reason, the muscles and tendons become inefficient, the strain of upholding the arches under the weight of the body may become too much for the ligaments; they stretch, and the arches sink down gradually till a condition of flat-foot or splay-foot is established, the bones altering in shape to fit each other in their modified positions in the flattened arch.

See also the Section on JOINTS, in which the arches are described more fully.

Ossification of Bones of Foot (Pls. XXVI, p. 305, XXVIII, p. 321).—**Tarsus.** Each tarsal bone has one *primary* centre.

	Calcaneum.	Talus.	Cuboid.	Lateral Cuneiform.	Navicular.	Intermed. Cuneiform.	Medial Cuneiform.
Primary centre appears at	6th month	8th month	Birth or soon after	1st year	3rd year	M. 4 yr. F. 3 yr.	M. 4 yr. F. 3 yr.

The centres for the navicular may be double (or even multiple) at first, but they rapidly fuse. The calcaneum alone has a *secondary* centre. The part of the bone that bears the medial and lateral tubercles is ossified from it; it appears at 8 in girls and 10 in boys, and the epiphysis unites at 15 and 18 respectively. Ossification of all the tarsal bones is completed after puberty. Part of the posterior tubercle of the talus may have a separate centre, and that portion of it may develop as an independent bone called the *os trigonum*.

Metatarsus.—A *primary* centre for each metatarsal appears in the ninth week of intra-uterine life. They are well ossified at birth. A *secondary* centre for each appears as follows, that for the first being a few months earlier than the others :—

Secondary Centre.	Appears at	Epiphysis fuses at	Relation of Epiphysial Line to Capsule of Neighbouring Joint.
For *base* of first	M. 3 yr.; F. 2 yr.	M. 18; F. 15	Outside.
For *head* of others	M. 3 yr.; F. 2 yr.	M. 18; F. 15	Outside.

Epiphyses have been seen in the bases of the lateral metatarsals instead of in the heads.

Phalanges.—Each has a *primary* centre for shaft and head, and a secondary centre for the base.

Primary Centre for	Distal Phalanx.	Proximal Phalanx.	Middle Phalanx.
Appears	At end of 3rd month	At end of 4th month	6th month—birth

Secondary Centre.	Appears at	Epiphysis fuses at	Relation of Epiphysial Line to Capsule of Neighbouring Joint.
For base	M. 3 yr. F. 2 „	M. 18 F. 15	Outside.

Structure and Variations.—The *tarsal* bones have the structure of short bones; their non-articular surfaces are pierced by numerous *nutrient vessels.* The *metatarsal* bones and the *phalanges* have the structure of long bones. The medullary cavity is relatively narrow, and may be absent in the distal two phalanges. The *nutrient foramen* of a metatarsal is on or near the plantar surface; it is directed towards the head in the first, towards the base in the others. In the phalanges, when it is present, it is on the plantar surface and is directed towards the base.

The **calcaneum** occasionally articulates with the navicular. The sustentaculum tali may be a separate bone, and so may be the peroneal tubercle. The articular surface for the medial malleolus on the **talus** extends on to the neck in an infant. Occasionally in an adult talus there is a small facet for the tibia on the medial part of the upper surface of the neck, probably due to the

Fig. 299.—Radiograph of the Hand at Birth.

The metacarpus and phalanges are well ossified, but the carpus is still entirely cartilaginous. (Compare with Fig. 300, and see also Pls. XVIII, p. 273, and XXVIII, p. 321.)

Fig. 300.—Radiograph of the Foot at Birth.

Calcaneum and talus are well ossified; the cuboid is quite distinct, and in this instance the lateral cuneiform is already beginning to ossify.

ankle joint being often in a state of extreme flexion. The *os trigonum*, when present, may be quite separate, or joined to the body of the talus by cartilage. An ossicle may be present between the talus and dorsal surface of navicular, and another on the dorsum between the talus, calcaneum, navicular, and cuboid. The tuberosity of the **navicular** is sometimes a separate bone. The metatarsal articular surface of the **medial cuneiform bone** may be divided into a dorsal and a plantar part, and the whole bone may be so divided; in both cases there is similar division of the tarsal surface of the first metatarsal. In rare cases a little separate ossicle is found between the posterior parts of the dorsal surfaces of the medial and intermediate cuneiform bones. Division of the **cuboid** has been recorded; in rare cases there is a very small facet for the lower part of the **head** of the talus on the medial side of the projecting angle of its posterior surface. The tubercle of the **fifth metatarsal** may be separate (*os Vesalianum*); as also the part of the base of the **first** into which the peroneus longus is inserted. A separate ossicle may be found between the bases of the first and second metatarsals. Fusion of **phalanges** is not uncommon, especially in the little toe. For an account of accessory bones of the foot, with bibliography, see Trolle (1948).

Sesamoid Bones

Sesamoid bones are embedded in tendons, but there is usually one surface free and smooth for articulation. The largest sesamoid bone is the **patella**. The *flexor hallucis brevis* has two little sesamoid bones in its tendons of insertion. They are about the size of half of a marrowfat pea, and, being compressed and oval, should not be mistaken for the pisiform bone. They play against the grooves on the plantar

surface of the head of the first metatarsal bone, and they add to the size and firm consistence of the medial part of the ball of the foot; the medial sesamoid may be divided transversely, and sometimes there is a minute nodule between the two. Occasionally there are minute sesamoid bones at the *other metatarso-phalangeal joints* and at the *interphalangeal joint* of the big toe and other interphalangeal joints. A sesamoid bone or cartilage is usually present in the tendon of the *peroneus longus* as it crosses the lateral side of the cuboid bone to enter the sole. The tendon of the *tibialis posterior* is thickened at the point where it glides over the spring ligament; the thickening has sometimes the character of a sesamoid cartilage. More seldom, a sesamoid bone is present--in the *tibialis anterior* near its insertion; in the *psoas major* as it passes over the pubic bone; in the lateral head of the *gastrocnemius* as it crosses the lateral condyle of the femur; and in the *gluteus maximus* as it overlies the greater trochanter.

DEVELOPMENT AND MORPHOLOGY OF THE LIMBS

The limbs appear in the Human embryo in the fourth week as small buds on the sides of the body near the cephalic and caudal ends of the trunk (Fig. 72). They are derived from a slight longitudinal ridge which lies ventral to the paraxial mesoderm and, since they appear opposite several segments of the body, each of them receives branches from a corresponding number of spinal nerves. The spinal nerves that contribute fibres to the upper limb are the lower five cervical and the upper two thoracic; and the lower limb contains branches from the last thoracic nerve, the five lumbar nerves, and the upper four sacral nerves. The buds arise from the ventro-lateral part of the trunk, and the nerves of a limb are accordingly derived from the *anterior primary rami* of the spinal nerves.

Each bud has two surfaces and two borders. At first the surfaces look ventrally and dorsally; the ventral aspect corresponds to the flexor surface of the adult limb, and the dorsal aspect to the extensor surface; the borders of each bud look headward and tailward, and are named **pre-axial and post-axial.** (Figs. 118-121, pp. 99, 100.)

During the second month slight constrictions appear in the elongating buds at positions that correspond to the elbow and the wrist, the knee and the ankle; and grooves appear on the dorsal surfaces of the extremities of the buds—indicating the division into digits. At the same time, the central or axial mesoderm of the bud condenses and passes through a pro-cartilage stage and then chondrifies to form the cartilage-models of the limb-bones. Chondrification begins in the roots of the limbs and spreads towards the digits, leaving unchondrified intervals where joints are to be formed. The cartilage developed along the pre-axial border of the forearm becomes the radius, and the pre-axial digit becomes the thumb; in the leg and foot the pre-axial cartilage and digit become the tibia and the big toe; similarly, the ulna and little finger, the fibula and little toe are developed at the post-axial borders.

During the third month the embryo—now called the *fœtus*—begins to assume the "fœtal position" (Fig. 121) with flexion at all the joints, notably those of the limbs. The wrist and the elbow are flexed and the upper arm is bent tailwards along the side of the thorax; the ankle is flexed and the foot is turned medially, the knee is flexed and the thigh is inclined headwards along the abdomen. At the same time the upper and lower limbs begin to be rotated around their long axes.

Rotation of the limbs.—The extensor surface of a limb-bud is on its dorsal aspect. As the limb grows, it bends so as to project ventrally and, in addition, the *upper limb* is rotated through about 90° so that the extensor surface of the elbow faces backwards and the *lower limb* undergoes a similar rotation in the opposite direction to make the extensor surface of the knee face forwards. The distal part of the upper limb requires an additional twist, equivalent to pronation of the forearm and hand, to bring its extremity into the adult position. In Man, to gain the erect posture, the limbs swing tailwards from the quadrupedal position to lie parallel to the long axis of the body; the rotation of the forearm and hand does not require to be so complete as in the fore-limb of a quadruped, and the final rotation of the foot which brings the ball of the great toe to the ground is not completed until after birth, when the weight of the body is taken on the foot as the child learns to walk. Rotation of the limbs takes place at least partly at the shoulder and hip joints and possibly in the shafts of the bones. No rotation of the limb-girdles is seen during development.

Homologies.—The homology between the limb-bones of Man and those of other animals, and the serial homology between the bones of the two limbs in Man, are fairly clear except in the limb-girdles, and the carpus and tarsus (p. 327).

Limb-Girdles.—The homologies of the parts of the girdles have become obscured owing to the structural alterations that have occurred in order to adapt the two limbs to their different functions. Even in four-footed animals the functions of the fore-limbs and hind-limbs are not quite the same, though both are used for support and locomotion; the fore-limb is at the same time adapted for *pull* and the hind-limb for *push*; the pelvic girdle is therefore more consolidated than the shoulder-girdle. The modifications from the primitive type are more varied

and more profound in the shoulder-girdle, and they began so long ago in phylogenetic development that in Man there is no evidence in ontogenetic development of how they came about.

The primitive, fundamental limb-girdle is a curved bar of cartilage embedded in the muscular substance of the side of the trunk at right angles to the long axis of the trunk. The cartilage is divisible into a dorsal part and a ventral part by means of an articulation of the middle of its lateral surface with the cartilage of the free portion of the limb.

In the pelvic girdle the *dorsal part* forms the ilium and the *ventral part* is divided into cephalic and caudal bars which become the pubis and ischium respectively. In the shoulder-girdle the

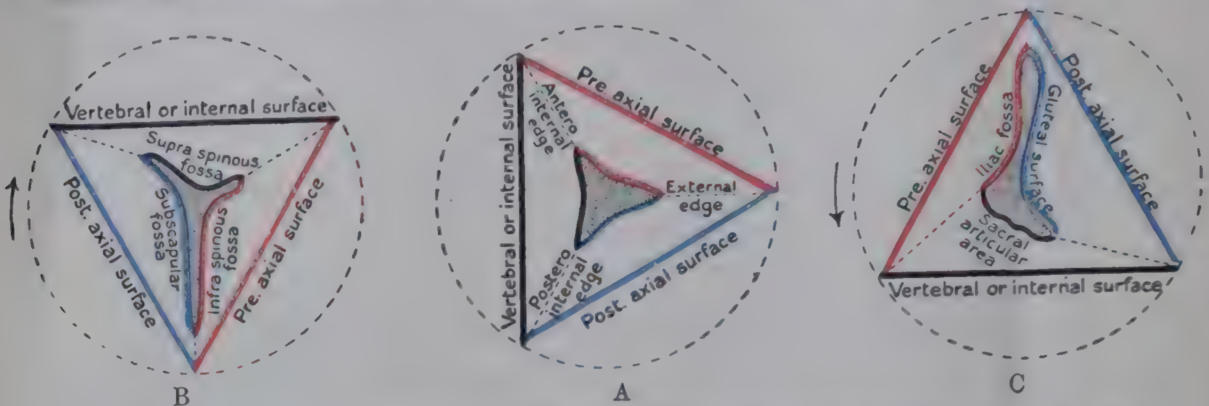


FIG. 301.—DIAGRAM OF HOMOLOGOUS PARTS OF SCAPULA AND ILIUM, ACCORDING TO FLOWER.

A : Ideal type ; three-sided rod. B : Scapula rotated forward through a quarter of a circle (90°), and the primitive medial or vertebral surface is now directed forwards. C : Ilium rotated backwards through a quarter of a circle and the primitive medial surface is now directed backwards.

dorsal part forms the blade of the scapula but the *ventral part* varies considerably in different vertebrates and homologies are difficult to establish. In Man it forms the upper part of the glenoid cavity and the coracoid process of the scapula. The suprasternal ossification (which may be separate as a suprasternal bone in Man) probably represents an epicoracoid element while the cephalic bar of the ventral part, the precoracoid of lower forms, seems to have been replaced, at least in part, by the membranous element of the clavicle. The exceptionally early ossification of the clavicle spreads from centres at each end before the cartilage has fully formed

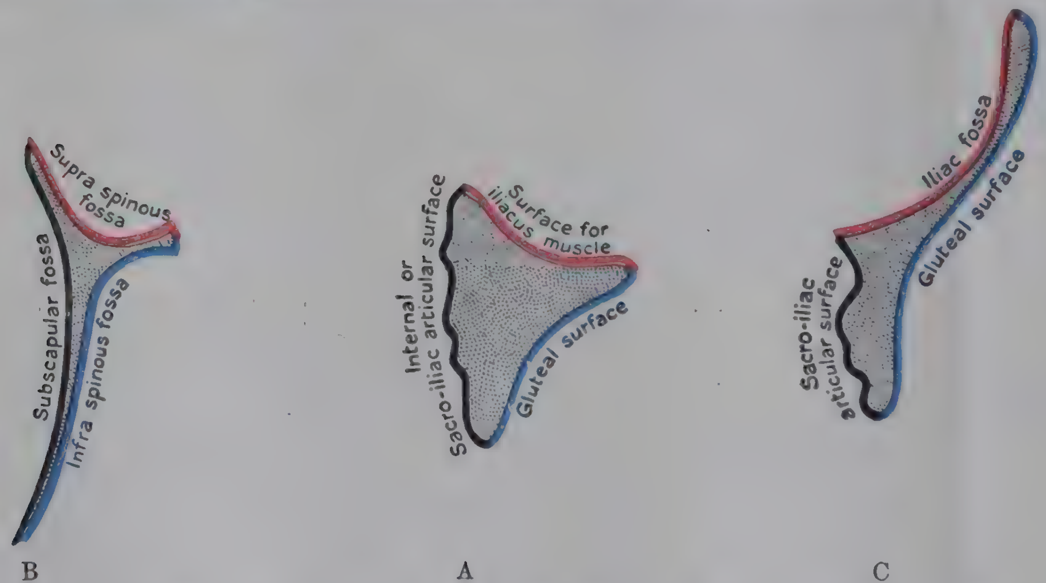


FIG. 302.—DIAGRAM OF HOMOLOGOUS PARTS OF SCAPULA AND ILIUM, ACCORDING TO HUMPHRY.

A : Primitive rod-like ilium of kangaroo, prismatic on section. B : Scapula. C : Ilium. The corresponding surfaces are similarly coloured.

and there is evidence that the middle third of the clavicle is membrane bone. Keith (1948) reviews these problems and provides references.

The limbs are usually regarded as being serially homologous, the pre-axial structures on the radial side of the upper limb corresponding to the pre-axial structures on the tibial side of the lower limb. Post-axial structures such as the ulna and fibula are similarly equivalent and the little toe corresponds to the little finger. In making comparisons due allowance has to be made for rotation of the knee and elbow in opposite directions during development so that the posterior surface of the shaft and the lateral epicondyle of the humerus correspond to the anterior surface and medial epicondyle of the femur. The olecranon is analogous to but not homologous with the patella.

The homologies of the carpal and tarsal bones are not so clear; they are given in the following table, together with the more generalized type from which they are evolved:—

Type.	Hand.	Foot.
Radiale (Tibiale)	= Scaphoid (body)	= Talus.
Intermedium	= Lunate	= Absent, or Os trigonum (?).
Ulnare (Fibulare)	= Triquetrum	= Calcaneum.
Centrale	= Absent, or fused with Scaphoid	= Navicular, less its tuberosity.
Carpale (Tarsale), i.	= Trapezium	= Medial Cuneiform.
Carpale (Tarsale), ii.	= Trapezoid	= Intermediate Cuneiform.
Carpale (Tarsale), iii.	= Capitate	= Lateral Cuneiform.
Carpale (Tarsale), iv. } Carpale (Tarsale), v. }	= Hamate	= Cuboid, plus the peroneal sesamoid.

The pisiform is omitted from the table, since it is now generally regarded as being a vestige of an additional digit placed post-axial to the little finger (digitus post-minimus). Its homologue in the foot is by some considered to be fused with the calcaneum. The peroneal sesamoid probably corresponds to the hook (sometimes an independent ossicle) of the hamate bone. Similarly, on the pre-axial border of the hand and foot, vestiges of a suppressed digit (prepollex and prehallux) may occasionally be met with. The tuberosity of the navicular bone of the foot may be the homologue of the pre-axial sesamoid in the hand, which probably fuses with the scaphoid to form its tubercle. The frequent occurrence of an increase in the number of digits seems to indicate that phylogenetically the number of digits was greater than at present and included a prepollex or prehallux, and a digitus post-minimus.

The view that the limbs are serially homologous has been widely held since the time of Flower (1870) and Huxley (1871); but it has also been argued that the limbs are, as Humphry (1858) phrased it, " placed at opposite ends of the trunk and the opposed surfaces of their upper segments have, consequently, been made to correspond with one another ". This " mirror image " idea has been supported by others, particularly by Drennan (1927) who superimposed an upper limb of one side of the body on the lower limb of the other side. Pre-axial structures of the one limb then correspond to post-axial structures of the other. Serial homology has the advantage that it agrees largely with the functional arrangement of the limbs for progression in one direction. In the scheme originally put forward by Flower the limb-girdles were assumed to rotate through 90° (Fig. 301). Humphry assumed that they were not involved in the rotation of the limbs (Fig. 302).

In Man the lower limbs have been specialized for the whole office of support and locomotion. The upper limbs have undertaken more varied functions, including that of prehension. The lower limbs are increased in strength and length and are constructed for stability; mobility is the aim achieved in the upper limb. The elements of the lower limb-girdle are welded into one bone which is firmly jointed to its fellow and to the backbone, and, with the adoption of the erect attitude, it assumes the special human characteristic of wide expansion of the ilia to support the abdominal viscera.

In order to be free and movable, the shoulder-girdle is not built into the wall of the body cavity. The scapula is only loosely connected with the axial skeleton by muscles; the clavicle is joined to the sternum by a freely movable joint; and, further, these two constituents of the girdle are not fused with each other but are connected by a movable joint. To obtain greater freedom and range of movement, the upper limb, including the ventral part of the scapula, becomes farther removed from the trunk, and the scapula loses the support received through the union of the coracoid element with the sternum, as in birds, reptiles, and, to some extent, in the lowest mammals. As a substitute for that support the clavicle is evolved as a new element; in its most specialized form, as in Man, it gives strength and stability to the girdle and keeps the upper limb removed from the trunk so that the movements are unhampered. Being itself a movable fulcrum, it enlarges the range of movement and, in particular, it facilitates abduction of the arm.

The head of the humerus articulates with a shallow cavity and is connected with the scapula by a lax capsule; in the femur, the presence of a long neck set at an angle to the shaft removes the limb from the trunk and enables the limb to have a wide range of movement, although the head of the femur articulates with a deep cup and is held firmly in place by a strong capsule.

The power of pronation and supination combined with the free movement permissible at the wrist joint give the upper limb a varied mobility which the lower limb does not possess. This is to a limited extent compensated for by the possibility of slight rotation at the knee joint, slight sideways movement at the ankle joint in full extension, and a considerable range of inversion and eversion of the sole of the foot. The knee and hip joints are particularly stable in full extension.

The hand, as a prehensile organ, has its phalanges increased in length and the carpus reduced; the opposability of the first metacarpal enables the hand to grasp cylindrical objects firmly, and the opposable fifth metacarpal enables it to grasp spherical objects. In the foot, strength and stability are required; the tarsal bones are large, and, having to sustain the weight of the body, the tarsus and metatarsus are built in the form of an arch; the foot does not have the prehensile function which it discharges in Apes, and therefore the digits are short and none of them is opposable.

MEASUREMENTS AND INDICES EMPLOYED IN PHYSICAL ANTHROPOLOGY

Craniometry

Craniology is the study of the skull, and it includes the consideration of the differences in the skull in the various groups of Mankind. Accurate measurements are required for the estimation of the differences, and the name *craniometry* is given to the methods of measurement.

Capacity of the Cranium.—The size of the skull varies considerably in the different races of Man. Apart from individual differences and the proportion of head-size to body-weight, the size is generally greater in the more highly civilized races than in the lower types. The size of the head is closely correlated with the size of the brain; and an estimate of the size of the brain can be formed from the dimensions of the cranial cavity. To determine the capacity of the cavity, fill it with some suitable material and then measure the cubage of the amount of material required. Various materials have been employed, each of which has its advantage. Liquids would be the most accurate, but the foramina make them useless, without special precautions. In practice, seeds, glass beads, and leaden shot have been found to be sufficiently serviceable.

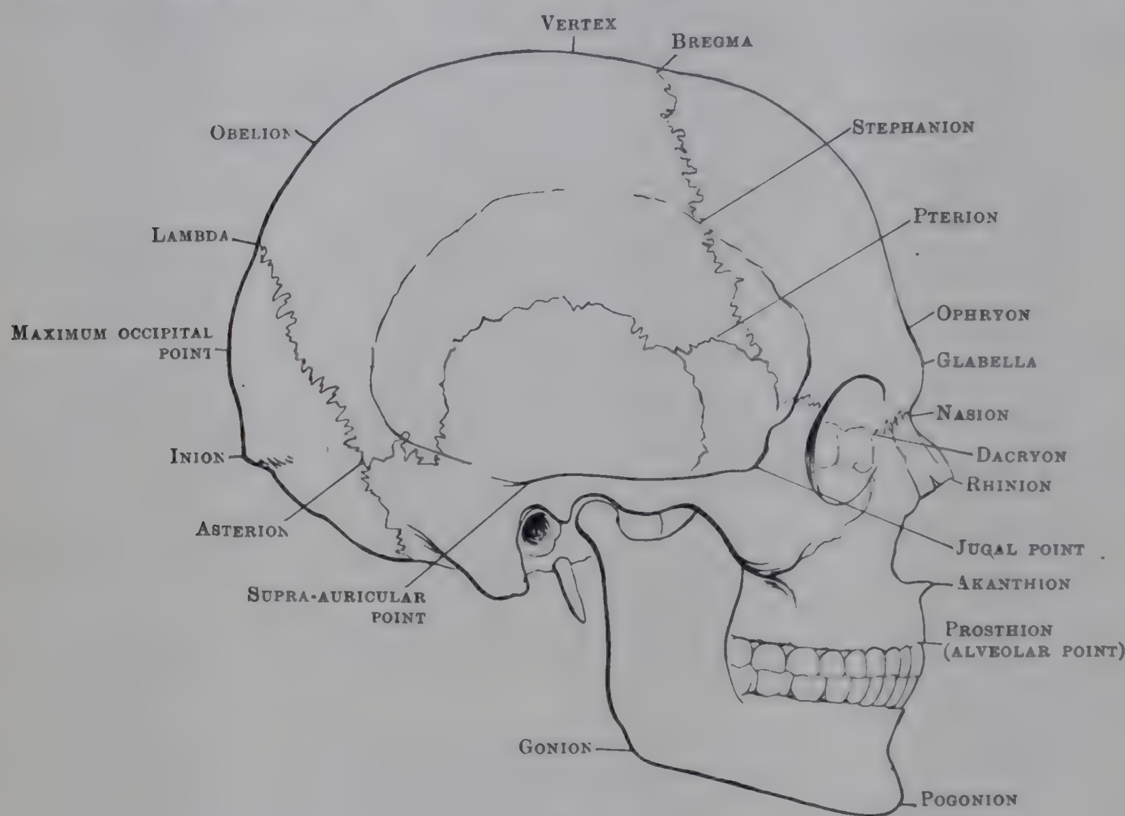


Fig. 303.

There is a wide range of variation in the capacity of different crania, but, owing to the varying thickness of bone and size of sinuses, the capacity is not directly proportional to the size of the skull as a whole. For purposes of classification and comparison, skulls are grouped according to their **cranial capacity** into the following varieties:—

- **Microcephalic skulls** are those with a capacity below 1350 c.c., and they include the skulls of Andamanese, Veddahs, Australians, Bushmen, Tasmanians, etc.; [μικρός (micros) = small; κεφαλή (cephalē) = head].
- **Mesocephalic skulls** range from 1350 c.c. to 1450 c.c., and they are found among the following races: American Indians, Chinese, and some African Negroes; [μέσος (mesos) = middle].
- **Megacephalic skulls** are those with a capacity over 1450 c.c. They are most commonly met with in the more highly civilised races: Mixed Europeans, Japanese, etc.; [μέγας (megas) = big].

Form of the Cranium.—The shape, as well as the size, has been used as a means of classifying skulls; but, in the past, undue emphasis may have been laid on differences in shape. These differences are expressed by the comparison of measurements between given points. The more important points from which measurements are taken are indicated in Fig. 303.

The measurements of the length of the skull may be taken between a variety of points—the nasion, the glabella, or the ophryon in front, and the inion or the maximum occipital point behind; or the maximum length alone may be taken without reference to any fixed points. In all cases, the measurement used should be stated. The widest part of the skull is very variable in position; note whether it occurs above or below the parieto-squamosal suture. The width of the skull may also be measured from one asterion to the other (**bi-asterionic width**) or from one stephanion to the other (**bi-stephanic width**). The height measurement usually taken is the distance from the basion to the bregma.

The relation of the breadth to the length of the skull is expressed by the **cephalic index**, which gives the proportion of the maximum breadth to the maximum length of the skull, assuming the length equal 100, or—

$$\frac{\text{Max. breadth} \times 100}{\text{Max. length}} = \textbf{Cephalic index.}$$

The results are classified into three groups :—

1. **Dolichocephalic,** with an index below 75 : Australians, Kaffirs, Zulus, Eskimos, Fijians.
2. **Mesaticephalic,** ranging from 75 to 80 : Europeans (mixed), Chinese, Polynesians (mixed).
3. **Brachycephalic,** with an index over 80 : Malays, Burmese, American Indians, Andamanese ; [βραχύς (brachys)=short ; δολιχός (dolichos)=long].

For other cranial indices and for measurements and indices of other parts of the skeleton, the reader is referred to previous editions of this text-book and to the special works of Martin (1928), Wilder (1920), Hrdlička (1920) and Drennan (1937).

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ARTHROLOGY

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Arthrology[1] is that branch of Anatomy which deals with the manner in which the individual bones of the skeleton are joined together. These **joints** or **articulations** between the bones vary in structure and function: some are immovable; others permit movement of varying extent and complexity. The chief kinds of joints have also developmental differences, with some relation to the different modes of origin of the conjoined bones.

To begin with, the skeleton in any region exists as a continuous thickening of mesoderm. Where next a cartilaginous phase intervenes, the cartilaginous precursors of the bones may still be continuous, as in the cartilaginous base of the skull, or may remain separate as in the limbs and be joined by zones of persisting membranous tissue. When ossification occurs, the bones are all formed separately, and therefore joints are found between their contiguous parts. Bones formed in membrane are connected by the intervening membranous tissue, and so become united by fibrous joints; bones formed in cartilage are connected either by cartilage or by membranous tissue according to the continuous or discrete formation of the preceding cartilages. The membranous connexion between bones formed from separate cartilages may persist and give rise to a fibrous joint, or may become chondrified and give rise to a cartilaginous joint; but usually the connecting membranous tissue forms a cellular disc called a *primitive joint-plate* in which further changes occur. The central part of the joint-plate is absorbed so that a cavity appears within it, whereas the peripheral part of the joint-plate along with the surrounding mesoderm form a fibrous sleeve with a specialized lining that connects the contiguous bones and bounds the joint-cavity that now exists between them.

Classification of Joints.—Bones are ultimately joined, therefore, in one of three ways:—

(1) By **fibrous joints**, where the bones have arisen in membrane or where they were preceded by discrete cartilaginous models and the primitive membranous connexion has persisted.

(2) By **cartilaginous joints**, either of a primary type where the uniting cartilage is the remains of a preceding continuous cartilaginous formation, or of a secondary type where the membranous tissue between bones ossifying from discrete cartilages is subsequently chondrified.

(3) By a more elaborate type of joint having a cavity between the bone-ends surrounded by fibrous ligaments lined with a specialized membrane. This lining membrane produces a fluid called *synovia* which passes into the joint-cavity, and is therefore itself called the *synovial membrane*. As the synovial fluid and membrane are characteristic of joints of this type, these are called **synovial joints**.

These three kinds of joints will now be considered in detail and the varieties of each described.

[1] For general works of reference, with bibliographies to date, see Bryce (1915) and Fick (1904–11).

FIBROUS JOINTS

Fibrous joints are of two types—suture and syndesmosis.

Suture.—A suture is a type of fibrous joint found only in the skull, in which a very thin layer of white fibrous tissue, called the *sutural ligament*, unites the opposed bone surfaces (Fig. 304); the union between the bones is so close that no movement can take place at the joint. Externally the sutural ligament is continuous with the periosteum and internally it is continuous with the outer layer of the dura mater (p. 997).

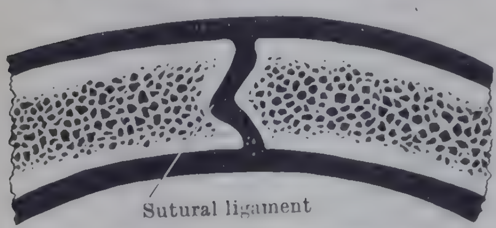


FIG. 304.—VERTICAL SECTION THROUGH A SUTURE (Sagittal).

Obliteration of the sutures usually begins between the ages of thirty and forty when the sutural ligaments become ossified, a process called *synostosis*. The process of obliteration begins on the deep aspect of the ligament and slowly extends to its superficial part; complete obliteration of the sutures does not occur until an advanced age (p. 211).

Varieties of Suture.—Different varieties of suture are named from the ways in which the opposed parts of the bones are fitted to one another. Sutures between bones joined edge to edge are commonly strengthened by toothed projections from the one bone fitting between similar processes on the other; such a suture is called **serrate** when the projections are pointed like the teeth of a saw (Fig. 305), or **denticulate** when the projections broaden towards their free ends like human teeth, and the bones are dovetailed together. In a **limbous** suture, serrate or dentate edges of the opposed bones alternately overlap one another in addition. Where plane overlapping bevelled edges of bone are united, a **squamous** suture is formed. When relatively flat surfaces of bone are joined together, as in the joint between the maxilla and the vertical plate of the palatine bone, a **flat** suture results. In a **wedge-and-groove** suture a crest on one bone fits into a groove on another, as the rostrum of the sphenoid fits into the groove between the alæ of the vomer. A **peg-and-socket** suture resembles the union between the fang of a tooth and its socket; but the only example in the skeletal system is the insertion of the styloid process in the temporal bone.

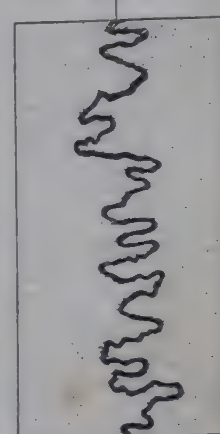


FIG. 305.—SURFACE VIEW OF SERRATE SUTURE (Sagittal). Cf. Fig. 153, p. 153.

Syndesmosis.—A **syndesmosis** is a fibrous joint in which the uniting fibrous tissue, much greater in amount than in a suture, forms an interosseous membrane or ligament. The inferior tibio-fibular joint is a syndesmosis where the bones are joined by an interosseous ligament; the attachment of the shaft of the radius to that of the ulna may be regarded as an example of syndesmosis in which an interosseous membrane unites the bones. Movement may be permitted at a syndesmosis by the flexibility of an interosseous membrane or the stretching or twisting of an interosseous ligament. This last occurs to an extremely small extent unless the ligament is composed largely of elastic fibrous tissue, as in the case of the ligamenta flava between the laminæ of adjacent vertebræ.

CARTILAGINOUS JOINTS

In a **cartilaginous joint** the bones are united by an intervening plate of cartilage. The sides of the plate are directly fused to the joint-surfaces of the two bones, and the perichondrium clothing its periphery is continuous with the periosteum covering the bones. As already indicated, cartilaginous joints are of two types, primary and secondary, which differ in development, structure, and function.

Primary Cartilaginous Joint.—The cartilage of the **primary** type of joint (Fig. 306) is a remnant of the continuous cartilaginous mass in which the articulating bones are formed, and it retains its original hyaline nature. This is the most rigid kind of cartilage; hence no movement is permitted at this type of joint unless, as in the solitary example of the union between the first rib and

the sternum, the uniting cartilage is a bar long enough to allow an appreciable degree of bending or twisting. The primary cartilaginous joints are intimately related to the mode of growth of the bones concerned (p. 116), and most of them

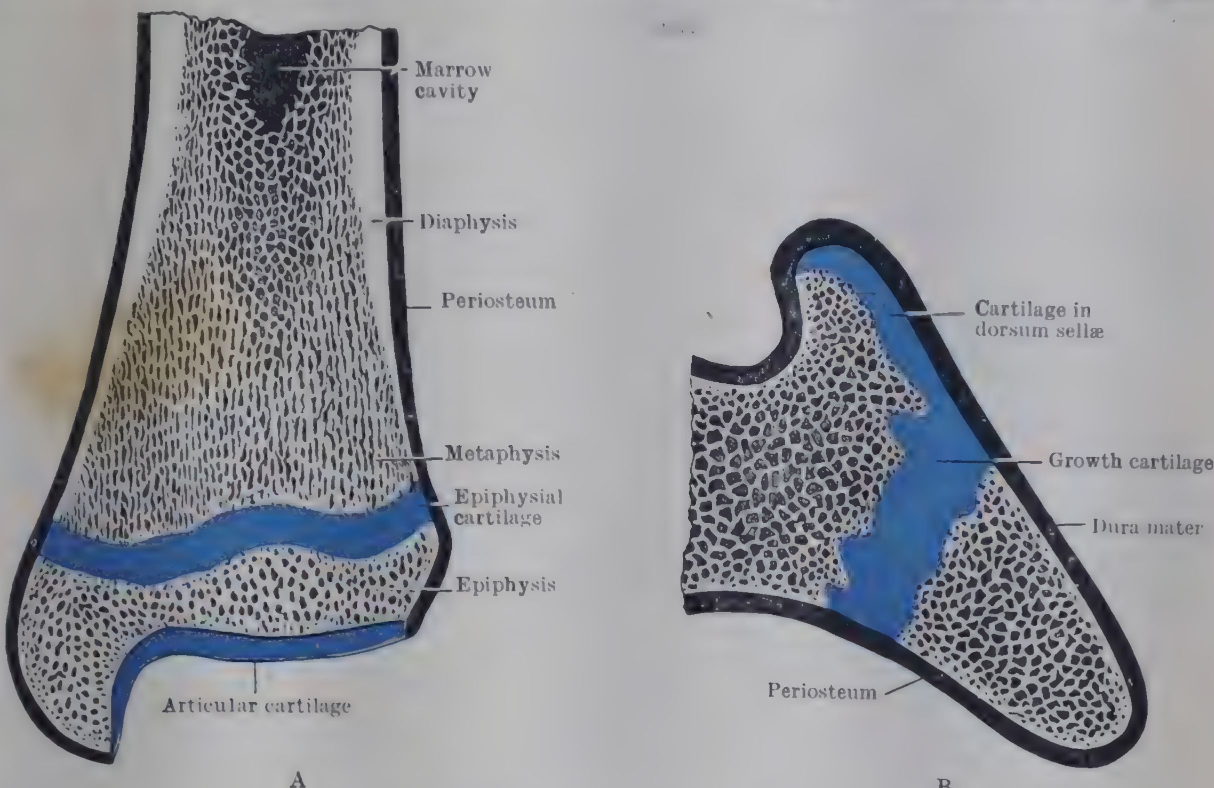


FIG 306.—PRIMARY CARTILAGINOUS JOINTS.

A. Diagrammatic section of joint between diaphysis and epiphysis of growing long bone.
B. Median section of joint between occipital and sphenoid bones in child aged one year.

become obliterated by synostosis before the age of twenty-five; only two pairs of joints escape this fate—the petro-basilar and the first sterno-costal.

Secondary Cartilaginous Joint.—The **secondary** type of cartilaginous joint is more specialized, occurs only in the median plane and persists throughout life. In its early stages of development it is represented by a plate of cellular membranous tissue between separate cartilaginous rudiments (Fig. 307), but later this plate differentiates into fibro-cartilage. When the cartilaginous rudiment undergoes a bony change, a thin lamina of the cartilage adjoining the fibro-cartilage remains unossified and persists as a lamina of hyaline cartilage between the bone and the fibro-cartilage (Fig. 313). Such a joint is that between the bodies of adjacent vertebræ. Fibro-cartilage is less rigid than hyaline cartilage: a slight amount of bending or twisting of the one bone upon the other may therefore take place at this type of joint, the amount depending on the thickness of the fibro-cartilaginous plate and the degree to which fibrous tissue is formed in it. In some such joints the centre of the fibro-cartilaginous plate is

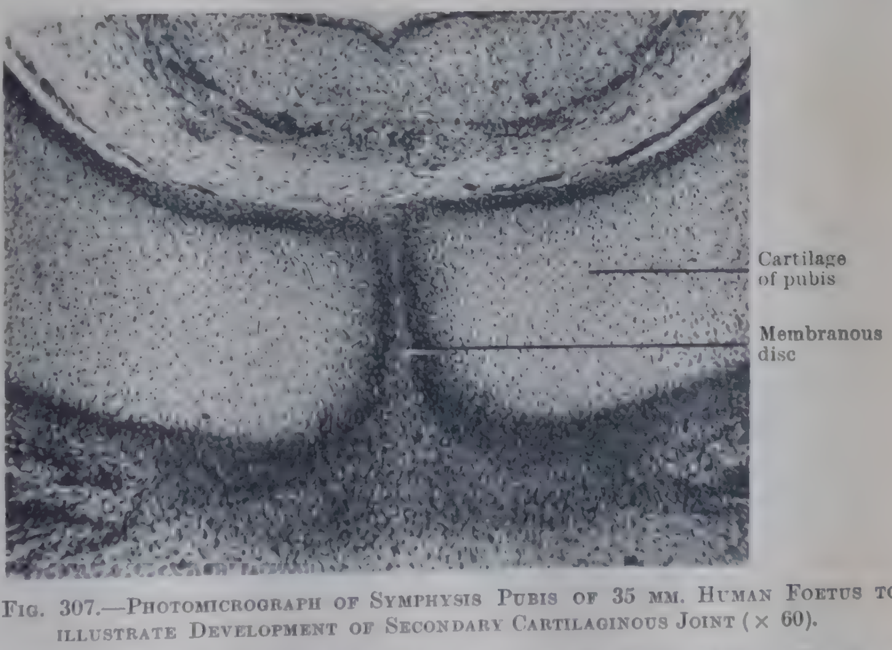


FIG. 307.—PHOTOMICROGRAPH OF SYMPHYSIS PUBIS OF 35 MM. HUMAN FOETUS TO ILLUSTRATE DEVELOPMENT OF SECONDARY CARTILAGINOUS JOINT (× 60).

modified either by the formation of an irregular slit-like cavity, as in the pubic symphysis, or by the presence of a core of soft, pulpy tissue, as in an intervertebral disc: these modifications increase the amount of movement. In fibro-cartilaginous joints additional strength is secured by the presence of ligaments around the joint.

SYNOVIAL JOINTS

The **synovial joint** (Fig. 308) is the most highly evolved type of joint: it is specialized to permit free movement. In accordance with the function of free movement the joint-surfaces of the articulating bones are separated by a **joint-cavity** and each is provided with a special, smooth bearing surface of hyaline cartilage. The bones are connected by flexible ligaments that are attached chiefly round about the bone-ends and these form the **capsular ligament.** The capsular ligament is lined with **synovial membrane** which bounds the joint-cavity and produces the synovial fluid within the cavity.[1]

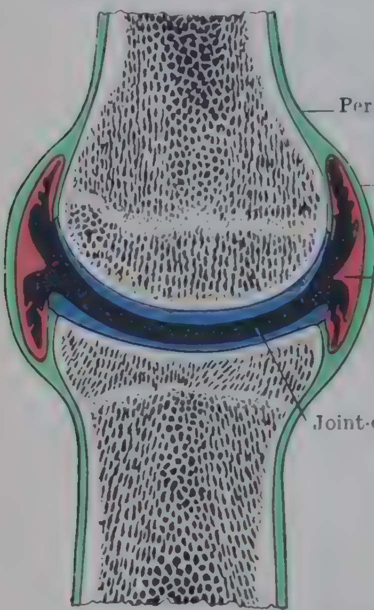


Fig. 308.—Diagram of a Synovial Joint.
Articular cartilage, *blue*; synovial membrane, *pink*; capsular ligament and periosteum, *green*.

The part of a bone that enters into the formation of a synovial joint—usually enlarged or expanded in the case of the extremity of a long bone—is composed of spongy bone with a thin superficial layer of particularly dense bone. The *articular surface* is that area of the bone which comes into contact during movement with the other bone of the joint, and it is covered with a layer of hyaline cartilage called the **articular cartilage.** This presents a firm, perfectly smooth, free surface, devoid of perichondrium. By its slight elasticity the articular cartilage lessens jarring shocks at the joint. It has no nerves and is, therefore, insensitive. It is avascular, and is nourished to some extent by permeation of fluid from the vascular ring in the synovial membrane at its periphery (p. 340), but principally by the synovial fluid itself (Strangeways, 1920). The appreciation of the difference in the nourishment of the peripheral and central portions of the articular cartilage is of fundamental importance in joint-pathology. The periphery of the cartilage is adequately nourished from the adjacent vessels and is liable to overgrowth changes, whereas the central part is less well nourished and is prone to degenerative changes.

The connecting structures of the synovial joint are the *articular ligaments.* These are arranged in various ways, but are always composed of dense white fibrous tissue which, by its flexibility, permits movement at the joint, but by its great tensile strength resists disruption. Every synovial joint is provided with a **capsular ligament**. This usually takes the form of a sleeve, each end of which is firmly attached in a continuous line around the articular extremity of one of the bones at a variable distance from the edge of the articular cartilage. Where more than two bones enter into the formation of the joint the capsular ligament has the form of a more irregular sac with openings tightly filled by the articulating parts of the bones. If the articular end of a bone is ossified from an epiphysial centre, the epiphysial line bears no constant relation to the line of capsular attachment in different joints: the epiphysial line may be intracapsular or extracapsular in position, or partly the one and partly the other. Small apertures in the capsular ligament give passage to nerves and vessels; there may be larger openings through which synovial pouches protrude. The capsular ligament may be strengthened or even replaced, in part, by adjacent muscle tendons or their expansions. The fibres

[1] The conventional term 'joint-cavity' is inexact. There is normally no real 'cavity', but only a solution of continuity between surfaces in contact.

of the ligament may form a dense feltwork; but where, during movement, any recurring strain must be resisted, the fibres there become arranged in parallel bundles in the line of the straining force; such specialized portions of the capsular ligament are usually thickened and distinguished by special names. Besides the capsular ligament with its possible special bands, other ligaments, standing apart from it, may unite the bones. These **accessory ligaments** may be extracapsular, like the costo-clavicular and coraco-clavicular ligaments of the clavicular joints, or intracapsular, like the cruciate ligaments of the knee joint.

Inside some synovial joints, pads of fibro-cartilage lie between the articular surfaces and blend peripherally with the capsular ligament. Such a fibro-cartilage may form a complete **articular disc** attached to the capsule all round, so as to divide the joint-cavity into two separate compartments (Fig. 309); the mandibular and sterno-clavicular joints are made bi-cameral in this way. Or the intra-articular fibro-cartilage may be wedge-shaped as in the acromio-clavicular joint, or crescentic as in the knee joint, with a free edge projecting into the joint cavity. Though articular discs may add their resilience to that of the articular cartilages in cushioning the bone-ends their principal function, according to MacConaill (1932), is to assist in maintaining a layer of synovial fluid between articular surfaces (see p. 388). In the sterno-clavicular joint the articular disc is so attached to the bones as well as to the capsule that it plays the part of an intra-capsular ligament also.

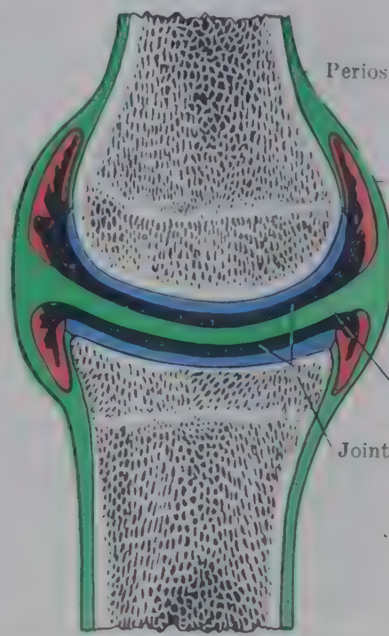


FIG. 309.—DIAGRAM OF A SYNOVIAL JOINT WITH ARTICULAR DISC DIVIDING THE JOINT-CAVITY INTO TWO COMPARTMENTS.

Articular cartilage, *blue*; synovial membrane, *pink*; capsular ligament, articular disc and periosteum, *green*.

The **synovial membrane** is one of the most important and most characteristic features of a synovial joint. It is a specialized stratum of delicate connective tissue—highly vascular, and velvety in appearance in the living—which lines the capsular ligament, and, with it, forms the capsule of the joint. At the attachments of the capsular ligament the synovial membrane is reflected on to the bones to clothe them as far as the edge of the articular cartilage. Thus, all intra-capsular bony surfaces are covered with hyaline cartilage on the articular areas and with synovial membrane on the non-articular areas. The transition between the two coverings is fairly abrupt; the junction goes obliquely from the free surface so that the membrane slightly overruns the bevelled edge of the cartilage. Often a redundant fold of the membrane from just beyond the junction overlaps the cartilage in addition. A varying amount of fatty or areolar tissue may intervene between the membrane and the ligament or bone which it covers. The fatty tissue, when large in amount, bulges the synovial membrane towards the joint-cavity, forming soft and highly compressible pads or folds; these serve to fill up irregularities of the intra-articular surfaces, such as the fossæ at the lower end of the humerus, but permit projections on the other moving member of the articulation to occupy the fossæ in certain positions of the joint; in some such cases the subsynovial fatty tissue is then partially extruded through little gaps in the attachment of the capsular ligament. The synovial membrane is also folded over intracapsular tendons, ligaments, or cartilages, which usually are thus excluded from the joint-cavity. But it must be remembered that although the synovial stratum can be traced continuously over most intra-capsular surfaces except those covered with articular cartilage, it is not everywhere recognizable as a definite lining membrane. Where fibro-cartilages or ligaments within a joint are exposed to fairly continuous pressure, the synovial membrane over them is so thinned out that it is unrecognizable as a layer separate from the proper tissue of the cartilage

or ligament itself. Thus, the semilunar cartilages in the knee joint, under constant pressure between the articulating bones, have no synovial covering (Fig. 310); nor has that part of the deep surface of the capsular ligament of the hip joint which is exposed to constant pressure of the head of the femur.

Microscopically, synovial membrane is composed of a collagenous ground-work, showing delicate fibres and containing connective tissue cells of several kinds. Its thickness and cell-content vary in different situations: it is thickest where separated from underlying ligaments by a layer of areolar tissue, is very thin when covering fatty pads, and, as already described, thins out to disappearance in areas under pressure. The more mobile parts of the synovial membrane have numerous elastic fibres which prevent nipping of the membrane by the articular surfaces during movement of the joint (Davies, 1945). Towards its free surface the cells become rather flattened, but there is not a complete lining of mesothelial cells. From the surface, *synovial villi* may project into the joint-cavity, each a tuft, sessile or pedunculated, of the fibrous ground-work with cells embedded in it and arranged irregularly around its surface. *Synovial folds* are projections on a larger scale, involving a folding of the whole thickness of the membrane (Fig. 311); secondary folds may arise from primary ones, and for localized collections of these folds, covered in turn with villi, the term **synovial fringes** is apt. The folds and villi greatly increase the free surface of the synovial membrane, and this, in conjunction with the rich vascular and lymphatic supply of the membrane, accounts for the rapidity with which toxic absorption occurs in acutely infected joints.

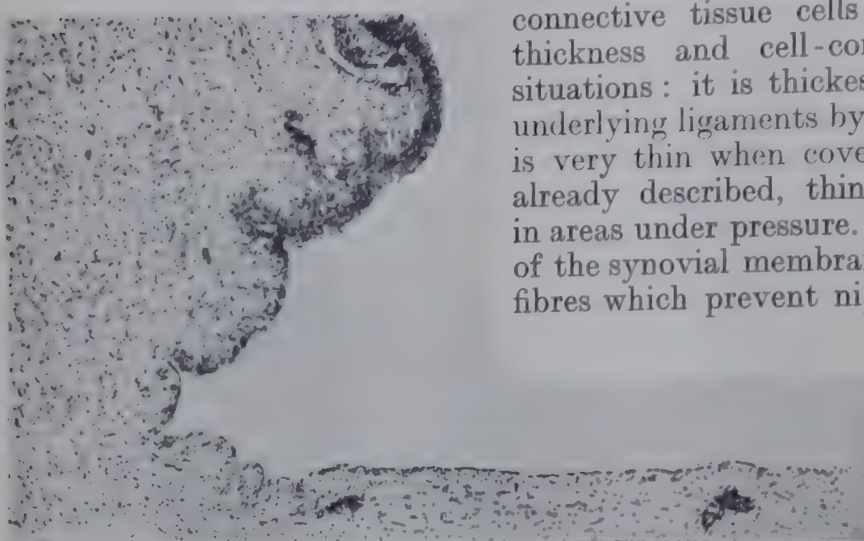


Fig. 310.—Section from Human Knee Joint.

The section is at the angle between the *semilunar cartilage* (below) and the *capsular ligament* (on left). Note that the *synovial membrane* forms a folded lining over the ligament but disappears on the surface of the cartilage. (Photomicrograph × 50.)

The **synovial fluid** is a clear, slightly yellow, glairy fluid deriving its name from its likeness in appearance and consistence to white of egg (for details regarding viscosity and volume see Davies, 1944). It is, in amount, sufficient only to cover with a thin film all surfaces within the joint—less than half a cubic centimetre in the knee joint. The synovial fluid is now regarded as a dialysate of blood-plasma to which there is an addition of mucin (Bauer, Ropes and Wayne, 1940). The actual source of the mucin, which is largely responsible for the viscid nature of the fluid, is still in doubt, but it is probably a secretion of the synovial cells. The function of the fluid is threefold: it serves to lubricate the joint-surfaces; it appears to be the main source of nourishment for the articular cartilage; and the cells it contains—constantly migrating from the synovial membrane, circulating in the fluid and entering the membrane again—remove by phagocytic action micro-organisms and the debris of wear and tear in the joint (Coggeshall, Warres & Bauer, 1940).

It will be clear that the synovial cavity of the joint, bounded by synovial membrane and articular cartilage, is completely closed. Where an opening in the ligamentous layer of the capsule allows the synovial layer to protrude, the imperforate continuity of the synovial layer is always maintained. But the synovial cavity is not completely closed in a histological sense: the synovial membrane, unlike the pleura or the peritoneum of the coelomic cavities, has no complete epithelial lining as a barrier between the cavity of the joint and the tissue-spaces around. The cavity is itself, in effect, an enormously enlarged tissue-space; that is how it was developed. This has a bearing on the rapid absorption which can take place from an acutely infected joint-cavity.

Bursæ.—Closely akin to synovial membrane are the walls of certain closed

sacs, known as **synovial bursæ**, that are found in many situations in the body. The bursæ contain fluid resembling synovia, and they serve to facilitate the play of one structure upon another. **Subcutaneous bursæ** are found between the skin and underlying bony prominences such as the olecranon and the patella. **Subfascial bursæ** are similarly placed beneath the deep fascia. **Subtendinous bursæ** are found where one tendon overlies another tendon or a projection of bone; the walls of such a bursa in the neighbourhood of a joint may be continuous

FIG. 311.—SYNOVIAL FOLDS FROM HUMAN KNEE JOINT.

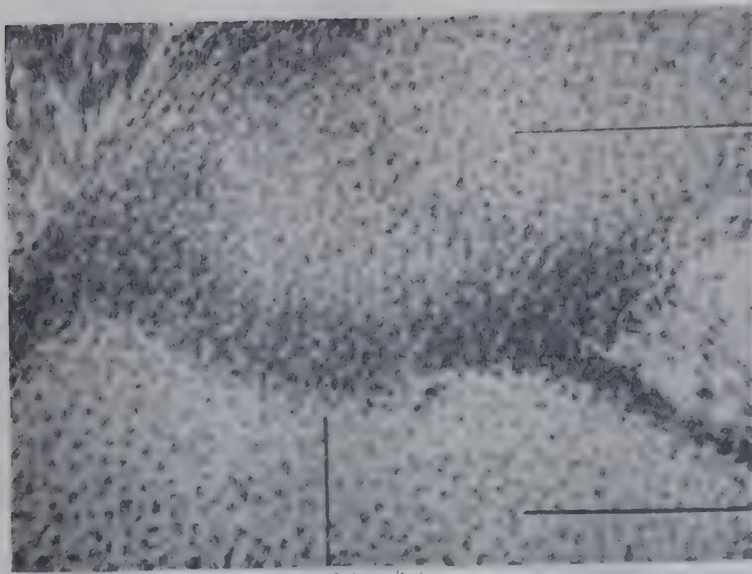
The *capsular ligament* (just appearing at base of photograph) is separated from the *synovial membrane* by loose areolar tissue. Note numerous blood-vessels in the synovial membrane. (Photomicrograph × 100.)

with the synovial membrane of the joint through an aperture in the capsular ligament.

Of the same nature are the **synovial sheaths** that surround tendons running in osteo-fascial tunnels, as in the case of the tendons passing behind the flexor retinaculum at the wrist and of the flexor tendons lying on the front of the fingers. The synovial layer lines the tunnel and is also reflected round the tendon that lies within it.

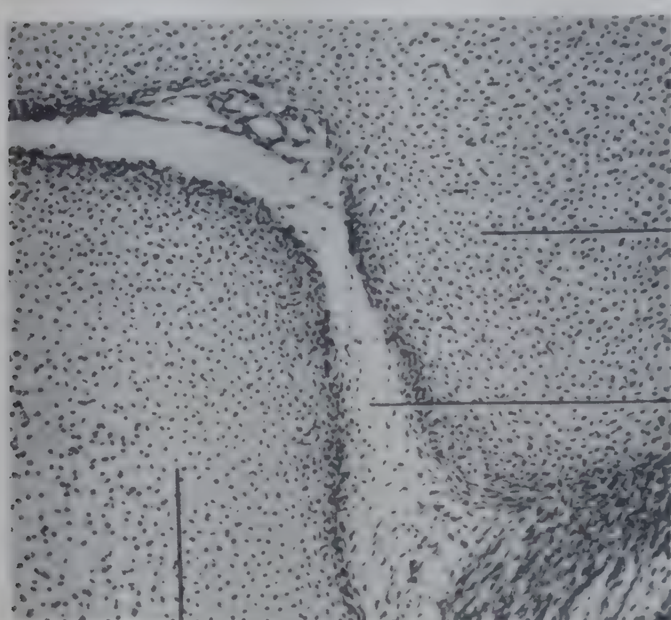
Development of a Synovial Joint.—After the cartilaginous precursors of the bones have been formed, their ends are separated from each other by a disc of very cellular mesenchyme that is called the **primitive joint-plate** (Fig. 312 A). There are no sharp lines of demarcation between the ends of the cartilages and the joint-plate, and indeed the cells of the joint-plate that are adjacent to a cartilage are to be regarded as a chondrogenetic layer that is associated with the growth in length of the cartilage (for this, and other details of joint-development, see Haines, 1947). As development proceeds, a process of differentiation occurs within the joint-plate and the two chondrogenetic layers become separated from each other by an intermediate stratum of loose tissue in which the cells are relatively scanty (Fig. 312 B). The intermediate stratum of loose tissue later undergoes liquefaction so that a **joint-cavity** appears between the ends of the cartilages; the cartilages in turn lose the chondrogenetic layers over the articular surfaces though a thin fibrillar layer may persist over them until birth. The mesenchymatous tissue that surrounds the joint-plate differentiates into a dense outer layer that forms the **capsular ligament**, and an inner loose layer that forms the **synovial membrane**. The synovial layer is invaded by extensions of the joint-cavity so that the typical relationship of joint-cavity to synovial membrane is established. *Intra-articular ligaments* and *fibro-cartilages* arise from thickenings that project inwards from the wall of the primitive joint cavity. A complete *articular disc* arises from a transverse mesenchymatous septum between double cavities which appear in the joint-plate. *Extra-capsular ligaments* may arise independently of the joint-plate, from separate membranous bands.

Morphology of Ligaments.—Certain articular ligaments and fibro-cartilages, whether or not arising ontogenetically after the common manner just described, have been credited with interesting phylogenetic histories, sometimes in different versions. Thus, a muscle tendon that originally stretches over a joint to the farther bone may acquire a new attachment on the



A. Costo-Transverse Joint of 20 mm. Human Foetus (× 100).

At this stage the primitive joint-plate is a very cellular disc not sharply demarcated from the adjoining cartilages.



B. Ankle Joint of 45 mm. Human Foetus (× 75).

There is an intermediate stratum of loose tissue between the medial malleolus and the talus, but between upper surface of talus and tibia this tissue has been absorbed.

C. Ankle Joint of 45 mm. Human Foetus (× 25).

The same specimen as in Fig. 312 B. to show the extent of the joint-cavity in relation to upper surface of talus.

Fig. 312.—Photomicrographs to illustrate the Development of Synovial Joints.

nearer bone, leaving the original terminal portion of the tendon to become a ligament fixed to both bones. Or the altered functioning of a joint in phylogeny may cause an earlier ligament or cartilage to be married into changed relations in the later type of joint. In the knee joint the medial and lateral ligaments are examples of stranded tendons, and the attachment of the lateral semilunar cartilage to the posterior cruciate ligament is a reminder of the different mechanism of an earlier vertebrate knee.

Such morphological points will be mentioned with the structures concerned, but it must be remembered that they are of interest rather than importance from the standpoint of present function.

Blood- and Lymph-Vessels. — A synovial joint is freely supplied by branches of the main arteries that are adjacent to it. These branches perforate the capsular ligament and break up within the synovial membrane into capillaries which form a rich and intricate network. Many of the capillaries are extremely close to the free surface of the synovial membrane and this accounts for the frequency with which haemorrhage occurs into the joint-cavity after even minor trauma (Davis, 1945). Adjacent to the peripheral margin of the articular cartilage the larger vessels of the synovial membrane branch and anastomose to form a vascular circle, the *circulus articuli vasculosus* of William Hunter (1743), and it is the terminal branches of this circle that overlie the margin of the cartilage and provide it with nourishment (p. 336).

The *lymphatic vessels* form a plexus within the synovial membrane, and from it efferent vessels pass towards the flexor aspect of the limb.

Nerve-Supply. The capsular ligament and synovial membrane are both supplied with nerves. The correlation that exists between the nerves of a joint and the nerves to the overlying tissues is expressed in Hilton's Law (John Hilton, 1863), viz.: "The same trunks of nerves, whose branches supply the groups of muscles moving a joint, furnish also a distribution of nerves to the skin over the insertions of the same muscles; and the interior of the joint receives its nerves from the same source." The nerves in the capsular ligament terminate in free endings and end-organs and probably transmit pain and proprioceptive impulses. In the synovial membrane all nerves, according to Gardner (1944), terminate in relation to blood-vessels and it is considered that many of these are vasomotor nerves.

Joint-Approximation Forces.—It is useful to consider the factors concerned in maintaining the integrity of the union between the bones in synovial joints, in which, for the sake of a joint-cavity to assist free movement, structural continuity of the united bones is given up. Two minor factors common to all such joints are the **force of cohesion** and **atmospheric pressure**—the cohesion because of the smooth joint-surfaces in contact with each other except for an intervening capillary layer of fluid, and the pressure because the atmosphere is excluded from the closed synovial cavity. A third factor of very different value in different joints is **interlocking of the coapted bones**; this is well marked in the hip joint, but is completely absent in plane joints.

The most important factors are the **strength of the articular ligaments** and the **tension of the muscles** around the joint. These two act together in varying proportions; in, for example, the shoulder joint, with its relatively lax capsule, the ligamentous factor is small, whereas in the hip joint, with well developed ligamentous bands in its capsule, it is of more importance. But it must be emphasized that white fibrous tissue ligaments cannot resist continuous strains without lengthening permanently, so that they must ever be supported by the contractile tension of muscle. Whether at rest or in contraction, the muscles around a joint are ever exerting by their active tonicity a force of joint-approximation. Their efforts may be relieved considerably by suitably disposed ligaments, but no ligament will for long resist stretching under constant strain if unaided by muscular tension. Thus, in flat-foot deformity, while the displacement of bones is permitted by over-stretched ligaments, this in turn is due to diminished support from muscles deficient in tone. In the knee joint, where the capsular ligament is largely formed of tendinous expansions from muscles acting on the joint, a beautiful example is seen of close structural and functional co-operation of muscle and ligament.

Limitation of Movement.—Four factors are concerned in the limitation of movement at synovial joints: the apposition of soft parts, the locking of the articulating bones, the tightness of ligaments, and the tension of fully stretched muscles. **Apposition of soft parts** obviously limits movements in such examples as flexion of the elbow when the front of the forearm is pressed against the front of the upper arm, and flexion of the knee when the back of the leg meets the back of the thigh. **Locking of the bones** probably occurs only exceptionally; thus, in the elbow joint, in a few cases pressure facets at the sides of the olecranon fossa of the humerus indicate that extension must have been limited by actual contact of the olecranon with the humerus, but in the majority of cases tension of the muscles and ligaments in front of the joint is the limiting factor. The **tension of ligaments** is an important factor in the limitation of movement. The various parts of a capsular ligament are tense in only certain positions of a joint and they are concerned, therefore, not only in the final limitation of a movement but also in directing the movement of the articular surfaces on each other. In the hip and knee joints the major ligaments are lax in flexion and tense in extension. Furthermore, it is in the position of extension at these joints that the articular surfaces are in fullest contact with each other. Tense ligaments and maximal contact of the articular surfaces are the essential features of a 'locked' joint, and it is when a joint is 'locked' that it is most stable and best adapted for weight-bearing. At many joints **muscular tension** reinforces the restraint on movement imposed by the ligaments, if it does not actually check movement before the ligaments are fully stretched. This effect of the muscles is called their *passive insufficiency* or *ligamentous action*. A good example of limitation of movement purely by muscular tension is the check imposed on flexion of

the hip by the tension of the hamstrings while the knee is fully extended; flexion of the knee lessens the tension of these muscles, and further flexion of the hip can then take place. The effect of muscles in limiting movement in the ordinary person can be appreciated when one considers the greater range of movement possessed by acrobats, who by constant practice conserve or even increase the full extensibility of muscle possessed by all in early life. Admittedly in such cases ligaments and articular surfaces also are modified to allow the extreme movements; but that muscles normally exert a restraint on movement beyond that exercised by ligaments is shown by the extreme movements sometimes produced in the convulsions of tetanus or epileptic fits, when the safeguarding muscular restraint operating in ordinary voluntary action is withdrawn.

Classification of Synovial Joints

Synovial joints may be subdivided for further consideration in terms of the shape of the articulating surfaces and the movements performed at the joint; these two factors being related can be used together in a system of classification. From the point of view of form only, a distinction can be made between **homomorphic** and **heteromorphic** joints. The articular surfaces in a homomorphic joint are similar in conformation; those in a heteromorphic joint are dissimilar. Combining further consideration of shape with an analysis of movement, we distinguish *plane* and *saddle* joints of homomorphic pattern, and *hinge, pivot, ball-and-socket, condyloid* and *ellipsoid* joints in the heteromorphic division.

Plane Joint.—In a typical plane joint the opposed surfaces are flat, and are equal in extent; but in many cases the term is a relative one, as the surfaces are slightly curved. Such curvature, however, is never sufficient to bring the joint into one of the other subdivisions, and has little influence on the movement. This is a simple **gliding**, in any direction, or twisting, of the one bone on the other within the narrow limits permitted by a slight laxity of the capsular ligament. Such joints are found between some of the carpal and tarsal bones, and between the articular processes of adjacent vertebræ.

Saddle Joint.—Here the concavo-convex articular surface of the one bone is reciprocally homomorphic with the convexo-concave surface of the other. Movements are permitted around two principal axes at right angles to each other, and to a less extent around intermediate axes. The only good example is the carpo-metacarpal joint of the thumb.

Hinge Joint.—In this, the articulating surfaces are arranged to permit movement around only one axis—and that a transverse one—as in the hinge of the lid of a box. The elbow and interphalangeal joints are good examples. Usually the articulating bones are in line in the normal anatomical position; movement around the transverse axis causing the bones to become increasingly angulated is termed **flexion**, while movement in the reverse direction is called **extension**. In cases where the normal position is angular, as at the ankle joint, suitably modified terms may describe the movements with less ambiguity, as *dorsi-flexion* and *plantar-flexion* in the example quoted. Two features in the disposition of the ligaments are common to all hinge joints. In the first place, the capsular ligament must be of sufficient length in front and behind to permit movement; of these parts one will be taut and the other lax in full flexion or full extension. In the second place, strong ligaments are placed at the sides of the joint, one end of each ligament being attached in the axis of the hinge; some parts of these ligaments therefore can be taut in all positions of the joint without restricting its movement.

Pivot Joint.—Here also movement can take place around only one axis, but a vertical one, as in the hinge of a gate. A more or less cylindrical articular surface **rotates** within a ring formed partly by bone, partly by ligament, as in the superior radio-ulnar joint; or, conversely, the ring may rotate around the cylindrical surface, as in the joint between the odontoid process and the anterior arch and transverse ligament of the atlas.

Ball-and-Socket Joint.—Here, as for example in the hip and shoulder joints, a " ball " formed by a spheroidal surface on the one bone rotates in a " socket " provided by a concavity in the other. This is the most completely movable form of joint, for movement can take place around an almost infinite number of axes passing through the centre of the 'ball'. For descriptive convenience three principal axes at right angles to one another are specially considered. Around a transverse axis, movements of **flexion** and **extension** take place as in a hinge joint. Movements sideways around an antero-posterior axis are named **abduction** in the case of a limb raised laterally, away from the median plane of the body, and **adduction** when the limb is brought towards or across the median

(2) Incudo malleolar joint

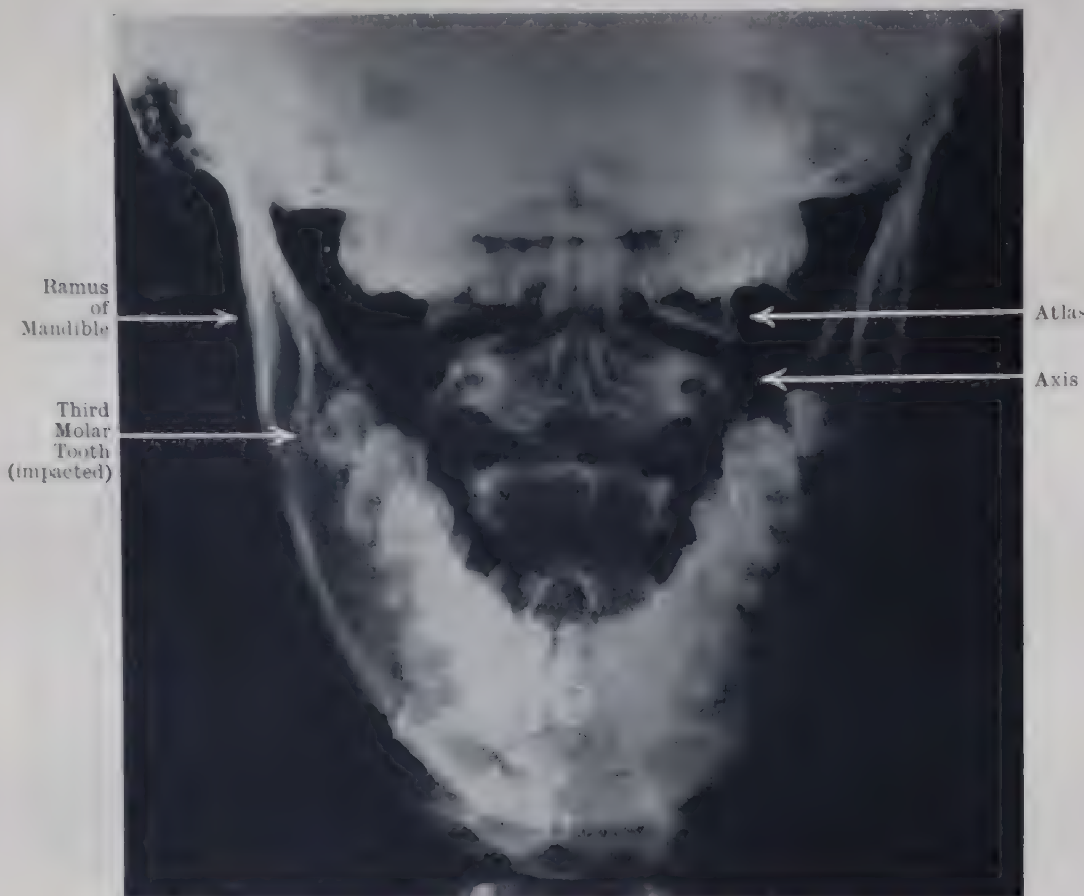


FIG. 1.—RADIOGRAPH TAKEN THROUGH OPEN MOUTH, SHOWING THE POSITION OF THE CERVICAL VERTEBRÆ IN RELATION TO THE JAWS AND THE MOUTH CAVITY.

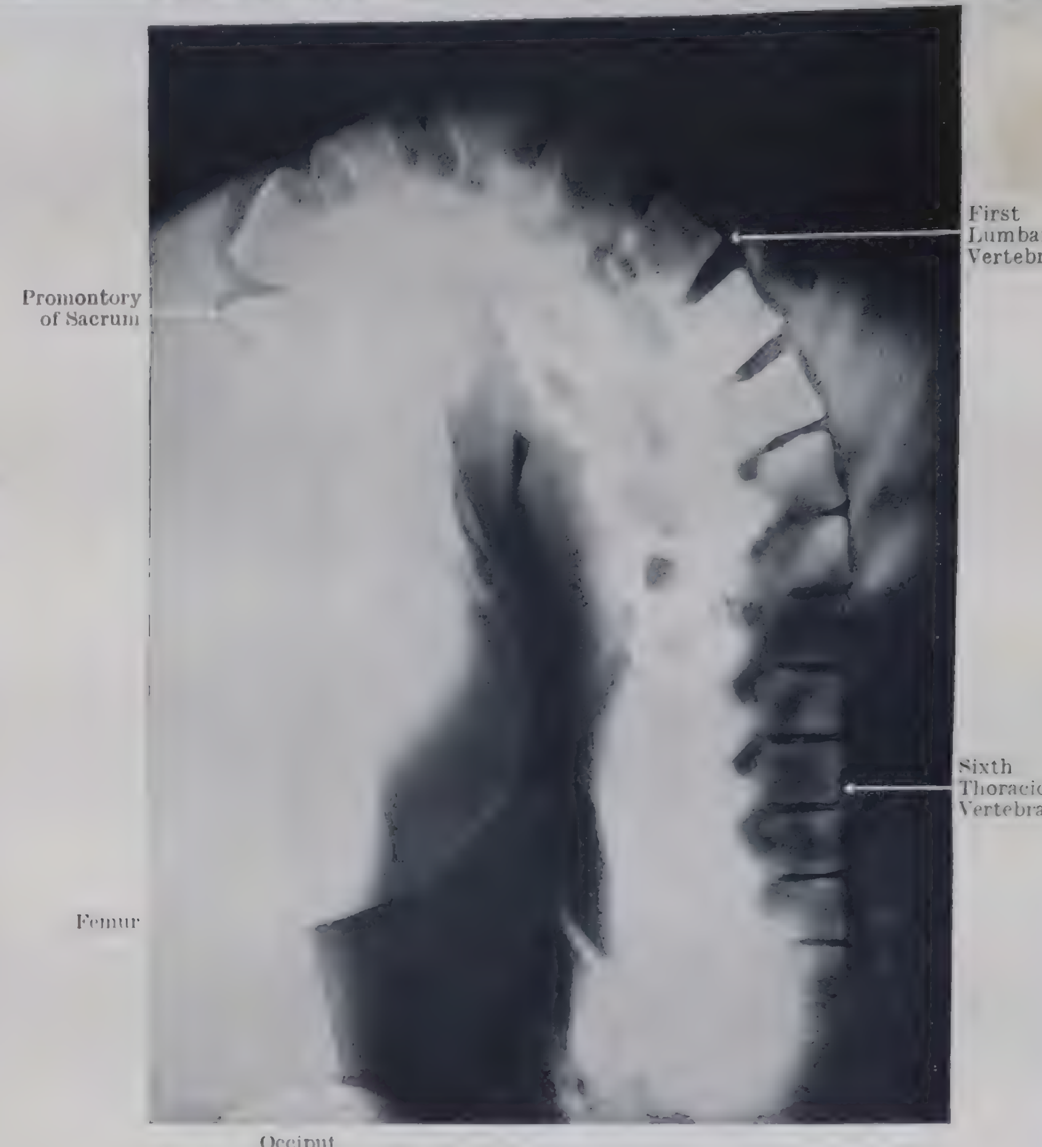


FIG. 2.—LATERAL RADIOGRAPH ILLUSTRATING EXTREME HYPER-EXTENSION OF VERTEBRAL COLUMN IN A TRAINED ACROBAT.

Note the apparent rotation of the lumbar vertebræ, due partly to the obliquity of the X-ray beam in that area.

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PLATE XXX

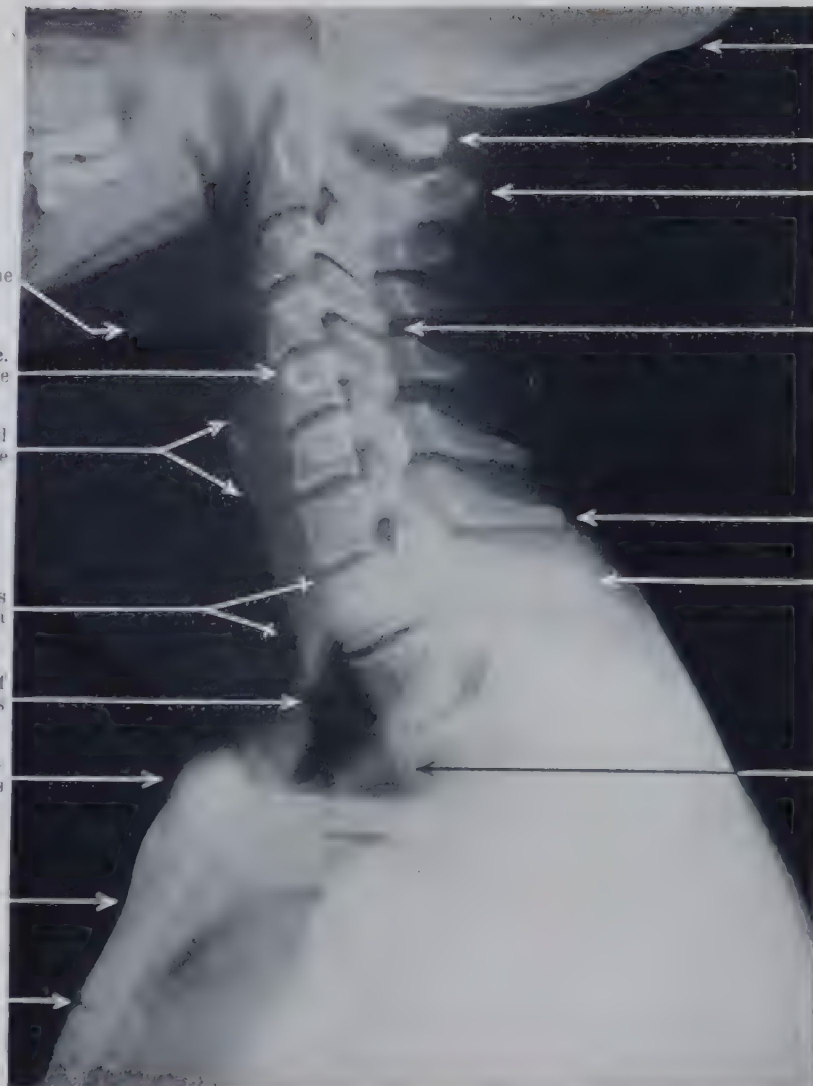

FIG. 1.—LATERAL RADIOGRAPH OF NECK OF WOMAN AGED 28 TO SHOW THE FORM AND ARTICULATIONS OF THE CERVICAL VERTEBRÆ.

Note the bony columns formed by the bodies of the vertebræ and the overlapping

FIG. 2.—OBLIQUE LATERAL RADIOGRAPH OF LUMBAR VERTEBRÆ OF WOMAN AGED 59 TO SHOW THE JOINTS BETWEEN ARTICULAR PROCESSES.

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plane. Around a vertical axis in the centre-line of the limb, the limb **rotates, medially or laterally.** **Circumduction** is a composite movement around a number of axes whereby the limb describes the side of a cone, the apex of which corresponds to the centre of the 'ball'. The stability of such a joint depends on the depth of the 'socket', but greater depth of socket proportionately limits movement.

Condyloid Joint.—In this variety the articular surfaces are of the ball-and-socket type; but, owing to the disposition of the ligaments and muscles, the movement of active rotation around a vertical axis is absent. **Flexion** and **extension, abduction** and **adduction**, and **circumduction** take place. The metacarpo-phalangeal joints of the fingers (but not of the thumb) are condyloid joints.

Ellipsoid Joint.—This is a further modification of the ball-and-socket joint: the articular surfaces, instead of being spheroidal are ellipsoidal, as in the radiocarpal joint. The curvature in the long axis of the joint-surfaces has a greater radius than in the short axis. Movement takes place around two principal axes at right angles, corresponding to the greatest and least diameters of the joint, and to a slight extent around intermediate axes. Circumduction also is allowed, but the ellipsoidal surfaces prevent rotation.

JOINTS OF TRUNK AND HEAD

INTERVERTEBRAL JOINTS

The joints between the free vertebræ are arranged on a common plan, with the exception of the specialized joints between the atlas and axis. The bodies of adjacent vertebræ are joined together and also the vertebral arches, but on each

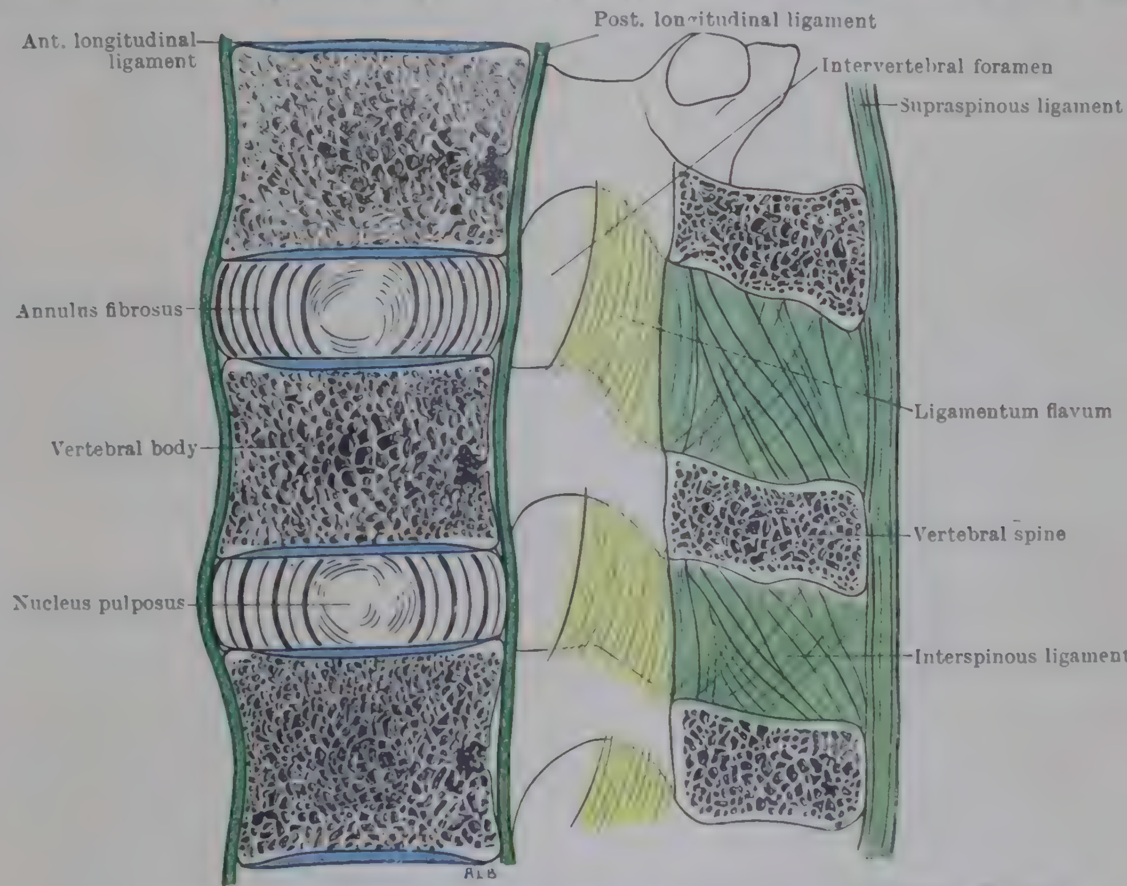

Fig. 313.—Median Section through Part of Lumbar Region of Vertebral Column.
Articular cartilage, *blue*; ligaments, *green* and *yellow* (lig. flava).

side, between these connexions, the pedicles remain free, being separated by the intervertebral foramina (Fig. 313).

Joints between Vertebral Bodies.—These joints are cartilaginous joints of the secondary type; for the bodies are united mainly by *fibro-cartilages*, though these are supplemented by *longitudinal ligaments*.

Intervertebral Discs.—The under surface of one body is united to the upper surface of the succeeding body by a fibro-cartilaginous **intervertebral disc** (Fig. 313). The peripheral part of this disc is called the *annulus fibrosus*, and is composed of fibro-cartilage so densely fibrous that the cartilaginous element is

appreciated with difficulty in microscopical section. The fibres run obliquely between the two vertebræ and are arranged in concentric rings, the fibres in successive rings having opposite obliquities. The central part of the disc, which is soft and gelatinous is called the *nucleus pulposus*. On each surface of the disc, above and below, there is a thin plate of hyaline cartilage, in the marginal part of which the annular epiphysis of the vertebral body develops. The surface of the vertebra with which the cartilage plate is in contact is perforated by numerous small foramina that are most apparent in the zone adjacent to the annular epiphysis. After the thirtieth year the discs are avascular and are nourished by fluid that traverses the foramina from the interior of the vertebrae and passes by diffusion through the cartilage plates. The discs between the cervical vertebræ do not extend quite to the lateral edges of the vertebral bodies, where, between the lipped edge of the body below and the bevelled edge of the one above, there is a small synovial joint. The discs account for nearly one-fourth of the length of the vertebral column but show considerable difference in their thickness in different regions, being thinnest in the upper thoracic region and thickest in the lumbar region. The discs are also slightly wedge-shaped, in conformity with the curvature of the vertebral column in their neighbourhood; this is particularly marked in the cervical and lumbar regions, where the anterior convexities are due chiefly to the greater thickness of the discs in front than behind. It is of considerable practical importance to note that the intervertebral disc forms one of the anterior boundaries of the intervertebral foramen (Fig. 313), and that the spinal nerves, as they pass through the foramina, lie directly behind the corresponding discs.

The nucleus pulposus is customarily described as a white glistening body that is composed of fibro-cartilaginous tissue embedded in a gelatinous matrix, but from the time of its first appearance in the foetus it undergoes a continuous structural change until late adult life. It was formerly believed to be derived from the notochord but this has been shown by Keyes and Compere (1932), and others, not to be strictly correct. Early in foetal life the notochordal cells in each intervertebral region proliferate rapidly but later undergo a mucoid degenerative process which results in the formation of a gelatinous nucleus pulposus. As the notochordal cells degenerate the nucleus is gradually invaded by the surrounding fibro-cartilaginous tissue. In young subjects the nucleus is still largely formed of gelatinous tissue and hence has a translucent appearance that contrasts sharply with the fibro-cartilaginous annulus fibrosus. With increase in age the gelatinous tissue is gradually replaced by fibro-cartilage until in old age the nucleus can no longer be recognized as a separate structure. Coincident with these changes in the structure of the nucleus pulposus, Puschel (1930) has shown that there is a progressive decrease in its water content, which at birth is 88 per cent but at seventy-two years is only 70 per cent.

The nucleus pulposus forms a variable proportion of the intervertebral disc in the different vertebral regions, but is always situated nearer its posterior than its anterior surface. It is normally under considerable pressure and, when the disc of a young or middle-aged subject is cut across, it protrudes above the level of the annulus fibrosus. The nucleus pulposus may be regarded as a water-cushion associated with equalizing the distribution of pressure between vertebræ, and the absorption of mechanical shocks that are constantly being transmitted along the vertebral column. For further information on the structure and function consult Beadle (1931) and Bradford & Spurling (1945).

Longitudinal Ligaments.—The **anterior** and **posterior longitudinal ligaments** also help to unite the bodies of the vertebræ. The **anterior ligament** (Fig. 321) is a broad band of some thickness that runs up and down the front of the column over the anterior surfaces of the vertebral bodies. It is narrowest at its upper end, where it has a pointed attachment to the anterior tubercle of the atlas; it becomes wider as it descends, and ends below by spreading on to the pelvic surface of the sacrum. It is firmly attached to the intervertebral discs and adjacent parts of the vertebral bodies; the superficial fibres pass over several vertebræ, the deepest join adjacent bones. The **posterior longitudinal ligament** (Fig. 314) is constructed on a similar plan. It is placed on the back of the vertebral bodies, in the anterior wall of the vertebral canal. Unlike the anterior ligament, it is broader above than below. Its upper end is continued into the membrana tectoria, which covers the odontoid process and its ligaments and is attached to the occipital bone. Opposite the bodies of the thoracic and lumbar vertebræ the posterior ligament narrows markedly, but remains broader opposite

the intervertebral discs, so that each edge presents a series of pointed dentations. Its narrow, lower end passes on to the anterior wall of the sacral canal. The posterior ligament is attached only to the discs and adjoining edges of the vertebral bodies; opposite the middle of each vertebra it is separated from the bone by an interval through which pass thin-walled veins (Fig. 313). The free surface of the ligament is separated from the spinal dura mater by loose areolar tissue with veins running in it; in the lower part of the canal the ligament is rather more intimately connected to the dura by fibrous bands. The posterior ligament, like the anterior one, is composed of longitudinal fibres of varying length: the most superficial run over several vertebræ; the deepest pass only from one bone to the next.

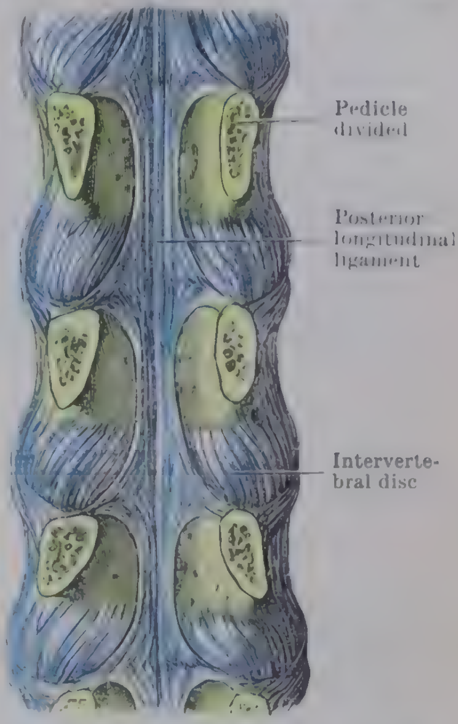

FIG. 314.—POSTERIOR LONGITUDINAL LIGAMENT OF VERTEBRAL COLUMN.

Joints between Vertebral Arches.—The vertebral arches are united by *synovial joints* between the articular processes, and by *accessory ligaments* which pass between the laminæ, between the transverse processes, and over and between the vertebral spines.

The **synovial joints** are of the plane variety; the shape and disposition of the joint-surfaces on the articular processes vary in the different regions of the column, as already described in the Section on Osteology. Each joint is surrounded by a thin **capsular ligament** lined with **synovial membrane**. The joint capsules are lax, particularly in the cervical region, so that slight gliding movements can take place between the bones.

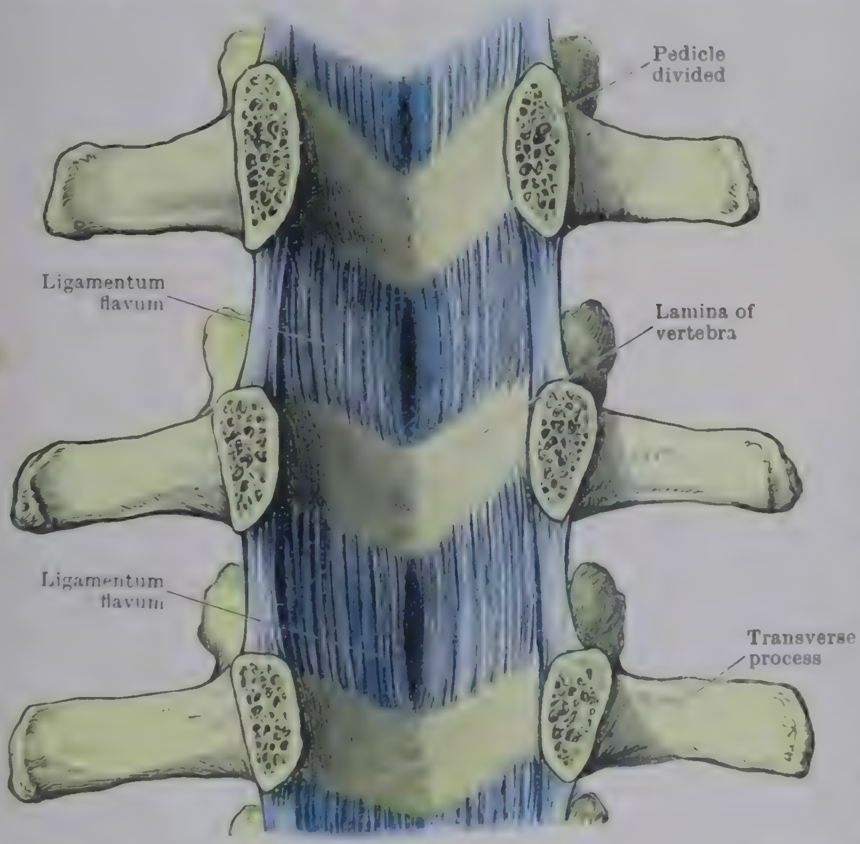

FIG. 315.—LIGAMENTA FLAVA SEEN FROM THE FRONT AFTER REMOVAL OF THE BODIES OF THE VERTEBRÆ BY SAW CUTS THROUGH THE PEDICLES.

The **accessory ligaments** are the supraspinous and interspinous, the intertransverse, and the ligamenta flava. The **interspinous ligaments** are relatively weak bands that run between the lower border of one vertebral spine and the upper border of the next below; they are longest and strongest in the loin (Fig. 313). The **supraspinous ligament** runs over the tips of the spines and is fused with the posterior edges of the interspinous ligaments; short fibres in the ligament join adjacent spines; longer ones connect spines several vertebræ apart.

In the neck, the supraspinous ligament merges into the triangular **ligamentum nuchæ**. This, in Man, is merely a fibrous partition between the muscles of the two sides of the back of the neck; it is attached above to the external occipital crest and deeply to the cervical spines, while its superficial border runs between

the external occipital protuberance and the spine of the last cervical vertebra. In quadrupeds the ligamentum nuchæ is a well-developed elastic ligament which relieves the muscles in supporting the head.

The intervals between the laminæ of adjacent vertebræ are filled by the **ligamenta flava**, so called because of their yellowish colour due to the presence of much elastic tissue. Each is attached above to the front of the lower border of a lamina, and below to the back of the upper border of the succeeding lamina (Fig. 315). There are two—a right and a left—in each vertebral interval; their medial borders are separated by a narrow, median chink through which pass veins that connect the venous plexus within the vertebral canal to the posterior vertebral plexus; laterally, they extend to the capsules of the intervertebral synovial joints, but do not blend with them. The ligamenta flava are the only markedly elastic ligaments in Man. By their elasticity they can permit separation of the laminæ in forward flexion of the vertebral column without falling, on extension of the column, into folds which might press upon the dura mater or be caught between the laminæ they connect; and their elastic tension assists the posterior vertebral muscles in maintaining the erect attitude.

The *intertransverse ligaments* are insignificant bands between the transverse processes. They are generally absent in the cervical region; they are marked only in the lumbar region. In the upper part of the column they tend to be replaced by the intertransverse muscles.

Movements of Vertebral Column

The adult vertebral column in the erect posture has four antero-posterior curves—cervical, thoracic, lumbar and sacro-coccygeal—and these have already been considered in the Section on Osteology on p. 135. As stated there, the *compensatory* or *secondary* curves (cervical and lumbar) are due mainly to the shape of the discs, whereas the thoracic curvature, which is a primary one, is caused mainly by the shape of the vertebræ. The sinuous form of the vertebral column, made up as it is of alternate bony vertebræ and resilient intervertebral discs, makes it a structure that is well adapted to its supporting and shock-absorbing functions. In old age the intervertebral discs shrink and the vertebral column tends to revert to its original primary curve; thus it is that some people in advanced years have a ' bowed back ' and appear to become smaller.

Movement between any two successive vertebræ is very slight; but the sum total of movement in the whole column is considerable (Pl. XXXI). The possibility of movement is due to the slight flexibility of the intervertebral discs coupled with the laxity of the capsules and the incomplete apposition of the articular surfaces of the intervertebral synovial joints. Where the discs are thick or numerous, movement is likely to be more free, though the arrangement of the fibres in the discs strictly limits movement between adjacent vertebræ in any direction; the semi-fluid nature of the nucleus pulposus tends to equalize pressure within each disc during movements between the vertebræ. The shape and set of the articular processes in the different regions affect the degree of movement permitted at the synovial joints.

The movements of the vertebral column are customarily described as forward **flexion**, backward **extension**, **lateral flexion**, and **rotation**. Lateral flexion and rotation are, however, always associated movements and neither can take place independently of the other. All the above types of movement can take place in all regions of the column, but the thickness of the intervertebral discs and the ' set ' and shape of the articular processes are the factors that largely determine the range of movements in the different regions. During flexion the anterior borders of the vertebræ are approximated whereas the distance between the posterior borders is increased: as full flexion is reached the anterior parts of the intervertebral discs are tightly compressed, but the posterior parts of the discs, the posterior longitudinal ligament and the ligaments of the vertebral arches all become taut, though the principal limiting factor to the movement is the tension of the posterior vertebral muscles. In extension, the vertebræ rock backwards on one another so that the distance between the anterior borders of the vertebræ is increased and the posterior borders are approximated (Pl. XXIX, p. 342). During this movement the anterior longitudinal ligament becomes increasingly taut whereas the other ligaments of the column are relaxed. The movement of extension of the column has a wider range than the movement of flexion, and is greatest in the cervical and lumbar regions. Much of

Fig. 1.—Forward Bend (Flexion).

Fig. 2.—Erect Position.

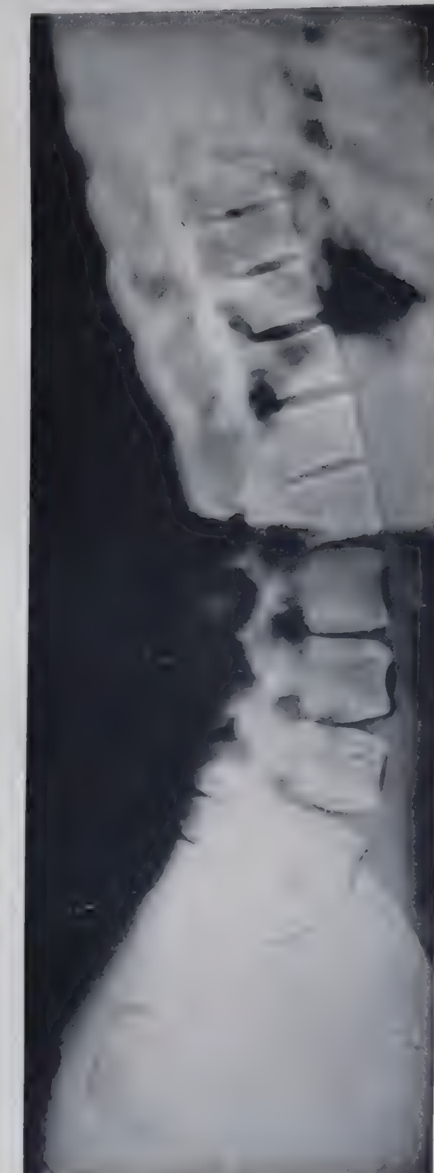

Fig. 3.—Backward Bend (Extension).
(Cf. Plate XXIX, Fig. 2, p. 342.)

Plate XXXI.—Three Lateral Radiographs illustrating the Extent of the Normal Antero-Posterior Movements of the Vertebral Column in the Thoracic and Lumbar Regions.

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PLATE XXXII

FIG. 1.—WITH THE ARM DEPENDENT. Note the position of the Anatomical Neck of the Humerus (indicated by the white crosses) and of the Scapula.

FIG. 2.—WITH THE ARM RAISED TO THE HORIZONTAL POSITION. Note that Scapular as well as Gleno-Humeral Movement has taken place.

FIG. 3.—WITH THE ARM RAISED VERTICALLY. In addition to further Scapular Movement, Gleno-Humeral Movement has continued until the Shaft of the Humerus is in line with the Spine of the Scapula.

PLATE XXXII. THREE RADIOGRAPHS OF THE SHOULDER TO DEMONSTRATE THE MECHANISM OF ABDUCTION AND ELEVATION OF THE ARM. (See p. 487.)

Note that in addition to movement of the scapula on the chest wall, and of the humerus at the shoulder joint, lateral rotation of the humerus also takes place.

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the apparent movement of flexion of the vertebral column during the bending forwards of the body is in reality due to flexion at the hip joints and also movement of the head at the atlanto-occipital joints.

In the neck, where the discs are relatively preponderant for the length of that part of the column, all movements are fairly extensive. The articular surfaces, set obliquely in a transverse plane, facilitate *flexion* and *extension* but cause *lateral flexion* and *rotation* to be accompanied each by some degree of the other movement. Thus, when the neck is bent to one side, each lower articular process on that side glides downwards and backwards on the upper process of the vertebra below, while on the other side each lower process mounts upwards and forwards upon the superior process below it; hence bending to one side is accompanied by a slight rotation to that side.

In the thorax, the small proportion of the fibro-cartilage relative to the length of the thoracic region, the presence of the ribs and sternum and the imbrication of the long, sloping spines all tend to limit movement. The vertical disposition of the articular processes hinders *antero-posterior* movement but interferes less with *lateral flexion*, which is accompanied by a crowding together of the ribs on the side of flexion and a spreading apart on the opposite side. *Rotation* is facilitated by the centre of curvature of the articular processes being near the centre of the vertebral body; but this is counterbalanced by the restraint imposed by the ribs and sternum. Rotation and lateral flexion are, however, always associated, and in complete extension of the vertebral column these movements are greatly diminished, if not altogether lost.

In the lumbar region the discs are thick; but the articular processes, vertically set with curvatures centred behind the vertebræ altogether, tend to restrict movements of all kinds—rotation in particular. Fairly free flexion and extension occur, especially at the lumbo-sacral joint where the intervertebral disc is thickest. When the vertebral column is flexed the lumbar curve is lost (Pl. XXXI) and lateral flexion, which is possible in the erect posture, is greatly diminished. Owing to the laxity of the intervertebral synovial joints some rotation may take place and this is associated with lateral flexion.

Atlanto-Occipital Joints

The skull is joined to the atlas by a pair of **atlanto-occipital synovial joints** between the occipital condyles and the superior articular facets of the atlas, and by the **anterior** and **posterior atlanto-occipital membranes**, which connect the arches of the atlas with the margins of the foramen magnum (Fig. 316).

Atlanto-Occipital Membranes.—The **anterior atlanto-occipital membrane** is attached superiorly to the anterior margin of the foramen magnum, and inferiorly to the anterior arch of the atlas; in the middle, the membrane is thickened by fibres prolonged upwards from the anterior longitudinal ligament: the right and left margins blend with the capsular ligaments of the synovial joints. The **posterior atlanto-occipital membrane** likewise reaches the capsular ligament at each side. Its upper border is attached to the posterior margin of the foramen magnum. The median part of its lower border is attached to the posterior arch of the atlas; but the lateral part, on each side, arches over the vertebral artery and the first cervical nerve as they cross the posterior arch of the atlas; this part of the lower edge of the membrane is thickened and is sometimes ossified.

Atlanto-Occipital Joint.—Each of the pair of synovial joints is enclosed by a **capsular ligament** which is attached at the margins of the articular surfaces and is lined with **synovial membrane**. The atlantal articular surface is concave; the occipital surface is convex. But the corresponding surfaces of the joints of the two sides are really segments of one ellipsoidal surface whose transverse diameter is the longer, and functionally the joints act together as a single ellipsoidal articulation. Movement therefore takes place around two principal axes—nodding or bending the head forwards and backwards around a transverse axis, and bending the head sideways around an antero-posterior axis. No rotation takes place between the skull and the atlas beyond a little slipping of the occipital condyles, the one forwards the other backwards, on the atlantal facets, giving the face a slight oblique tilt; the joint-surfaces are then in better apposition, and this is the natural pose of greatest ease and stability.

Atlanto-Axial Joints

The **atlas** and the **axis** have *bilateral synovial joints* between their opposed articular processes, and a *median synovial joint* formed by the articulation of the odontoid process with the anterior arch of the atlas and with the transverse ligament; in addition, various *accessory ligaments* connect the axis to the atlas, and the odontoid process to the occipital bone.

Lateral Atlanto-Axial Joint.—Each of the paired joints is of the plane variety, enclosed by a loose **capsular ligament** with a **synovial lining.** The articular surfaces have slight reciprocal curvatures, and are inclined obliquely laterally and downwards. Applied to the back of the capsule is an **accessory atlanto-axial ligament** which runs obliquely downwards and medially from the back of the lateral mass of the atlas to the back of the body of the axis (Fig. 317).

The anterior arch of the atlas is connected to the front of the body of the axis by a membranous expansion from each side of the pointed upper part of the anterior longitudinal ligament as it descends from the anterior tubercle of the

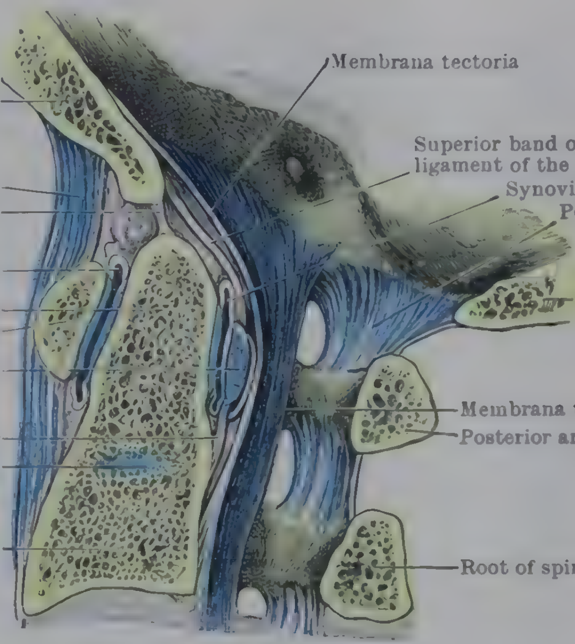

Fig. 316.—Median Section through Atlanto-Occipital and Atlanto-Axial Region.

atlas. The gap between the posterior arch of the atlas and the arch of the axis is bridged by a membrane, in series with the ligamenta flava, which is pierced at each side by the second cervical nerve. The position of this nerve behind the atlanto-axial joint bespeaks the different morphological value of this joint compared with other intervertebral synovial joints; it is held to be homologous with the small synovial cavity at the side of each cervical intervertebral disc.

Median Atlanto-Axial Joint.—The **articulation of the odontoid process with the atlas** is a pivot joint provided with two little synovial cavities (Fig. 316). The smaller of these cavities is between the facet on the front of the odontoid process and the facet on the back of the anterior arch of the atlas; the larger cavity is between the posterior facet on the odontoid process and the transverse ligament of the atlas; each cavity is enclosed by a thin capsular ligament lined with synovial membrane.

The transverse ligament of the atlas is a stout band that passes behind the odontoid process, between the tubercles on the medial sides of the lateral masses of the atlas (Fig. 317). From the middle of the transverse ligament a small band of longitudinal fibres passes upwards to the anterior edge of the foramen magnum, and another passes downwards to the back of the body of the axis (Fig. 316). These bands, together with the transverse ligament, constitute a cruciform structure known as the **cruciate ligament** of the atlas.

Occipito-Axial Ligaments

The axis is connected with the occipital bone indirectly by the longitudinal bands of the cruciate ligament, and, more directly, by the apical and alar ligaments of the odontoid process and by the membrana tectoria.

Ligaments of Odontoid Process.—Lying immediately in front of the upper band of the cruciate ligament, there is a slender cord which stretches from the apex of the odontoid process to the anterior edge of the foramen magnum: this is the **apical ligament** of the odontoid process, a structure developed from the rudiment of a supra-atlantal disc and the segment of notochord passing from the first cervical centrum to the cranial base. The **alar ligaments** of the odontoid process are short, stout bands that run, one from each side of the apex of the odontoid process, upwards and laterally to the medial side of each occipital condyle (Fig. 317).

Membrana Tectoria.—The odontoid process and the cruciate and alar ligaments are covered over posteriorly by the **membrana tectoria** (Figs. 316, 317), a broad

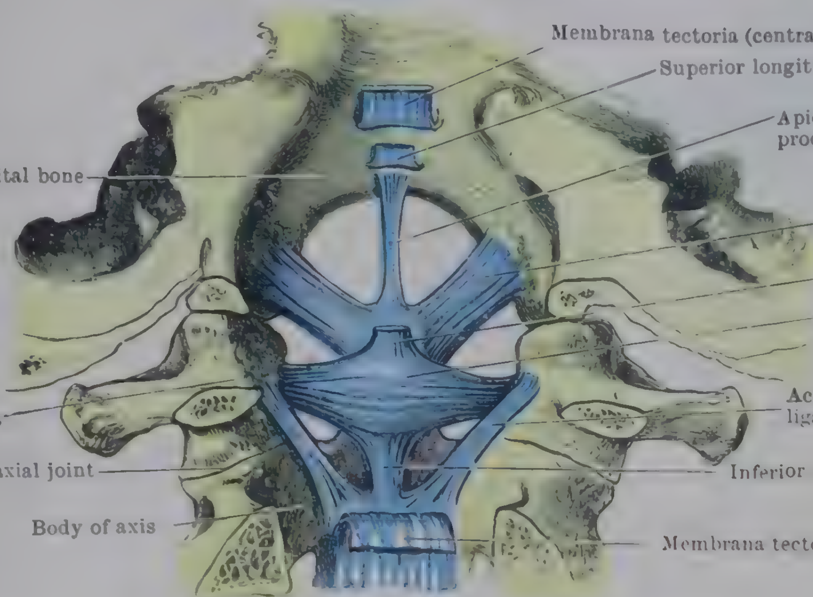

FIG. 317.—DISSECTION FROM BEHIND OF LIGAMENTS CONNECTING OCCIPITAL BONE, ATLAS, AND AXIS WITH ONE ANOTHER. (The capsular ligaments of the atlanto-occipital and atlanto-axial joints have been removed.)

sheet continuous below with the upper end of the posterior longitudinal ligament, and attached above to the occipital bone within the anterior edge of the foramen magnum between the anterior condylar canals. A small synovial bursa sometimes lies between the membrana and the median part of the transverse ligament of the atlas. The lateral margin of the membrana tectoria overlies and blends with the accessory atlanto-axial ligament. The upper end of the spinal dural tube is closely attached in front to the posterior surface of the membrana tectoria, and, behind, to the anterior surface of the posterior atlanto-occipital membrane.

Movements of the Head

The movements of the head at the **atlanto-occipital joints** have been referred to in the description of those joints.

The combined movements at the three **atlanto-axial joints** serve to effect rotation of the head around a vertical axis, the skull and the atlas moving as one. While the ring formed by the anterior arch and transverse ligament of the atlas pivots round the odontoid process, the lateral masses of the atlas glide, the one forwards and the other backwards, on the upper articular facets of the axis. Owing to the oblique disposition of these lateral joint-surfaces, rotation of the head to one side is accompanied by a slight vertical descent of the head, so that the median pivot joint around the odontoid process resembles in action a rising butt-hinge. Excessive rotation is checked by the alar ligaments and to a less extent by the accessory atlanto-axial ligaments. But the descent of the head, by approximating the attachments of the alar ligaments, serves to delay their check action, and this action can be obviated during a further degree of extreme lateral

rotation by tilting the head backwards and to the opposite side. When the face looks straight forward the lateral joint-surfaces are not fully in apposition; slight rotation to one side secures better apposition and a pose more easily maintained.

Mandibular Joint

The **mandibular joint** is formed by the articulation of the **head of the mandible** with the **articular fossa** and the **articular eminence** of the temporal bone. It is a synovial joint possessing a complete articular disc of fibro-cartilage which divides the joint-cavity into two separate compartments—an upper one between the disc and the articular surface on the temporal bone, and a lower one between the disc and the head of the mandible.

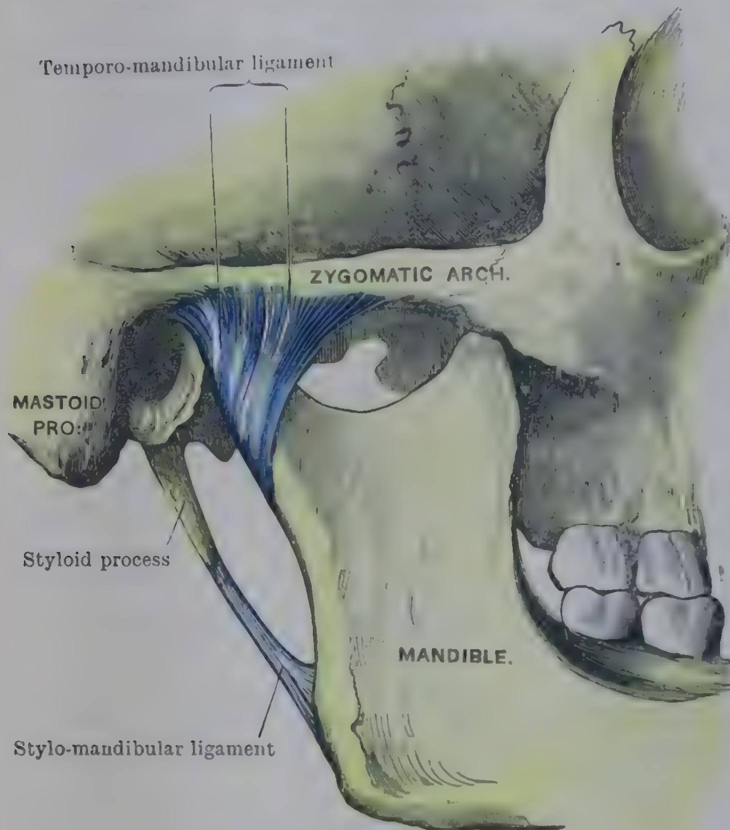

Fig. 318.—Mandibular Joint.

The **temporal articular surface** is concavo-convex from behind forwards, extending from the squamo-tympanic fissure over the articular fossa and eminence to the anterior border of the eminence (Fig. 319). The **head of the mandible** is a narrow ellipsoidal bar of bone directed medially and slightly backwards, markedly convex from before backwards but only slightly convex from side to side.

The **capsular ligament** is loosely arranged around the joint. It is attached superiorly around the limits of the temporal articular surface, and inferiorly to the neck of the mandible. Each compartment of the joint has its separate **synovial membrane**, which lines the capsular ligament but disappears over the surface of the disc. The capsular ligament is thickened laterally by a strengthening band, called the **temporo-mandibular ligament**, which is directed downwards and backwards from the lower border and tubercle of the zygoma to the lateral and posterior aspect of the neck of the mandible (Fig. 318). Anteriorly the capsular ligament receives part of the insertion of the lateral pterygoid muscle.

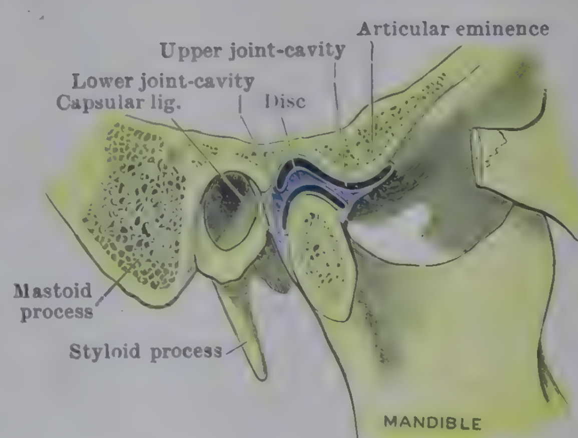

Fig. 319.—Antero-posterior Section through the Mandibular Joint.

The **articular disc** separates the highly incongruent joint-surfaces and is moulded upon them in different positions of the joint; it is therefore concave below and concavo-convex above (Fig. 319). It is attached all round to the capsular ligament, and, anteriorly, through the capsule, to the lateral pterygoid tendon. In the embryo the lateral pterygoid tendon passes backwards between the head of the mandible and the squamous temporal bone to be attached to the malleus, and it is the part between the bones that becomes compressed and forms the disc (Harpman and Woollard, 1938). The disc is thick anteriorly and in the middle; between these thickenings it is thin, and the posterior half of the disc thins out as it passes down behind the head of the mandible.

Accessory Ligaments.—Two other ligaments in the vicinity of the mandibular joint may be mentioned here. The **spheno-mandibular ligament** is a thin band that runs from the spine of the sphenoid bone and the adjacent medial end of the squamo-tympanic fissure downwards and forwards to the lingula and the adjoining part of the deep surface of the ramus of the mandible (Fig. 320). It lies a little medial to the capsule of the mandibular joint; intervening between the two, there are the maxillary artery and the first parts of its middle meningeal and inferior dental branches, the auriculo-temporal and inferior dental nerves, and a process of the parotid gland. This ligament is of interest because it is developed from the sheath of that part of the cartilage of the mandibular arch (Meckel's cartilage) that lies between the base of the skull and the mandibular foramen. The **stylo-mandibular ligament** is merely a thickened band of deep cervical fascia between the styloid process and the lower part of the posterior border of the ramus of the mandible (Figs. 318, 320).

Nerve-Supply.—The mandibular joint is supplied from the **mandibular** nerve by twigs from its **auriculo-temporal** and **masseteric** branches.

Movements at Mandibular Joints

Movement at each mandibular joint has two components. In the upper compartment the head of the mandible and the disc, acting as one by virtue of the attachment of the lateral pterygoid muscle to both, glide forwards and downwards round the postero-inferior surface of the articular eminence. In the lower compartment a hinge-like rotation of the head of the mandible under the concave surface of the disc takes place around a transverse axis. The upper part of the joint, therefore, acts like a plane joint, the lower part like a hinge joint; but the two components of movement are never completely dissociated, and for this reason there is no stationary axis of movement. In the movements of **opening** and **closing the mouth** the two components are equally involved; and, of course, the joints on both sides of the head act together. The forward and downward displacement of the mandibular foramen is compensated to some extent by backward movement of the angle of the jaw, so that no undue tension is put upon the inferior dental vessels and nerves.

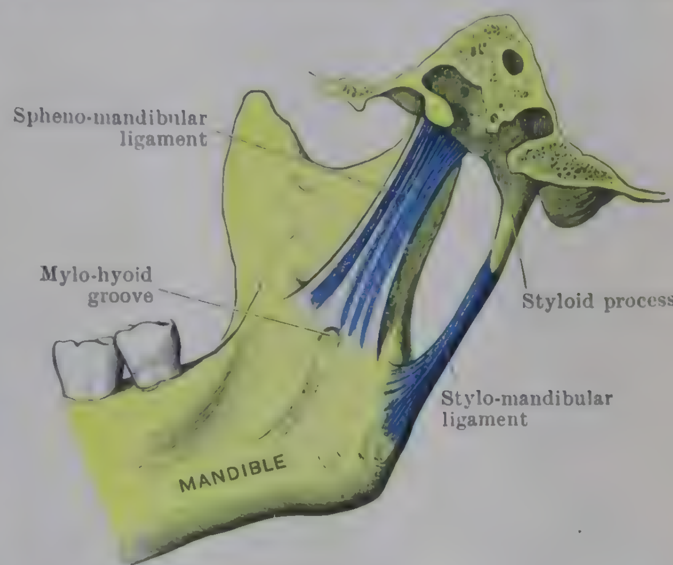

Fig. 320.—Accessory Ligaments of Mandibular Joint.

In the antero-posterior movements of **protraction** and **retraction** of the lower jaw, it is mainly the gliding action in the upper compartment which is involved, the joints of both sides acting together. The oblique **grinding** movements of chewing are brought about by alternate or opposite movements in the upper compartments of the two joints, combined with associated hinge movements in the lower compartments.

It is worth noting that the upper attachment of the main (anterior) band of the temporo-mandibular ligament is on the axis of the curved, downward-and-forward gliding movement in the upper compartment, and therefore, to some extent, the ligaments of the two sides resemble the collateral ligaments of a hinge joint. Their tension will not vary much throughout this upper-compartment movement, and hence they do not completely prevent the possibility of dislocation of the mandibular head on to the front of the articular eminence. As this danger, however, arises only in excessively wide opening of the mouth, the associated rotation in the inferior compartment in such a position, by putting a strain upon the ligament, brings about a certain amount of safeguarding tension.

JOINTS OF RIBS AND STERNUM

The ribs articulate posteriorly with the thoracic vertebræ; with the exception of the first rib and the last two or three ribs, which themselves deviate from the common form, each rib articulates after a common plan with the bodies of two adjacent vertebræ by its head and with the transverse process of the lower of these vertebræ by its tubercle. Anteriorly, the ribs end in costal cartilages, which, with the exception of the last two, make further connexions with the sternum or with one another.

Costo-Vertebral Joints

Joints of Heads of Ribs (Fig. 321).—The **head** of each typical rib has two articular facets—superior and inferior—separated by a horizontal crest. Between the bodies of each two typical thoracic vertebræ, there is situated, postero-laterally, a little cupped depression bottomed by the edge of the intervertebral disc and completed above and below by slightly concave facets on the sides of the adjacent vertebræ. Into this depression the head of the rib is fitted, its crest being bound to the intervertebral disc by a short, thick **intra-articular ligament**. The facets on the head articulate with the facets on the vertebral bodies, of which the lower is in numerical correspondence with the rib.

The whole articulation is surrounded by a **capsular ligament**, within which the intra-articular ligament forms a complete horizontal septum between upper and lower joint-cavities, both provided with synovial membranes. The anterior part of the capsular ligament is specially thickened to form the **radiate ligament** of the head of the rib, which passes medially from the front of the head to the adjacent parts of the disc and vertebral bodies, spreading fanwise upon them, under cover of the edge of the anterior longitudinal ligament. Three

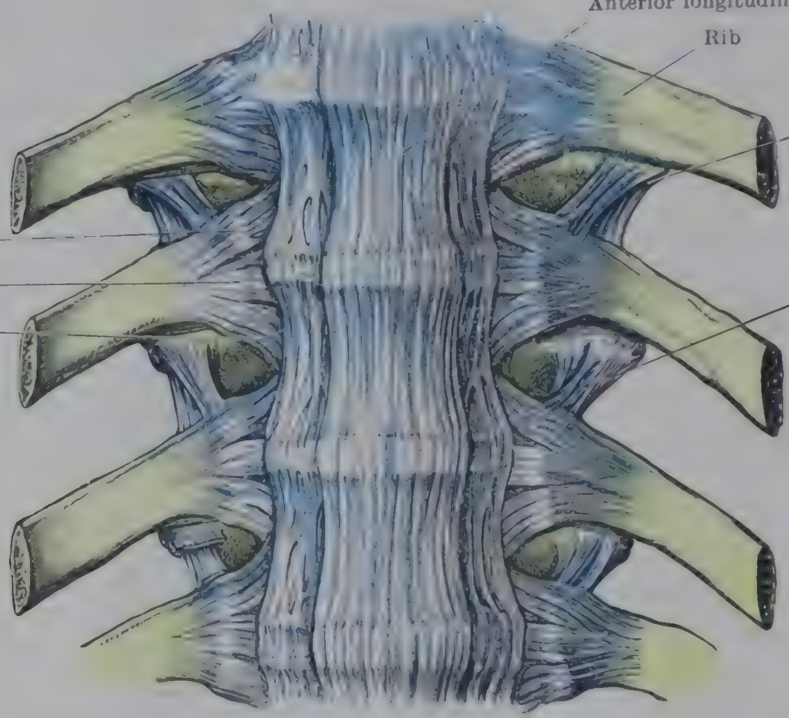

Fig. 321.—Anterior Longitudinal Ligament of Vertebral Column, and the Costo-Vertebral Joints as seen from the Front.

radiating bands are often to be seen, especially in the middle joints of the series, a central one blending with the intervertebral disc, and upper and lower bands attached to the vertebral bodies. The back of the capsule is connected to the adjacent denticulation of the posterior longitudinal ligament.

The intra-articular ligament and the connexion between the capsular ligament and the denticulation of the posterior longitudinal ligament are said to be related to the *conjugal ligament* which in certain mammals connects the heads of a pair of ribs across the back of the intervertebral disc. Conjugal ligaments are present in the human fœtus, but disappear later, except for the formation of the above-mentioned structures from their lateral ends.

Costo-Transverse Joints.—Each typical rib further articulates by its **tubercle** with the transverse process of the lower of the two vertebræ to which its head is joined; and it is attached to the transverse processes of both vertebræ by certain accessory ligaments. A small costo-transverse synovial joint surrounded by a thin **capsular ligament** is formed between the medial part of the costal tubercle and the circular facet on the anterior surface of the corresponding transverse process near the tip. Strengthening this joint, on its postero-lateral aspect, there is the **lateral costo-transverse ligament**—a stout band running between the rough,

lateral part of the costal tubercle and the tip of the transverse process. It is in contact with the capsular ligament of the costo-transverse joint but is not fused with it.

The **inferior costo-transverse ligament** also binds the rib to the same transverse process; it is composed of very short fibres that bridge the narrow interval between the back of the neck of the rib and the front of the transverse process.

Finally, the rib is attached to the transverse process of the vertebra above by the **superior costo-transverse ligament** (Fig. 321). This ligament consists of an anterior and a posterior band that spring from the upper border of the neck of the rib, and are separated laterally by the posterior fibres of the external intercostal muscle. The anterior band has medially a thickened free border, but laterally it blends with the posterior intercostal membrane; its fibres pass upwards and laterally to the lower border of the transverse process above. The posterior band ascends vertically, or with a medial inclination, to the medial part of the lower border of the transverse process above, and in some cases extends medially on to the inferior articular facet of the vertebra above.

The vertebral connexions of the **first rib** and of the **last two or three ribs** are atypical. The head of each of these ribs has a single facet that articulates with an impression on the side of only the corresponding vertebra. The intra-articular ligament is therefore absent in each case, and there is a **single synovial cavity**; the radiate ligament is incompletely developed. The superior costo-transverse ligament of the first rib is represented by feeble bands attached to the seventh cervical transverse process. The tubercles of the lowest ribs do not form synovial joints with the transverse processes; their costo-transverse ligaments are progressively less well defined: those of the last rib may be absent altogether.

Anterior Connexions of Ribs and Costal Cartilages

The anterior end of each rib is continuous with a bar of hyaline cartilage, called the *costal cartilage*, which is solidly united to the rib in a concavity at its end. The first seven costal cartilages articulate with facets on the side of the sternum; and certain of the cartilages articulate with one another.

Sterno-Costal Joints (Fig. 322).—Little synovial cavities usually develop in these joints between the sternum and the costal cartilages, except in the case of the first, which remains a continuous cartilaginous joint. The cavity of each of the others is divided into two by an **intra-articular ligament**, until the corresponding sternal segments fuse together; in most cases the second sterno-costal joint cavity remains double throughout life; the cavities in the remaining joints tend to become obliterated in old age. The **capsules** of these little joints are strengthened in front and behind by fibres that spread fanwise over the anterior and posterior surfaces of the sternum. These fibres are better marked in front, and there they interlace with those of the opposite side to form a felted membrane which is fused with tendinous fibres of the pectoralis major muscles.

Interchondral Joints.—The tips of the eighth and ninth costal cartilages form little **synovial joints**, each with the lower border of the cartilage above. In addition, synovial joints are formed between slight bosses developed on the adjacent margins of the fifth to the eighth or ninth cartilages. All these joints between cartilages are enclosed by short **articular capsules** strengthened in front and behind by oblique ligamentous bands. The terminal part of the tenth cartilage is united to the ninth by a syndesmosis.

The last two costal cartilages are short conical structures ending freely amongst the muscles of the flank.

Sternal Joints

The **manubrio-sternal joint** lies between the manubrium and the body of the sternum and is of a singular type. Prior to its ossification the sternum is a continuous bar of hyaline cartilage, but the manubrio-sternal joint is early demarcated by the transformation of the hyaline cartilage opposite the second costal cartilage into fibro-cartilage. When ossification in the sternum is complete a thin layer of the hyaline cartilage above and below the fibro-cartilage remains unossified so that the joint has an appearance similar to that of a secondary cartilaginous joint. Sometimes

the central part of the fibro-cartilage is absorbed and a cavity is formed within it, and less frequently the joint is obliterated by synostosis in old age. Special longitudinal fibres and the neighbouring sterno-costal ligaments strengthen this joint in front and behind. The cartilaginous **xiphi-sternal joint** between the body of the sternum and the ziphoid process is usually ossified in early adult life.

Movements of Ribs and Sternum

The active movements of the ribs and sternum are those associated with respiration. The capitular and costo-transverse joints of each rib together form a hinge with an axis through the two joints; owing to the backward tilt of the transverse process of the typical thoracic vertebra, this axis is directed laterally and backwards, and, at all except the first two costo-vertebral joints, also slightly downwards. At the second costo-vertebral joint the axis is in the horizontal plane, and at the first there is a slight inclination upwards. Thus hinged posteriorly, the anterior part of the rib is raised during inspiration and lowered during expiration. As the anterior end of the rib is below the level of the posterior end, raising the rib in inspiration causes the anterior end to travel forwards as well as upwards and, owing to the obliquity of the axis of the hinge, a little laterally as well. The sternum, attached to the anterior ends of the upper ribs, is also made to travel upwards and forwards, and the lateral deviation of the anterior ends of the ribs causes an opening out of the angles between the sternum and the costal cartilages. The obliquity of the axis of movement posteriorly is most marked in the case of the middle ribs, which possess long, inclined cartilages, and therefore the greater lateral movement of the anterior ends of these ribs can readily take place. But in the upper ribs, where the axis is less oblique, the lateral movement is slight or absent; shorter cartilages therefore suffice, set almost at right angles to the sternum. As the first rib is so much shorter than those which succeed it, the upwards and forward excursion of its anterior end is less in extent, and the movement of the upper border of the sternum is correspondingly reduced (see Haines, 1946). The greater travel—especially in the forward direction—imposed upon the rest of the sternum by the longer ribs causes a bending of the breastbone at the manubrio-sternal joint. The result of all this on the capacity of the thorax is to increase its antero-posterior diameter. But its transverse diameter also is increased, for the following reason. The sternal attachments of the ribs to some extent hamper the movements of their anterior ends and to that extent 'fix' the anterior ends, so that the raising of the ribs is in part translated into a twisting of the anterior parts of the costal arches, causing torsion of the cartilages and rotation at the sterno-costal joints. But to begin with, each costal arch is so disposed that the middle part is below the level of a line between its two ends—like a bucket-handle hanging down below the rim of the bucket. Hence this longitudinal twisting of the costal arch causes the middle part of the rib to rise upwards and outwards, so increasing the transverse width of the thorax.

Expiration is accompanied by reverse movements whereby the antero-posterior and transverse diameters of the thorax are diminished. Although it is convenient thus to describe the respiratory movements of the thorax as taking place in alternate opposite directions between the extreme inspiratory and expiratory positions, it should be explained that the 'resting' position of the thorax is midway between these extremes. This is the position of balance between the elastic tension of the costal arches tending upwards and the muscular and mechanical pull of the abdominal wall and contents tending downwards. The first half of the complete movement in either direction between full expiration and inspiration represents a recoil to this mean position; beyond this point, the second half of the movement is the result of positive muscular effort.

Apart from respiratory movements, the ribs move passively with changes in the thoracic part of the vertebral column. Flexion of the column causes a crowding together of the ribs; extension causes a spreading apart; bending of the column to one side brings about a crowding of the ribs on that side of the trunk, and spreading on the opposite side.

JOINTS OF UPPER LIMB

JOINTS OF SHOULDER GIRDLE

In order to promote freedom of movement of the arm, the shoulder girdle remains relatively independent of the skeleton of the trunk; only one joint, and a freely movable one—the *sterno-clavicular*—exists between the two. The scapula is

attached to the axial skeleton by muscles only. The bones of the girdle are themselves movably united to each other at the *acromio-clavicular joint.*

Sterno-Clavicular Joint

At the **sterno-clavicular joint** the medial end of the clavicle articulates with the sternum (an articular disc intervening), and with the first costal cartilage. The clavicular surface is more extensive than the sternal, but the medial articular surface is prolonged a little way over the upper surface of the cartilage of the first rib. The bony surfaces are reciprocally concavo-convex, being convex vertically and concave horizontally on the clavicular side. But the curvatures are slight and not fully congruent. and the clavicular and sternal surfaces are separated by the articular disc, so that the joint cannot function as a

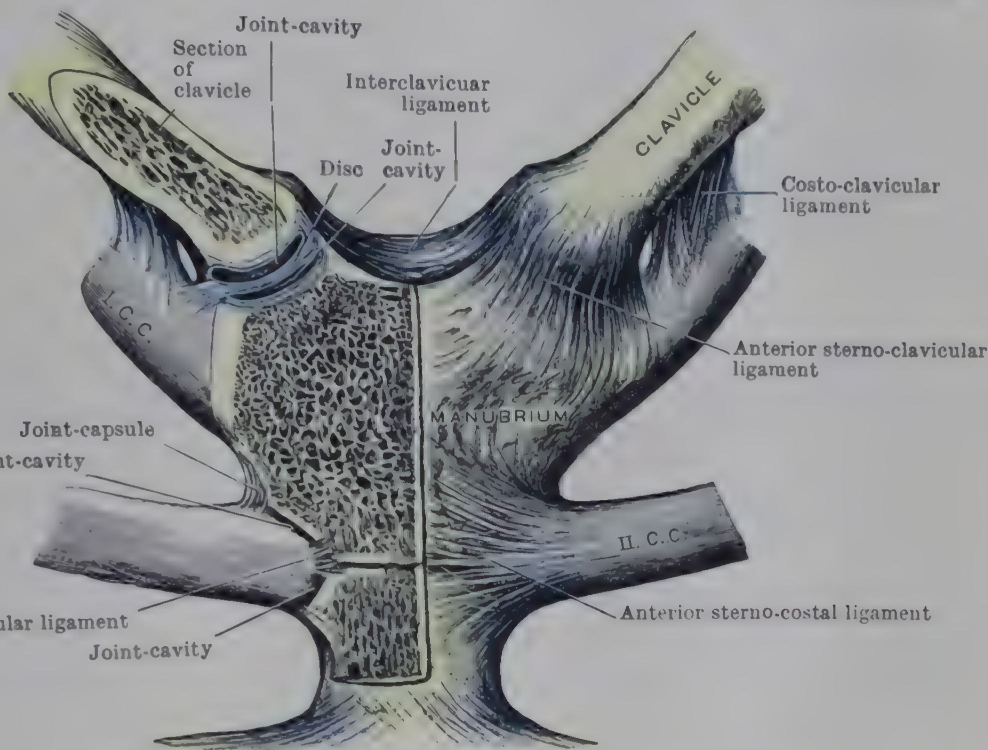

FIG. 322.—STERNO-CLAVICULAR AND STERNO-COSTAL JOINTS.

saddle joint. It is rather, in its movements, of the ball-and-socket type. The articular cartilage in this joint is partly fibrous.

A **capsular ligament** surrounds the whole joint and is attached around the clavicular and the sterno-chondral articular surfaces. The epiphysis at the sternal end of the clavicle is intra-capsular. The inferior part of the capsular ligament, passing between the costal cartilage and the clavicle, is weak, but the other parts of the ligament are strong. being reinforced in front, behind, and above, by thickened bands called the *anterior* and *posterior sterno-clavicular ligaments* and the *interclavicular ligament.*

The **anterior** and **posterior sterno-clavicular ligaments**, of which the anterior is the stronger, run downwards and medially from clavicle to sternum (Fig. 322). The origin of the sterno-hyoid muscle extends across the posterior ligament; this muscle and the sterno-thyroid separate the back of the left joint from the left innominate vein and the left common carotid artery, and the right joint from the innominate artery. The **interclavicular ligament** is formed by fibres from the strengthening band on the upper aspect of the capsular ligament that pass across the floor of the suprasternal notch, to which some of them are attached, to join similar fibres from the joint of the opposite side. The interclavicular ligament is thought to be a derivative of the embryonic *episternal band.*

Within the joint there is a complete fibro-cartilaginous **articular disc**, which blends with the capsular ligament in front and behind, but has its firmest attachment above to the clavicle and below to the first costal cartilage, just wide of the sternal articular surface. Hence the disc, in addition to cushioning the articular

surfaces from shocks transmitted along the clavicle from the shoulder, has an important ligamentous action in preventing such forces from driving the sternal end of the clavicle upwards and medially along the sloping chondro-sternal surface. Also, when the clavicle is depressed, as by a heavy weight carried in the hand, any tendency for the medial end of the bone to start up out of its sternal socket is resisted by the disc, supported by tension of the upper part of the capsular ligament and of the obliquely-disposed anterior and posterior bands.

There are two separate **synovial cavities** within the sterno-clavicular joint, save when, exceptionally, the thinner central part of the articular disc is perforated.

The **costo-clavicular ligament** is an accessory ligament placed on the lateral side of this joint. It ascends from the upper surface of the first costal cartilage near its lateral end to a rough tubercle on the under aspect of the medial part of the clavicle. The ligament is related anteriorly to the tendon of the subclavius muscle, and posteriorly to the innominate vein, on the right side, and, on the left side, to the subclavian or the innominate vein or to both. It limits elevation of the clavicle, and, by its strength in this connexion, compensates for the weakness of the adjacent inferior part of the sterno-clavicular joint-capsule; to a lesser extent it limits antero-posterior clavicular movement also.

Nerve-Supply.—The sterno-clavicular joint is supplied by twigs from the **medial supraclavicular nerve.**

Acromio-Clavicular Joint

The **acromio-clavicular joint** is a small synovial joint, of the plane type, between oval facets on the lateral end of the clavicle and on the medial border of the acromion (Fig. 324). The joint-surfaces, covered with fibrous articular cartilage, slope downwards and medially so that the clavicle tends to override the acromion.

A **capsular ligament**, of no great strength, surrounds the joint; it is stoutest above, and is there reinforced by fibres from the trapezius. A wedge-shaped, fibro-cartilaginous **articular disc**, attached to the upper part of the capsule, partially divides the joint-cavity in most cases. Only rarely does it form a complete partition; and sometimes it is absent altogether.

Nerve-Supply.—The acromio-clavicular joint is supplied by the **pectoral, suprascapular** and **circumflex** nerves.

Coraco-Clavicular Ligament.—The real strength of the union between clavicle and scapula depends on the powerful **coraco-clavicular ligament** (Fig. 324), which anchors the lateral end of the clavicle over the coracoid process. It is divided into two parts, called from their shape the conoid and trapezoid ligaments, which form anteriorly a re-entrant angle occupied by a synovial bursa.

The **conoid ligament** passes upwards and slightly backwards from an apical attachment at the angle between the two parts of the bent coracoid process to a wider insertion on the conoid tubercle on the under surface of the clavicle. The **trapezoid ligament** bears antero-laterally from the conoid ligament. Its lower attachment is to a short ridge on the posterior part of the upper surface of the coracoid process; its upper end is wider, and is attached to the trapezoid ridge on the under side of the acromial end of the clavicle. The attached borders of the trapezoid ligament are slightly askew, and its surfaces so oblique as to be more nearly horizontal than vertical.

The conoid ligament is so set as to restrain backward movement of the acromial end of the clavicle without similar movement of the scapula, the trapezoid ligament to restrain forward movement. Both ligaments, but more particularly the trapezoid, prevent the acromion from being carried medially below the lateral end of the clavicle when blows fall upon the lateral surface of the shoulder.

Movements of the Shoulder Girdle

Movements of the shoulder girdle serve to increase the range of movement at the shoulder joint by suitable alteration in the position of the socket for the head of the humerus, brought about by movement of the scapula upon the thoracic wall. Thus, forward movement of the scapula round the chest causes the glenoid cavity to be directed more

forwards; backward movement causes the cavity to look laterally; upward movement of the scapula, combined with rotation so that the inferior angle passes forwards and upwards, causes the fossa to be turned increasingly upwards; and sinking of the scapula with medial rotation of the inferior angle turns the cavity slightly downwards. But in all these changes of position the shoulder is kept boomed out from the trunk by the thrust of the clavicle upon the acromion, thus further to secure freedom of shoulder-movement. The lateral angle of the scapula must therefore travel in an arc of a circle whose radius is the clavicle: but the medial part of the scapular blade, in its ambit, is held close to the chest wall by the muscles, and must travel in a curve of shorter radius—the radius of the thoracic curvature. Hence, the set of the scapula relative to the clavicle must be capable of modification, and this is brought about by alteration, at the acromio-clavicular joint, of the angle between the clavicle and the scapular spine: that is the function of this gliding joint. One particular result of the different arc of travel of the acromion and lateral angle of the scapula from that of the medial part of the blade is to obviate, in forward movement of the shoulder, any marked change in direction of the glenoid cavity which would diminish the power of forward thrusting movement of the arm.

The clavicle is pivoted at its sternal end, but its acromial end moves, in association with the scapula, forwards, backwards, upwards, downwards, and, of course, in intermediate directions. A small amount of rotation around the long axis of the bone (not more than 45°) also can take place at the sterno-clavicular joint, but only in association with other movements of the acromial end and scapula. This rotation occurs particularly with elevation and depression, when scapular rotation also takes place.

Scapular Ligaments

The following ligaments attached wholly to the scapula are not connected with any joint.

The **suprascapular ligament** bridges the suprascapular notch, and so continues the line of the superior border of the scapula laterally to the root of the coracoid process. Sometimes it is partly or completely ossified. Fibres of the inferior belly of the omo-hyoid are attached to its medial portion. The suprascapular nerve enters the supraspinous fossa through the foramen completed by the ligament, while the suprascapular vessels pass over the ligament to reach the fossa.

The **spino-glenoid ligament** is a weak band that stretches between the lateral border of the scapular spine and the back of the neck of the bone, over the suprascapular nerve and vessels. It may be regarded as formed from a fusion of the fasciæ over the contiguous supraspinatus and infraspinatus muscles.

The **coraco-acromial ligament** is functionally related to the shoulder joint, with which it will be described.

SHOULDER JOINT

The **shoulder joint** is a synovial joint of ball-and-socket type in which freedom of movement is developed at the expense of stability. The spheroidal surface of the head of the humerus articulates with the shallow glenoid cavity of the scapula, each surface being covered with articular cartilage. The area of the scapular 'socket' is little more than a third of that of the humeral 'ball', so that the coaptation of these surfaces contributes very little to the security of the joint. Nor does the capsular ligament play a great part, for it is of necessity lax enough to permit the required freedom of movement. The real strength of the joint lies in the muscles which surround it. They are attached close up to the articular areas and are intimately related to the joint-capsule; hence they are admirably disposed for the purpose of keeping the articular surfaces in firm contact in all positions, although at the sacrifice of the greater power that would be obtained were they inserted farther from the centre of movement in the joint.

Labrum Glenoidale (Fig. 324).—The labrum glenoidale is a fibro-cartilaginous rim, triangular in cross-section, attached to the edge of the glenoid cavity, which is slightly deepened by it. At the notch above the middle of the anterior edge of the cavity the labrum is less solidly attached to the bone and a synovial fold intervenes between the two. The long tendon of the biceps arises within the joint from the supraglenoid tubercle, and is there fused to the labrum glenoidale.

Capsular Ligament.—The capsular ligament forms a cylindrical sleeve attached close to the articular area of each bone. On the scapular side it is attached external to the labrum glenoidale and partly to the labrum itself, especially above and behind. On the humeral side the ligament is attached above

to the anatomical neck immediately medial to the tuberosities; but below, it extends on to the medial surface of the shaft of the bone some way from the articular head. The upper epiphysial line of the humerus is therefore chiefly extracapsular, but comes within the joint on the medial side. When the arm is by the side the lower part of the capsule is lax and forms a redundant fold (Fig. 325) that becomes taut when the arm is abducted. The anterior part of the capsular ligament is immediately related to the tendon of the subscapularis muscle, the superior part to the supraspinatus tendon, and the posterior part to the tendons of the infraspinatus and teres minor muscles. All these tendons blend with the ligament towards their insertion, and as they are intimately concerned in the maintenance of the head of the humerus in its correct relationship to the glenoid cavity during move-

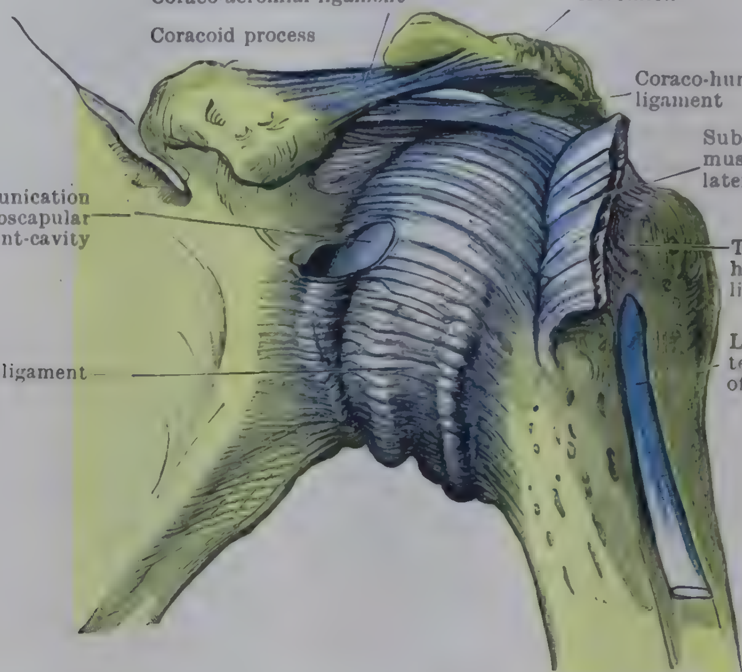

Fig. 323.—Capsule of Shoulder Joint from the Front.

ments at the shoulder joint they are often termed "articular" muscles. The inferior part of the capsular ligament, which is also the weakest, is relatively unsupported by muscles, but as the arm is raised from the side the long head of the triceps and the teres major are increasingly applied to this surface of the joint.

There are two **openings** in the capsular ligament (Fig. 323). One is an interruption in its attachment to the humerus at the upper end of the bicipital groove; the long tendon of the biceps escapes through the aperture so formed. The other opening is in the front of the capsular ligament under cover of the subscapularis tendon, and through it the subscapular bursa communicates with the synovial cavity of the joint.

The fibres of the capsular ligament run for the most part longitudinally from bone to bone. In addition to longitudinal fibres, a few fibres run transversely round the capsular ligament. The **transverse humeral ligament** is a special bundle of transverse fibres that arch over the opening through which the biceps tendon leaves the joint and bridge the upper end of the bicipital groove (Fig. 323).

Three slightly thickened bands of longitudinal fibres are to be seen on the internal surface of the anterior part of the capsule, although not visible on the outside of the joint. These are the *superior*, *middle*, and *inferior gleno-humeral ligaments* (Fig. 324). The **superior gleno-humeral ligament** is attached to the upper part of the labrum glenoidale immediately anterior to the long tendon of the biceps, and passes laterally, alongside the tendon, to reach the humerus near the upper surface of the lesser tuberosity. It has been considered homologous with the ligament of the head of the femur, but has also been regarded, possibly with more likelihood, as representing the base of the synovial fold by which, in the fœtus, the long tendon of the biceps is attached to the upper part of the capsule. The **middle gleno-humeral ligament** is attached to the scapula close to the superior band and reaches the humerus at the front of the lesser tuberosity. The opening in the capsular ligament under the subscapularis tendon is

between the superior and middle bands. The **inferior gleno-humeral ligament**, usually the best marked of the three, is attached to the scapula immediately below the notch in the anterior border of the glenoid cavity and to the humerus on the under surface of the neck.

Accessory Ligaments.—The **coraco-humeral ligament** is an accessory ligament on the upper aspect of the joint (Fig. 323). It springs from the lateral side of the root of the coracoid process and runs laterally upon the capsular ligament as a raised band which gradually flattens as it blends laterally with the upper and posterior part of the capsular ligament; it reaches the neck of the humerus opposite the greater tuberosity. This band greatly strengthens the upper part of the capsular ligament, which is under tension when the arm hangs by the side.

Arching over the upper aspect of the shoulder joint, but not connected to its

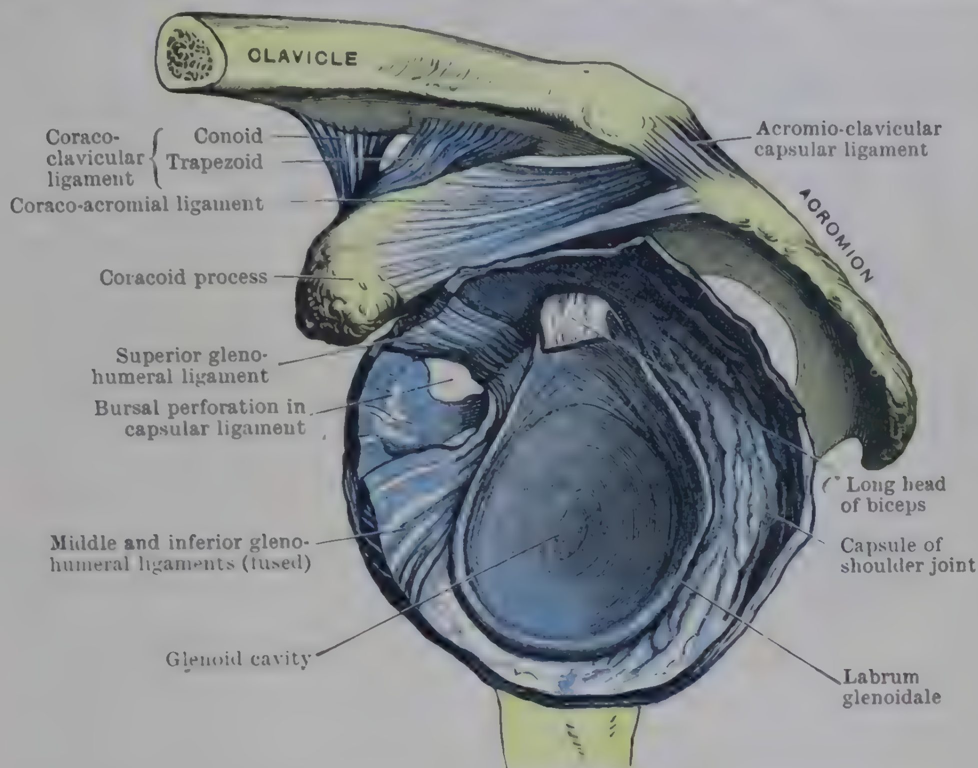

FIG. 324.—CAPSULE OF SHOULDER JOINT CUT ACROSS AND HUMERUS REMOVED.

capsule, is the **coraco-acromial ligament** (Figs. 323, 324). It is triangular, and horizontally placed. Its base is attached to the lateral border of the horizontal part of the coracoid process and its apex to the tip of the acromion in front of the acromio-clavicular joint. The anterior and posterior borders of the ligament are stronger than the middle portion. Sometimes a prolongation of the pectoralis minor tendon pierces the base of the ligament and blends, below it, with the coraco-humeral ligament. Superiorly, the coraco-acromial ligament is covered by the deltoid muscle; inferiorly, it is separated by the subacromial bursa from the supraspinatus tendon, which lies above the shoulder joint. The acromion and the coracoid process, with the coraco-acromial ligament stretching between them, form a protective arch against which the head of the humerus is pressed (the joint-capsule and overlying muscles intervening) when force is transmitted upwards along the humerus as when, standing at a table, the weight of the body is supported on the edge of the table by the down-stretched arms.

Synovial Membrane.—The synovial membrane of the shoulder joint lines the capsular ligament and thus extends downwards as a pouch when the arm is by the side. From the capsular ligament the membrane is reflected upwards on the humerus to the edge of the articular cartilage. The membrane protrudes through the opening in the front of the capsule to be continuous with the lining of the *subscapular bursa*. The size of this bursa varies; when large it may be wrapped round the upper border of the subscapularis tendon underneath the coracoid process, but this upper, *subcoracoid* extension may be represented by a separate bursa of that name, not communicating with the joint. Occasionally the synovial mem-

brane protrudes through an opening in the back of the capsular ligament to form a small bursa beneath the infraspinatus tendon.

In this neighbourhood there is always a large *subacromial bursa* which separates the coraco-acromial arch and the deltoid muscle from the upper and lateral aspect of the shoulder joint and the tendons lying upon it; this bursa does not communicate with the interior of the joint.

The relation of the *long tendon of the biceps* to the synovial membrane is important (Fig. 325). The intracapsular part of the tendon is covered with a sheath of synovial membrane which is continued along the tendon in the upper part of the bicipital groove. The synovial sheath is then reflected upwards as a lining to the osteo-fascial tunnel in which the tendon runs, and so passes into continuity with the synovial lining of the capsular ligament. As the tendon runs over the upper part of the articular head of the humerus, it has a steadying influence upon movements of the shoulder joint.

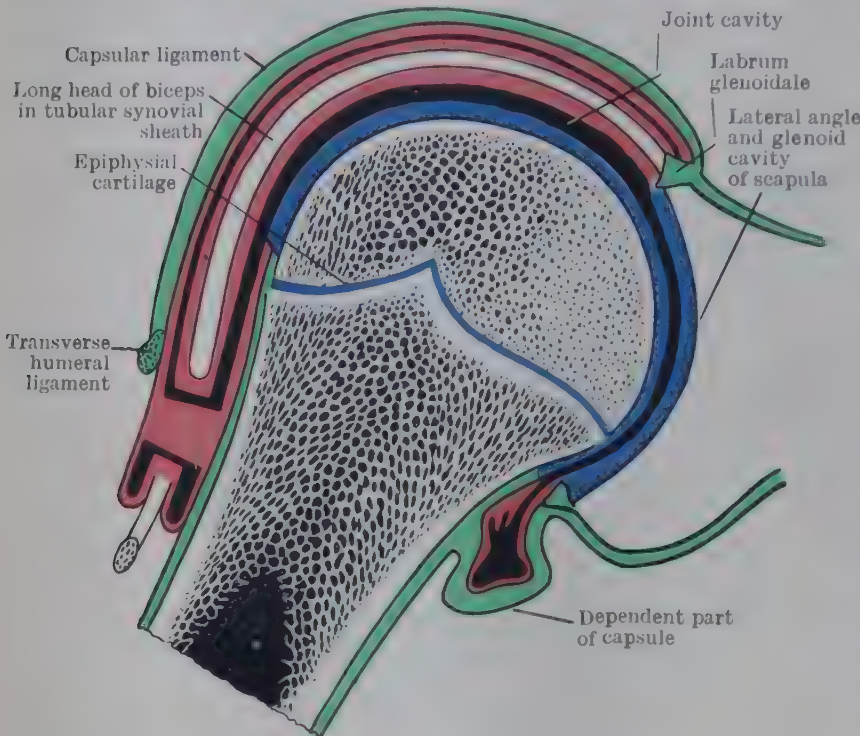

FIG. 325.—DIAGRAMMATIC CORONAL SECTION THROUGH SHOULDER JOINT.

The cavity of the joint is enlarged to show the relation of the synovial membrane to the long tendon of the biceps muscle. Articular cartilage, *blue*; synovial membrane, *pink*; capsular ligament and periosteum, *green*.

In the embryo the long tendon of the biceps at first lies outside the developing joint-capsule; this is the persisting relationship in some lower mammals. But later in human development the tendon sinks through the capsular ligament and is attached to its deep surface by a mesentery-like fold of synovial membrane; this condition persists in most higher mammals. Normally, in Man, the 'mesentery' breaks down before birth, leaving the tendon unattached to the capsule but surrounded by a sheath of synovial membrane.

Nerve-Supply.—The shoulder joint is supplied by branches from the **suprascapular, circumflex, and subscapular nerves.**

Movements at the Shoulder Joint

The form of the articular surfaces and the disposition of the capsular ligament allow a wider range of movement at the shoulder joint than at any other joint in the body. Being, as it is, a ball-and-socket joint, movement can take place around an infinite number of axes intersecting in the centre of the globular head of the humerus. The principal axes of descriptive convenience are: (1) a transverse axis around which the arm moves forwards in **flexion** and backwards in **extension**; (2) an antero-posterior axis around which occur the movements of **abduction** (away from the side of the trunk) and **adduction** (towards the side of the trunk); and (3) a vertical axis around which the arm **rotates medially** and **laterally**. **Circumduction** is a combination of antero-posterior and sideward movements around successive axes, when the arm swings round the side of a cone whose apex is the point of intersection of the various axes in the head of the humerus.

Since in the normal position, with the arm by the side, the glenoid cavity looks slightly forwards as well as laterally, and the humeral head is turned slightly backwards as well as medially, the strict 'transverse' and 'antero-posterior' axes of the joint are set obliquely to coronal and sagittal planes of the trunk. Thus, for example, the true transverse axis of the joint runs medio-laterally and slightly forwards, and, in flexion-extension movements around this axis, the arm swings forwards and medially, backwards and laterally. Similarly, in true abduction the arm is carried a little forwards as well

as laterally, in the "plane of the scapula", a plane at right angles to the glenoid fossa through its vertical diameter. Abduction in this plane does not involve torsion of the capsular ligament and therefore provides the most easeful position in the treatment of certain injuries at the shoulder (Johnston, 1937).

Rotation of the humerus takes place around an axis that passes through the centre of the head and the centre of the capitulum. The range of rotation varies with the position of the humerus. When the arm is by the side it can be rotated about 170° but when the arm is vertically upright the range of rotation is greatly reduced.

The amount of movement that occurs at the shoulder joint during movement of the upper limb is usually difficult to estimate because almost all free movements at the shoulder joint are accompanied by associated movements of the shoulder girdle. The total apparent movement of the humerus is therefore made up of its real movement upon the scapula plus movement of the scapula upon the chest-wall, with associated movements at the clavicular joints: the effective mobility of this ball-and-socket joint is thus increased by the mobility of the socket itself. The range of scapular movement is considerable and accounts for much of the apparent movement that takes place in the free limb; it is estimated, for example, that in moving the arm from the pendent position into a vertically upright one, almost half the movement is due to a displacement of the scapula (for movements of scapula see p. 356). Cathcart (1884) was the first to state that movement of the scapula occurs early in abduction—he estimated that after the arm has moved about 30°. The commencement of movement of the scapula is, however, usually coincident with the commencement of movement at the shoulder joint (Cleland, 1884, and Lockhart, 1930) and in raising the arm to an upright position the two movements are associated throughout. Gleno-humeral movement is, however, more concerned in the raising of the arm to the horizontal position, and scapular movement more concerned in bringing the arm into a vertically upright position from the horizontal. (See also p. 487 and Pl. XXXII, p. 347). It must be stressed, however, that in bringing the arm from the horizontal to the vertically upright position there is considerable gleno-humeral movement, and it is during this action that the humerus is brought approximately into line with the spine of the scapula, which is to be regarded as the fully abducted position of the shoulder joint proper (Lockhart, 1930).

The association of shoulder-girdle movement with shoulder-joint movement not only increases the range of movement of the free limb, but also increases its power of movement. It has already been stated that because the muscles that act upon the shoulder joint are attached close to the centre of movement in the joint, their force is thereby lessened. The muscles acting on the scapula (p. 482), however, have the advantage of much greater leverage, and therefore the scapular movements add greatly to the total force of movements of the arm. The adjuvant effect of scapular movements is strikingly illustrated in those in whom the scapulo-humeral joint is completely fixed as the result of disease or of surgical treatment to combat disease. Provided that care has been exercised to secure fixation in such a position as will allow full advantage to be taken of scapular movement, these patients may retain a considerable degree of mobility of the arm upon the trunk. Nevertheless it must be realized that, normally, movements at the shoulder joint and movements of the scapula are not dissociated but take place together.

It is to be observed that when the arm is raised to the vertically upright position the medial epicondyle of the humerus is always directed forwards and slightly medially, and this direction of the epicondyle is constant irrespective of the plane (sagittal, coronal or any intermediate) through which the limb has been raised. When the limb is raised in the coronal plane the humerus undergoes a lateral rotary movement of more than 90°, whereas if it is raised to the upright in the sagittal plane it undergoes a slight medial rotation if the initial dependent position of the limb is the anatomical one with the palm of the hand directed forwards. The causal factor of the lateral rotation is probably the muscular action of the scapulo-humeral muscles, though it has been suggested that a contributory cause is the contact of the greater tuberosity of the humerus with the sloping coraco-acromial arch when the humerus nears its limit of full abduction. (For discussion of this problem see Lockhart, 1933, Johnston, 1937, Martin, 1940, and MacConaill, 1946.)

ELBOW JOINT

The **elbow joint** is a large synovial joint, of the hinge type, in which the bones of the forearm articulate with the lower end of the humerus. The upper ends of the radius and ulna are tied together by the annular ligament of the radius,

but in such a way as to permit movement between these two bones at what is described separately as the superior radio-ulnar joint; the cavity of this joint is freely continuous with that of the elbow joint. The annular ligament plays a part in the structure of both, but it will be described with the superior radio-ulnar joint.

Articular Surfaces.—The **humeral articular surface** at the elbow comprises the grooved *trochlea* and the spheroidal *capitulum*, together with the sulcus between them. This composite surface is covered with a continuous layer of articular cartilage. The capitulum is limited to the anterior and distal aspects of the bone, while the trochlea extends from the lower edge of the coronoid fossa on the front of the humerus round to the lower edge of the olecranon fossa on the back (Figs. 223, 328). The **ulnar surface** of the elbow joint (Fig. 329) is the *trochlear notch*, covered with articular cartilage interrupted along a transverse line across the deepest part of the notch; this surface articulates with the trochlea of the humerus. The **radial surface** is the slightly cupped upper surface of the *head* of the radius, covered with articular cartilage continuous with that round the sides of the head in the radio-ulnar joint; the concave part of the upper surface of the head articulates with the capitulum, and the raised margin with the capitulo-trochlear groove. The radial and ulnar surfaces are not strictly congruent with the corresponding humeral surfaces, and the degree of accurate apposition varies slightly in different positions of the joint. The articular surfaces are most fully in contact when the forearm is in a position midway between full pronation and full supination and is flexed to a right angle.

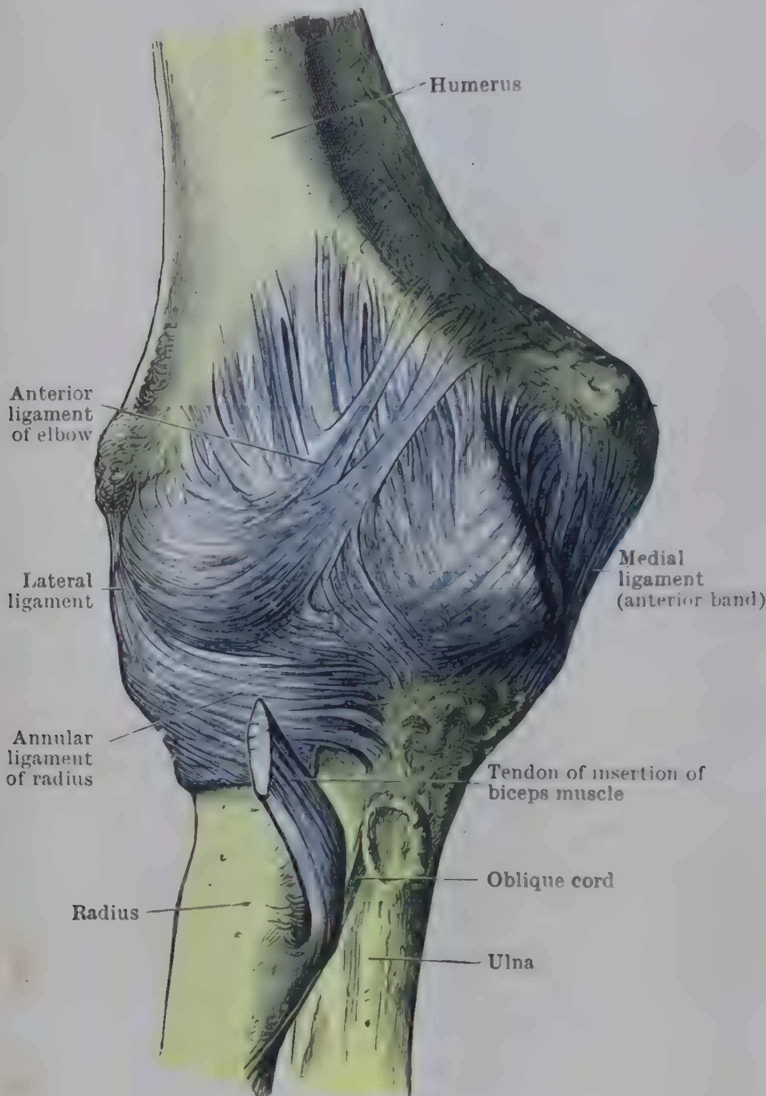

Fig. 326.—Front of Elbow Joint.

Capsular Ligament.—A capsular ligament completely invests the joint. Following the usual arrangement in a hinge joint, this ligament is relatively weak in front and behind, but is specially strengthened at the sides. The parts in front and behind are called the *anterior* and *posterior ligaments* of the elbow joint; the anterior is taut only in extension and the posterior only in flexion. The strong portions at the sides of the capsular ligament constitute the *lateral* and *medial ligaments*; these, being attached to the humerus in the axis of movement at the joint, remain tense in all positions.

The **anterior ligament** (Fig. 326) is composed of fibres that run for the most part longitudinally, but also transversely and obliquely; it is thicker in the middle than at the sides. Proximally, it is attached to the front of the humerus immediately above the radial and coronoid fossæ; distally, it is attached to the anterior border of the coronoid process of the ulna and to the anterior part of the

annular ligament of the radius; at the sides it blends with the medial and lateral ligaments. The brachialis muscle covers the greater part of the anterior ligament, and some deep fibres are inserted into the ligament, which is therefore drawn upwards when the muscle contracts to flex the joint.

The **posterior ligament** is very weak in its medial part, but is here closely attached to the overlying tendon of the triceps, which affords ample support to the joint-capsule and draws it upwards in extension. The fibres in that part of the ligament run mainly from the sides of the olecranon fossa to the margin of the olecranon; some fibres stretch across the fossa above the olecranon as a transverse band with a free upper edge which falls short of the upper margin of the fossa. Beneath these transverse fibres a few longitudinal strands pass to the upper part of the fossa and afford slight support to the synovial pouch within it. The lateral part of the posterior ligament is a stronger band that runs from the back of the lateral epicondyle to the ulna at the posterior border of the radial notch and also to the annular ligament. The posterior ligament blends at the sides with the medial and lateral ligaments.

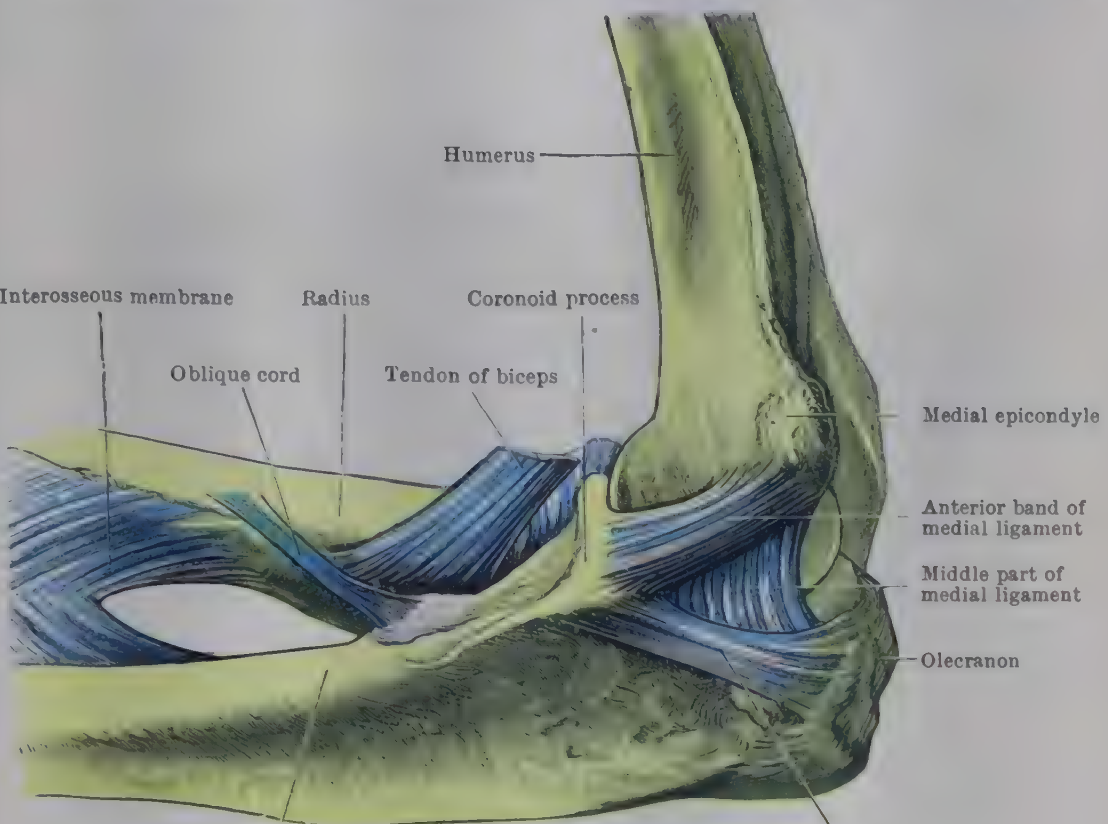

FIG. 327.—MEDIAL ASPECT OF DISSECTION OF ELBOW JOINT, WITH ANTERIOR AND POSTERIOR LIGAMENTS REMOVED.

The **lateral ligament** (Fig. 326) is a strong, triangular band whose apex is attached above to the antero-inferior aspect of the lateral epicondyle of the humerus in close relation to the overlying common origin of the extensor muscles. Distally, the middle part of the base of the ligament blends with the annular ligament of the radius, and the slightly thicker portions in front and behind sweep forwards and backwards to be attached to the margins of the radial notch on the ulna.

The **medial ligament** (Fig. 327) is composed of three fairly distinct bands, continuous with one another. An *anterior band* passes from the fore part of the medial epicondyle of the humerus to the medial edge of the coronoid process of the ulna; it is closely associated with the common origin of the superficial flexor muscles and gives rise to fibres of the flexor digitorum sublimis. A *posterior band* is attached above to the back of the medial epicondyle and below to the media edge of the olecranon. Between these bands there is a middle, thinner part of the ligament, triangular in shape, and presenting a grooved external surface which is

crossed by the ulnar nerve as it passes from upper arm to forearm; its upper end is attached to the under surface of the medial epicondyle, and its base is fixed distally to the upper border of a *transverse band* which stretches between the attachments of the anterior and posterior bands on the coronoid process and the olecranon. The lower edge of this transverse ligament is free, and through the narrow gap between this edge and the bone the synovial membrane protrudes slightly during movement of the joint.

Synovial Membrane.—The synovial membrane of the elbow joint lines the capsular ligament and is reflected on to the humerus to line the radial and coronoid fossæ in front and the olecranon fossa behind (Fig. 328). Distally, it is prolonged downwards on the deep surface of the annular ligament, and is then reflected on to the neck of the radius. This reflexion is supported by a few loose fibres which pass from the lower border of the annular ligament to the neck of the radius. The synovial membrane passing from the medial side of the radial neck to the

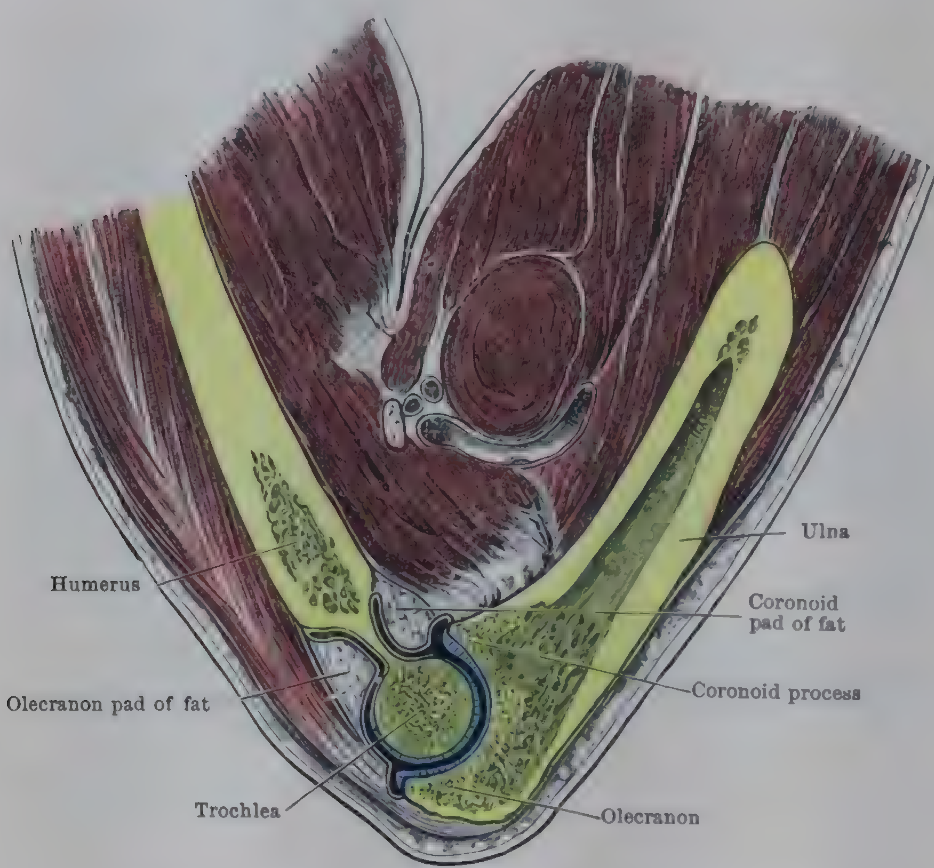

Fig. 328.—Vertical Section through Humero-Ulnar Part of Elbow Joint.

lower border of the radial notch on the ulna is supported by a lax band of fibres called the **quadrate ligament**, which stretches between these two points. Various synovial folds project a little way into the interior of the joint, filling small angular recesses between the edges of the articulating surfaces. Well-marked subsynovial fatty pads fill the radial and coronoid fossæ in extension of the joint and the olecranon fossa in flexion (Fig. 328). A synovial fold, which forms the greater part of a circle, also overlies the peripheral part of the head of the radius and is interposed between it and the corresponding part of the capitulum of the humerus. There are no openings in the capsular ligament of the elbow joint, but slight pouching of the synovial membrane may occur beneath the edge of the transverse band of the medial ligament, beneath the lower border of the annular ligament, and above the transverse fibres that bridge the upper part of the olecranon fossa.

Nerve-Supply.—The elbow joint derives its supply anteriorly from the **musculo-cutaneous, median** and **radial** nerves, and posteriorly from the **ulnar** nerve and the radial nerve through its **branch to the anconeus** muscle.

Movements at the Elbow Joint

This being a hinge joint, movement occurs only around a transverse axis—a movement of **flexion** when the forearm makes anteriorly a diminishing angle with the upper arm, and of **extension** when this angle is opened out again. The axis of movement passes through the humeral epicondyles and is not at right angles with either the humerus or the bones of the forearm. In full extension, with the forearm supinated, the upper arm and fore-arm form an angle—the 'carrying angle'—opening laterally, more pronounced in women than in men. The axis of movement bisects this angle; hence in full flexion the forearm comes up in line with the upper arm. If the humerus is rotated slightly medially, as it is with the arm hanging naturally by the side, the hand approaches the mouth when the forearm is flexed; this movement of bringing the hand to the mouth is also usually associated with some abduction of the upper arm at the shoulder joint. The 'carrying angle' is not apparent when the forearm is pronated (p. 367), and in that position the wrist, elbow and shoulder joints are all in line with one another when the elbow joint is extended—this is the position of the upper limb in which pushing and pulling movements are usually performed.

Flexion can proceed until checked by apposition of upper arm and forearm and by the tension of the posterior muscles and ligament. Extension cannot occur beyond the straight position of the limb; it is then limited by the tension of the anterior muscles and ligament. The lateral and medial ligaments are fairly tense in all positions, the anterior part of each being specially tight in extension and the posterior part in flexion.

Limitation of movement by locking of the bones seldom occurs. That it does take place in some persons is shown by the occasional presence of small cartilage-covered facets at the bottom of the coronoid fossa and at the sides of the olecranon fossa which obviously must have made contact during life with the coronoid and olecranon processes.

As already mentioned, the joint-surfaces are in closest contact in a position of right-angled flexion, with the forearm midway between pronation and supination. This is therefore the position of greatest stability and is the position naturally assumed when the hands are engaged in fine manipulations.

RADIO-ULNAR JOINTS

The bones of the forearm are united at their upper and lower ends by synovial joints which act together to provide movement of the radius on the ulna around a vertical axis; these joints are therefore of the pivot type. In addition, the shafts of the two bones are connected by fibrous interosseous bands in the manner of a syndesmosis.

Superior Radio-Ulnar Joint

At the **superior radio-ulnar joint** the discoidal head of the radius rotates within the ring formed by the radial notch on the ulna and the annular ligament of the radius. The notch on the ulna is lined with articular cartilage continuous with that on the lower half of the trochlear notch in the elbow joint; the surface of the radial notch is concave antero-posteriorly but is flat vertically and is inclined slightly laterally below (Fig. 329). The head of the radius is covered with a continuous layer of cartilage above and around the sides. The upper surface is slightly cupped and rotates under the capitulum of the humerus, while the sides of the head bear on the annular ligament and radial notch.

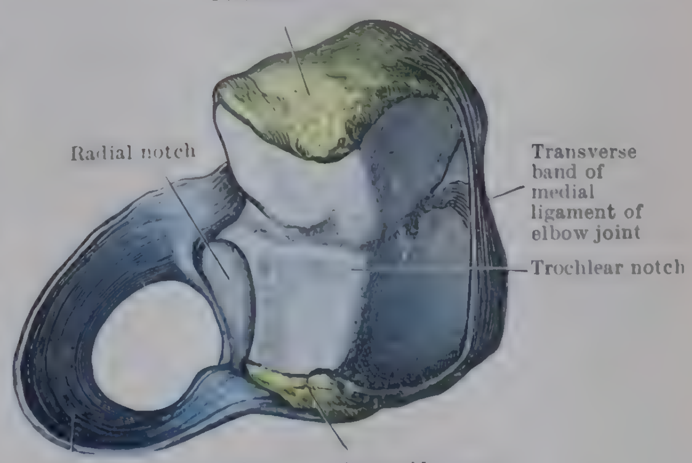

FIG. 329.—ANNULAR LIGAMENT OF RADIUS AND SUPERIOR ARTICULAR SURFACES OF ULNA.

Annular Ligament of Radius.—The annular ligament of the radius is a strong, well-defined curved band attached by its ends to the anterior and posterior margins of the radial notch on the ulna so as to form nearly four-fifths

of a ring which is completed by the notch itself. This ring is slightly narrower at its lower border than above, forming a segment of a hollow cone; and the radial head, enclosed by the ring, is reciprocally bevelled all round. This arrangement tends to prevent the radius from being pulled downwards through the ring. The annular ligament is supported above by its firm fusion with the lateral ligament and lateral parts of the anterior and posterior ligaments of the elbow joint (Fig. 326). Below, it is only feebly attached to the neck of the radius, distal to the epiphysial line, by fibres which are too loose to interfere with movement.

As already explained, the annular ligament is lined with **synovial membrane** which is carried down from the elbow joint and is reflected on to the upper part of the neck of the radius and carried across to the lower border of the notch on the ulna by the *quadrate ligament* (p. 364). The synovial cavities of the two joints are thus freely continuous with each other.

Inferior Radio-Ulnar Joint

The **inferior radio-ulnar joint** is formed between the head of the ulna and the ulnar notch on the radius. The bony surfaces are covered with articular cartilage; the lateral and distal ulnar surfaces are continuous with each other over a rounded border.

Articular Disc.—The chief uniting structure is the fibro-cartilaginous, triangular **articular disc**, which is attached by its base to the sharp edge on the radius between the ulnar and carpal surfaces and by its apex to the lateral side of the root of the ulnar styloid process (Fig. 330). This disc provides an additional joint-surface, for its upper surface articulates with the distal aspect of the head of the ulna. Thus, the joint-cavity is L-shaped in vertical section, with a vertical limb between the ulna and the radius and a horizontal limb between the ulna and the articular disc (Fig. 332). The distal surface of the disc forms part of the proximal articular surface of the wrist joint; but the cavities of the two joints do not communicate, except in some cases where the disc is perforated.

Capsular Ligament.—The capsular ligament is represented only by transverse bands of no great strength which stretch from radius to ulna across the front (Fig. 331) and back of the joint. The distal edges of these bands blend with the margins of the articular disc, but proximally they are separated from each other by a pouch of the synovial lining of the joint, called the *recessus sacciformis*, which extends upwards a little way between the radius and ulna.

Nerve-Supply.—The inferior radio-ulnar joint is supplied by twigs from the **anterior** and **posterior interosseous** nerves.

Connexion between Shafts of Radius and Ulna

The shafts of the radius and ulna are connected by the oblique cord and the interosseous membrane of the forearm.

Oblique Cord.—The oblique cord is a slender fibrous band which passes from the lateral border of the tuberosity of the ulna downwards and laterally to the radius just distal to its tuberosity (Figs. 326, 327); it is possibly a degenerated portion of the flexor pollicis longus.

Interosseous Membrane.—The interosseous membrane is a strong fibrous sheet which stretches between the interosseous borders of the radius and ulna. Proximally, it reaches to within an inch of the level of the radial tuberosity: through the gap between its upper edge and the oblique cord the posterior interosseous vessels pass to the back of the forearm. Distally, the interosseous membrane is continued into the fascia on the dorsal surface of the pronator quadratus muscle; this portion is pierced by the anterior interosseous vessels. The fibres of the interosseous membrane mostly run medially and downwards from radius to ulna; but on the back there are varying bands of an opposite obliquity which are probably connected with the long muscles of the thumb.

The interosseous membrane serves to increase the surfaces of origin of the deep muscles of the forearm, to brace together the radius and ulna, and, because of the

obliquity of the main fibres, to transmit to the ulna part of any force passing upwards from the hand along the radius. The tension of the membrane varies during radio-ulnar movement, being greatest in semi-pronation.

Movements at Radio-Ulnar Joints

Movement at the radio-ulnar joints takes place around an axis that passes through the centre of the head of the radius above and the apical attachment of the articular disc below. The movement is chiefly on the part of the radius; its upper end rotates under the humeral capitulum and within the ring formed by the annular ligament and the radial notch on the ulna, while its lower end, bearing the hand, travels round the lower end of the ulna, to which it is tethered by the articular disc. Starting from the supine position, in which the bones of the forearm are parallel and the palm is directed forwards (if the forearm is extended at the elbow), in the movement of **pronation** the lower end of the radius is carried forwards and medially round the lower end of the ulna until the palm is turned backwards and the shafts of the radius and ulna cross each other. Movement in the reverse direction is termed **supination.** These movements cannot be dissociated from slight accompanying rotation of the humerus at the shoulder joint—medially with pronation and laterally with supination—unless the elbow joint is flexed. But the ulna also changes position in pronation and supination. Its lower end precedes the lower end of the radius around the opposite half of the circle of excursion, moving backwards and laterally as the radius travels forwards and medially during pronation, and in the reverse direction during supination. This excursion of the lower end of the ulna is the magnified result of slight flexion-extension movements of its upper end at the elbow joint, which also cannot be dissociated from radio-ulnar movement proper, in conjunction with the humeral rotation already mentioned. The movement of supination is stronger than pronation; and screws and screwing instruments are made so as to be manipulated by supination of the right forearm.

When the upper limb is straight, the axis of humeral rotation is in the same line as the axis of radio-ulnar movement, and therefore pronation and supination can be supplemented by the full extent of rotation at the shoulder joint so that it is then possible to turn the hand through about three and one half right angles.

WRIST (RADIO-CARPAL) JOINT

The **wrist joint** proper is formed between the distal surface of the radius and the articular disc, and the proximal row of carpal bones (except the pisiform).

Articular Surfaces.—The radius and the disc together form a concave, ellipsoidal surface of shallower curvature in its long axis from side to side than in its short axis from before backwards (Fig. 330). A similar surface, but convex, is provided distally by the proximal articular areas of the scaphoid, lunate, and triquetral bones, closely united by interosseous ligaments which are flush with the articular cartilage on the proximal surface of the bones (Fig. 332). The joint is therefore ellipsoidal in type. The *articular cartilage on the radius* is divided by a low ridge into a triangular lateral area and a quadrangular medial area. In the normal, straight position of the hand, the scaphoid bone is opposite the lateral radial area, the lunate is opposite the medial area and the disc, and the triquetral is in contact with the medial portion of the joint-capsule (Fig. 332). When the hand is bent to the ulnar side, the triquetral is then moved over to lie opposite the disc (Pl. XXXIII, p. 370).

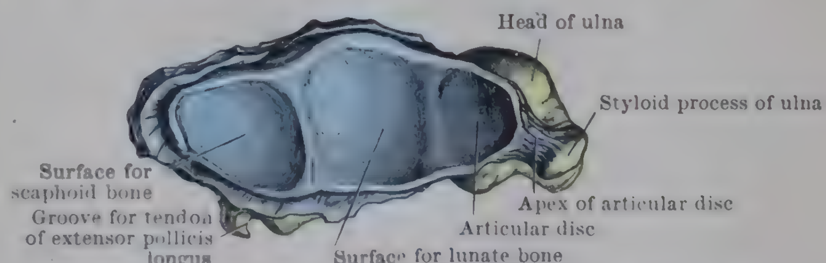

Fig. 330.—Proximal Articular Surface of Wrist Joint.

Capsular Ligament.—A capsular ligament surrounds the joint. It is attached close to the articular areas; its proximal attachment is distal to the inferior epiphysial lines of the radius and ulna.

The anterior part of the capsular ligament, called the **anterior radio-carpal ligament**, is formed chiefly of a broad band of fibres that spread downwards with a medial inclination, from the anterior edge of the distal end of the radius to the first carpal row—some longer fibres extending to the capitate bone in the second row (Fig. 331). From the anterior edge of the disc and the base of the ulnar styloid process some fibres pass downwards and laterally to the carpus, and others pass laterally to the radius, blending with the capsule of the inferior radio-ulnar joint.

On the back of the joint, the **posterior radio-carpal ligament** is composed of fibres that run mainly from the posterior edge of the lower end of the radius downwards and medially to the bones of the first carpal row, particularly the triquetral bone.

At the sides, the capsular ligament is specially strengthened to form the **lateral** and **medial ligaments** (Fig. 331). The lateral ligament runs from the radial styloid process to the scaphoid bone immediately lateral to its proximal articular surface; the radial artery crosses this ligament deep to the long abductor and short extensor tendons of the thumb. The medial ligament spreads downwards from the ulnar styloid process to the medial, non-articular border of the triquetral bone and to the pisiform bone.

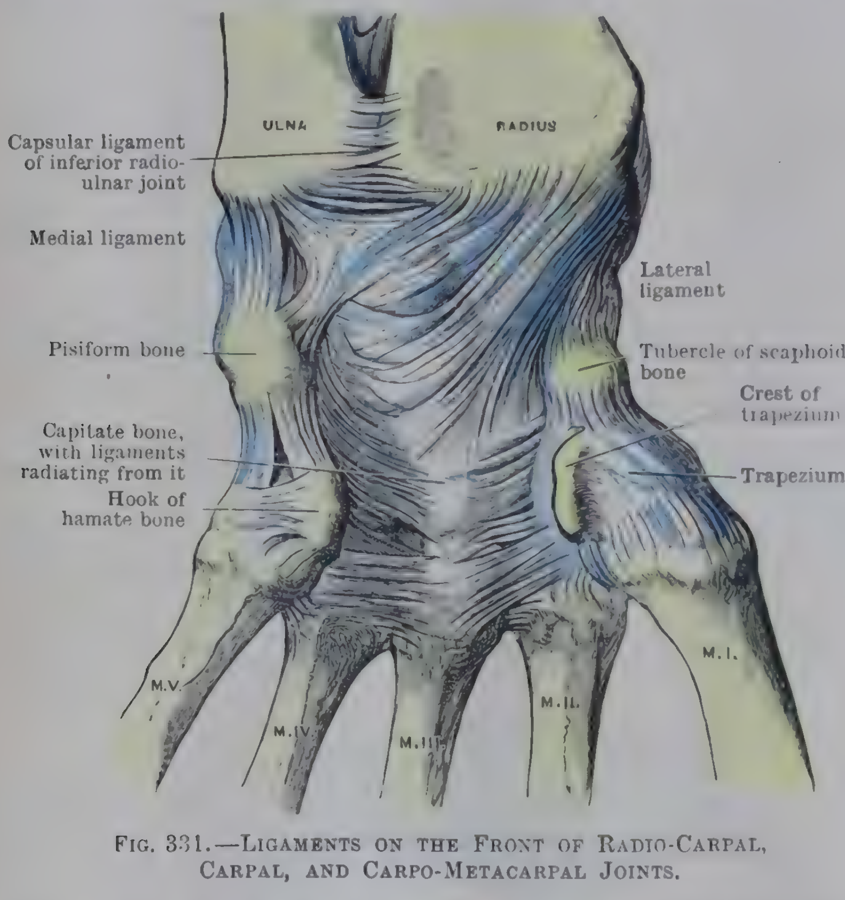

FIG. 331.—LIGAMENTS ON THE FRONT OF RADIO-CARPAL, CARPAL, AND CARPO-METACARPAL JOINTS.

Synovial Membrane.—A synovial membrane lines the capsular ligament. In exceptional cases the synovial cavity communicates with the inferior radio-ulnar joint through a perforated articular disc, or with the intercarpal joint when one of the interosseous ligaments of the proximal carpal row forms an incomplete barrier.

Nerve-Supply.—The radio-carpal joint (in common with the carpal and carpo-metacarpal joints—described later) receives its supply from all three main nerves of the upper limb:—from the median nerve, through the **anterior interosseous** branch; from the radial nerve, through the **posterior interosseous** branch; and from the ulnar nerve, through the **dorsal branch and deep (palmar) branch.**

Movements at the Radio-Carpal Joint

In free movements of the hand at the wrist much of the apparent movement at the radio-carpal joint is the result of movement between the proximal and distal rows of carpal bones (transverse intercarpal joint). Movements at the radio-carpal and transverse intercarpal joints are usually closely associated and for that reason movements at these joints are considered together (p. 370).

INTERCARPAL JOINTS

The carpal bones are articulated in two rows—proximal and distal—that form with each other an important joint called the **transverse intercarpal joint.** The joints between the individual bones of the carpus are mostly of the plane or gliding type, but the capitate undergoes a marked rotation during movements of the hand.

Joints of the Proximal Row.—Of the bones of the proximal row, the scaphoid, the lunate, and the triquetral are tied together by palmar, dorsal, and interosseous bands.

The **palmar** and **dorsal ligaments** pass between neighbouring parts on those aspects of the bones. The **interosseous ligaments** are short bands that pass between contiguous surfaces, uniting them in their whole antero-posterior depth near their proximal margins, and leaving joint-clefts between their distal parts, which are therefore coated with articular cartilage (Fig. 332).

Pisiform Joint.—The pisiform bone rests on the palmar surface of the triquetral bone, and forms with that bone a separate little synovial joint surrounded by a thin, but strong, **capsular ligament**. It is further anchored by strong bands—the **piso-metacarpal** and **piso-hamate ligaments**—to the base of the fifth metacarpal and the hook of the hamate bone; these ligaments resist the pull of the flexor carpi ulnaris muscle upon the pisiform bone, and, in effect, provide additional insertions for that muscle.

Joints of the Distal Row.—All four bones of the distal carpal row are connected by **palmar, dorsal,** and **interosseous ligaments**. The interosseous ligaments (Fig. 332) are, in general, not so extensive as those of the proximal row; they leave joint-clefts between the bones both proximally, running into the transverse intercarpal joint, and distally, running into the carpo-metacarpal joint. These two larger joints sometimes communicate with each other between bones of the distal row where an interosseous ligament is absent (most often that between the trapezium and trapezoid) or where it does not extend the whole way between the dorsal and palmar surfaces of the adjoining bones.

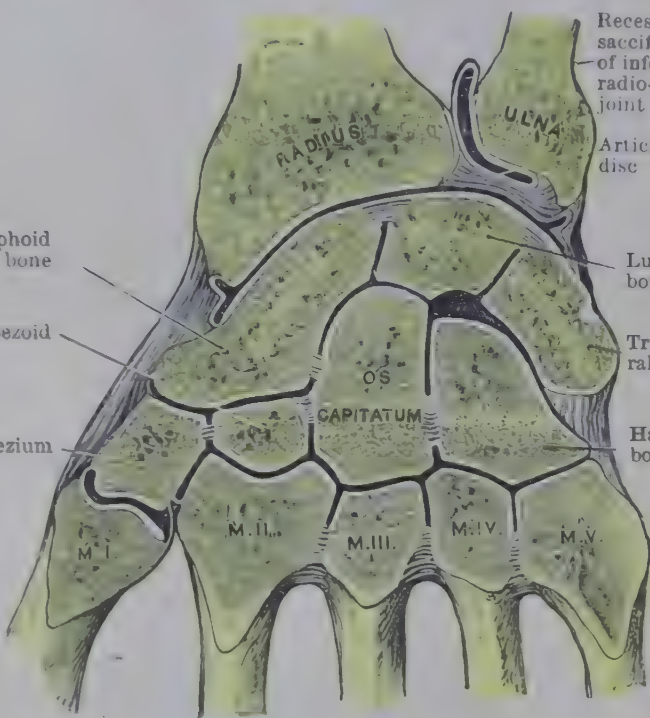

FIG. 332.—CORONAL SECTION through the radio-carpal, carpal, carpo-metacarpal, and intermetacarpal joints, to show joint-cavities and interosseous ligaments (diagrammatic).

Transverse Intercarpal Joint (Fig. 332).—This is the joint between the two carpal rows. The line of the joint is convex distally on the lateral side, where the trapezium and trapezoid are opposed to the rounded distal surface of the scaphoid. In the medial and larger part of the joint there is a deep concavity facing distally, bounded by the triquetral and lunate bones and the medial surface of the scaphoid bone, and occupied by the rounded head of the capitate bone and the proximal angle of the hamate bone.

The joint is surrounded by a **capsular ligament** made up, in front and behind, of irregular bands which run between the two rows of bones and constitute the **palmar** and **dorsal intercarpal ligaments**; the bands in the palmar ligament chiefly radiate from the head of the capitate bone (Fig. 331). At the sides of the transverse intercarpal joint the capsular ligament is strengthened as it passes between the scaphoid and trapezium and between the triquetral and hamate bones.

Intercarpal Synovial Cavity.—The intercarpal synovial cavity (Fig. 332) is large and complicated. The main part extends from side to side between the two rows of bones, and may be partially interrupted by an interosseous ligament connecting contiguous parts of the scaphoid and capitate bones. Offshoots of the cavity pass proximally between the three main bones of the proximal row until blocked by the interosseous ligaments; but, in rare cases, a deficiency in one of these may permit the intercarpal joint to communicate with the radio-carpal joint. Other offshoots pass distally between the four bones of the distal row, and not infrequently communicate with the carpo-metacarpal joint-cavity, especially on one or other side of the trapezoid.

Nerve-Supply.—The intercarpal joints are supplied by twigs from the **anterior** and **posterior interosseous** nerves and the **dorsal** and **deep branches of the ulnar** nerve.

Accessory Ligaments of Carpus.—The carpus, in each of its rows, forms a transverse arch with a palmar concavity. The concavity is bridged over by the **flexor retinaculum**, which is attached medially to the pisiform bone and the hook of the hamate bone, and laterally to the scaphoid tubercle and the crest of the trapezium. Through the tunnel behind the retinaculum, the median nerve and the flexor tendons enter the palm, while the ulnar vessels and nerve pass in front of it. The **extensor retinaculum** is merely a thickened portion of the deep fascia covering the back of the carpus and the lower end of the radius. By its intermediate attachments to the ridges on the radius, it provides a series of tunnels for the extensor tendons of the wrist and fingers (p. 512).

Movements at the Radio-Carpal and Carpal Joints.—The principal movements between the carpal bones are those that occur at the transverse intercarpal joint and, as movement at this joint is usually associated with movement at the radio-carpal joint, the movements at both joints are considered together; it is also to be noted that the muscle-groups acting on these joints are common to both.

Movements at these joints occur around transverse and antero-posterior axes. Around transverse axes the hand is bent towards the front of the forearm in **flexion** or towards the back of the forearm in **extension**. Around antero-posterior axes the hand is deflected towards the ulnar border of the forearm in **ulnar deviation (adduction)** or towards the radial border in **radial deviation (abduction)**. Oblique movements are also possible around intermediate axes, as well as a combined movement around successive axes bringing about **circumduction** of the hand on the forearm.

In *flexion* of the hand, movement occurs at both the radio-carpal and transverse intercarpal joints, but in full flexion, as can only occur when the fingers are extended, the greater part of the movement occurs at the transverse intercarpal joint. *Extension* of the hand is also a compound movement, but the range of movement is greater at the radio-carpal than at the transverse intercarpal joint. In both flexion and extension of the hand the distal row of carpal bones moves around a transverse axis that passes through the middle of the head of the capitate, and there is also, in both movements, a compensatory swing of the scaphoid on the lunate for the accommodation of the head of the capitate. In ulnar deviation (*adduction*) of the hand the greater part of the movement occurs at the radio-carpal joint, and during this movement the proximal row of carpal bones glides laterally so that the entire proximal surface of the lunate lies distal to the radius (Pls. XVI, p. 269, XXXIII). Radial deviation (*abduction*) of the hand is not such an extensive movement as ulnar deviation, and occurs entirely at the transverse intercarpal joint. In both ulnar and radial deviation the movement of the distal row of carpal bones upon the proximal row is round an antero-posterior axis that passes through the centre of the head of the capitate. (For a full consideration of these movements see Wright, 1935; MacConaill, 1941.)

It is important to note that slight extension is the position naturally assumed at the wrist when the hand is used for grasping purposes, and therefore, if the wrist joint is likely to become fixed through disease, fixation should be secured in a position of slight extension in order to conserve sufficient grasping power.

CARPO-METACARPAL AND INTERMETACARPAL JOINTS

Carpo-Metacarpal Joint of Thumb (Fig. 332).—This joint is self-contained between the base of the first metacarpal bone and the trapezium. The surfaces are reciprocally saddle-shaped, and the joint is completely enclosed by a strong but rather loose **capsular ligament** (Fig. 331), which is lined with synovial membrane. Deep to the capsular ligament lie three discrete ligaments that have been termed the **anterior** and the **posterior oblique** and the **radial carpo-metacarpal ligaments** (Haines, 1944). The radial ligament is attached to the adjacent surfaces of the trapezium and the first metacarpal on their radial sides. The anterior and posterior oblique ligaments are respectively attached to the corresponding surfaces of the trapezium and converge as they pass distally to be attached to the ulnar side of the base of the first metacarpal.

Movements.—This is a saddle joint and movement can therefore occur around two principal axes at right angles to each other; oblique movements are also possible around intermediate axes as well as a combined movement around successive axes that allows the movement of circumduction of the thumb. In addition, a limited amount of rotation can take place, and though this movement does not have a wide range it is extremely important as it allows the **opposition** of the thumb to the other fingers.

For the understanding of the movements of the thumb it is to be noticed that the dorsal surface of the first metacarpal is directed laterally and the palmar surface medially. In **flexion** the thumb is moved to the ulnar side in the plane of the palm and in **extension** it is carried to the radial side in the same plane. In **adduction** the thumb is carried directly backwards and in **abduction** it is carried forwards. In the movement of full flexion the thumb is carried directly in front of the palm of the hand and it is during the latter part of this movement that the metacarpal bone undergoes a *medial* rotation of about 30° so that the palmar surface of the thumb becomes opposed to the corresponding surfaces of the fingers. Conversely, when the thumb is

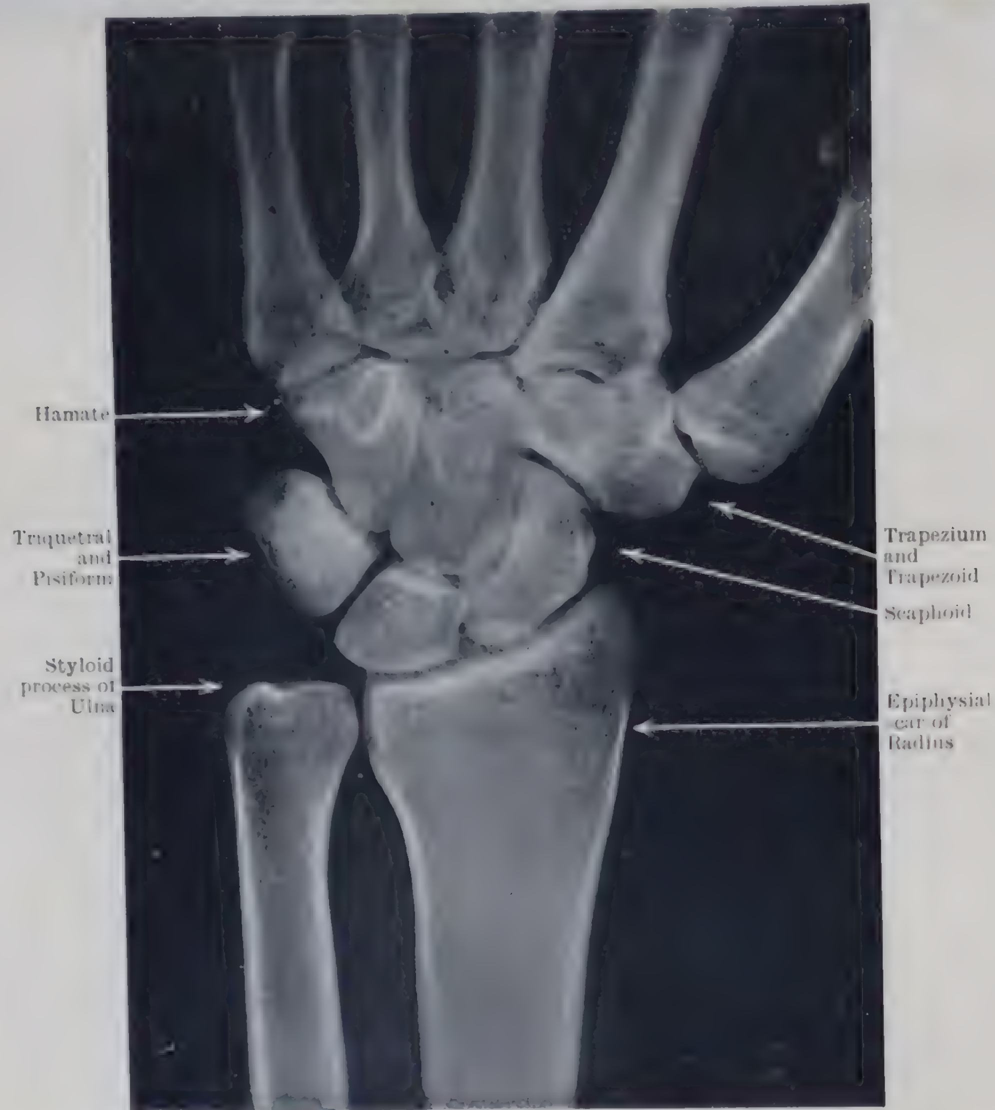

Fig. 1.—Radiograph of Wrist showing the relation of the Carpus to the Radius and Ulna in Extreme Radial Flexion (Abduction) at the Radio-Carpal Joint.

Note the wide space between the head of the Ulna and the Triquetral bone.

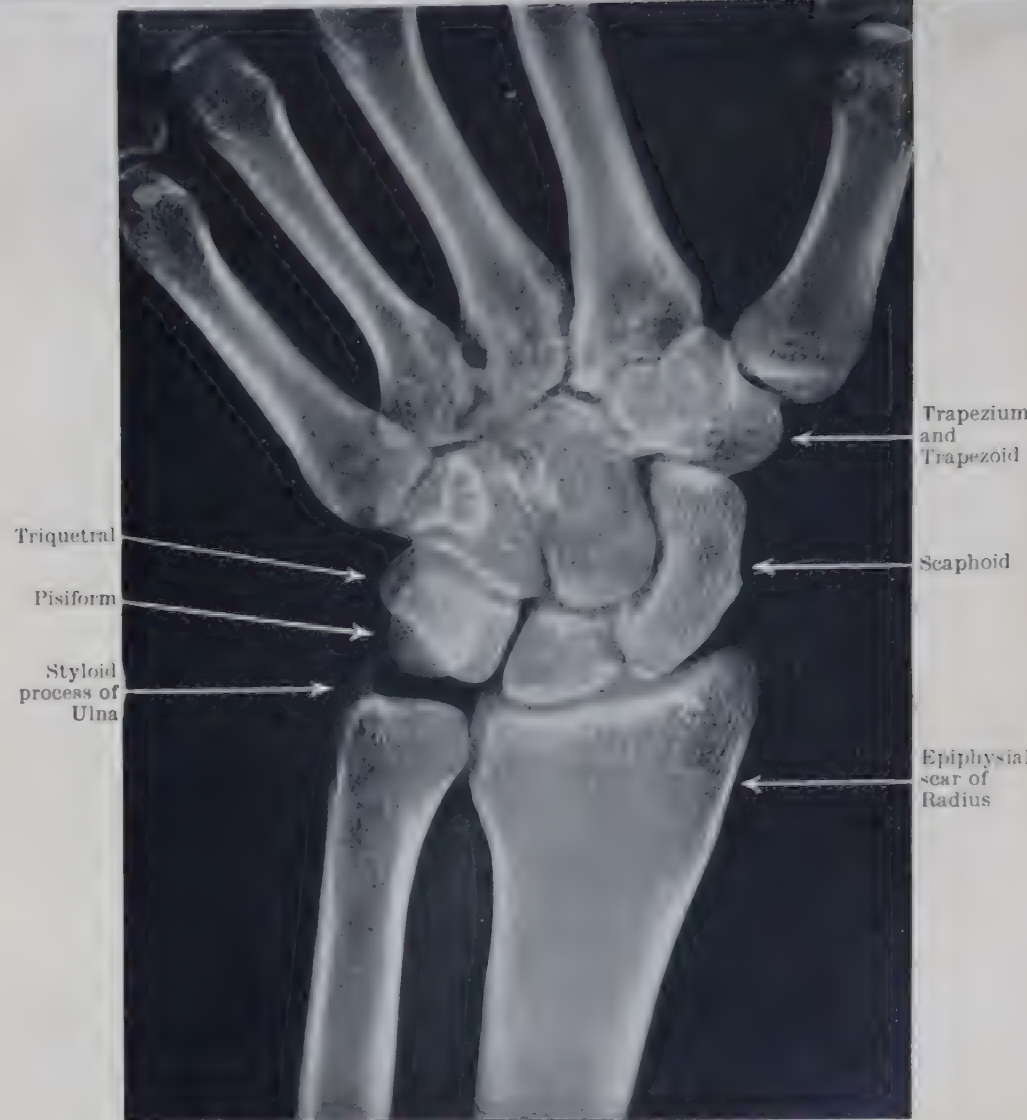

Fig. 2.—Radiograph of the same Wrist in Extreme Ulnar Flexion (Adduction) at the Radio-Carpal Joint.

Note the alteration in the relation of the Carpus to the Radius and the movement that has taken place between the proximal and distal rows of carpal bones. **The space between the Triquetral, the Ulna and the Radius is occupied by the triangular articular disc of the inferior radio-ulnar joint and the articular cartilages covering the bones.**

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PLATE XXXIV

Fig. 1.—Lateral Radiograph of Left Knee of Young Man aged 22, in Extension.

Note the areas of contact of the Femur with the Patella and Tibia: also the sesamoid bone (Fabella) in the lateral head of the gastrocnemius muscle.

Fig. 2.—Lateral Radiograph of the same Knee, Semi-Flexed.

Compare with Fig. 1, and note the change in the areas of contact of the Femur with the Patella and Tibia. For posterior radiograph of the same knee, see Plate XXI, p. 296.

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moved into full extension the first metacarpal undergoes a slight lateral rotation as the movement nears its completion. The movement of medial rotation has been shown to be caused by the posterior oblique carpo-metacarpal ligament that becomes increasingly taut during flexion of the metacarpal, and similarly lateral rotation is dependent on the anterior oblique carpo-metacarpal ligament becoming taut during extension (Haines, 1944). During the movement of opposition a certain amount of medial rotation of the first phalanx occurs at the metacarpo-phalangeal joint and this supplements the rotation of the metacarpal (Bunnell, 1938).

Common Carpo-Metacarpal Joint (Fig. 332).—The bases of the medial four metacarpal bones form, with the distal row of carpal bones, a common carpo-metacarpal joint. The line of the joint is highly irregular. Laterally, the base of the second metacarpal is recessed between the trapezium and trapezoid and between the trapezoid and the capitate bone, with all of which it articulates; next, the third metacarpal articulates with the capitate bone at a small transverse segment of the joint-line; the fourth metacarpal causes the line to become angular again as it articulates to a small extent with the capitate and to a greater extent with the hamate bone; finally, the fifth metacarpal articulates only with the medial, bevelled facet on the hamate bone.

The joint is surrounded by a **capsular ligament** in which various **palmar** and **dorsal carpo-metacarpal** slips can be distinguished passing from the distal carpal bones to the metacarpal bases. An **interosseous ligament** is usually present, stretching from contiguous parts of the capitate and hamate bones to the third or the fourth metacarpal base or to both; this ligament may divide the joint into separate medial and lateral compartments.

The **synovial cavity** of the common carpo-metacarpal joint extends upwards between the four distal carpal bones, and there usually communicates with the transverse intercarpal joint. Distally, the cavity is continuous with the little joints between the bases of the medial four metacarpal bones. (Fig. 332.)

Intermetacarpal Joints (Figs. 331, 332).—These joints are formed between small articular facets on the contiguous sides of the bases of the medial four metacarpal bones. The three little joints are closed in front, behind, and below by **palmar, dorsal,** and **interosseous ligaments** that pass transversely between adjacent bones. Proximally, their cavities open into the common carpo-metacarpal joint.

Nerve-Supply.—The carpo-metacarpal and intermetacarpal joints are supplied by twigs from the **anterior** and **posterior interosseous** nerves and the **dorsal** and **deep branches of the ulnar** nerve.

Movements.—Very little movement is possible between the carpus and the medial four metacarpal bones. It is more appreciable in the case of the fifth metacarpal, whose articulation with the hamate bone is of a flattened saddle type; around an oblique axis, this metacarpal bone can be flexed a little way across the palm in a fashion similar to the more extensive opposition movement of the metacarpal bone of the thumb.

METACARPO-PHALANGEAL AND INTERPHALANGEAL JOINTS

Metacarpo-Phalangeal Joints.—Each metacarpo-phalangeal joint (Fig. 333) is formed between the slightly cupped base of the proximal phalanx and the rounded metacarpal head, which is covered with articular cartilage distally and on the front but not on the back.

Capsular Ligament.—The capsular ligament is strengthened on each side by a **collateral ligament** which radiates fanwise from the tubercle and adjacent

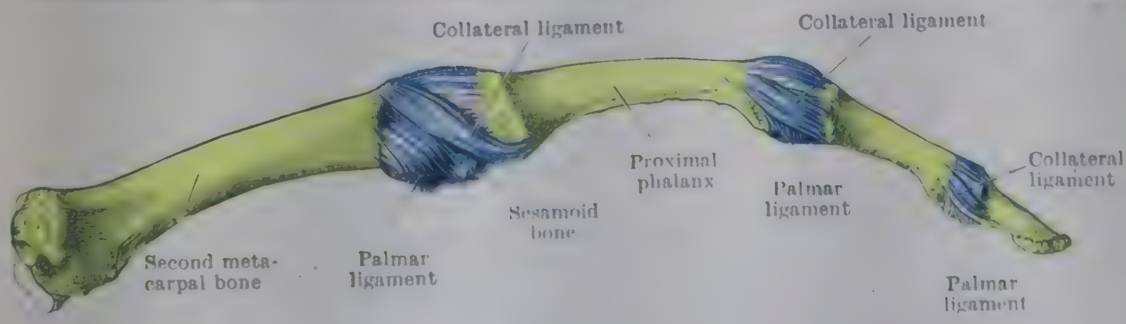

Fig. 333.—Metacarpo-Phalangeal and Interphalangeal Joints.

depression on the side of the metacarpal head to the side of the base of the proximal phalanx and to the front of the joint-capsule.

On the front there is a dense, fibrous pad, called the **palmar ligament**, which

blends with the collateral ligaments at the sides and is firmly fixed distally to the base of the phalanx but is only weakly attached proximally to the neck of the metacarpal bone. This pad is grooved in front by the long flexor tendons. In the thumb there are two sesamoid bones embedded in it; there is usually one such sesamoid in the radial side of the pad on the index finger and occasionally in the ulnar side in the little finger.

The capsular ligament is deficient **dorsally**, where it is replaced by the expansion of the long extensor tendon, which blends at the sides with the collateral ligaments.

Deep Transverse Ligaments of the Palm.—The palmar ligaments of the medial four joints are connected by strong transverse bands, called the **deep transverse ligaments of the palm**, which indirectly bind together the heads of the medial four metacarpal bones. The interossei tendons descend behind these bands; the lumbrical tendons pass in front of them.

Nerve-Supply.—The metacarpo-phalangeal joints of the thumb, the forefinger, and the middle finger are supplied by the **median** and **radial** nerves; those of the ring and little fingers by the **ulnar** nerve. (See also the paragraph on nerve-supply below.)

Movements.—The metacarpo-phalangeal joints are of condyloid type, having all the movements of a ball-and-socket joint except rotation. The proximal phalanges can be **flexed** to at least a right angle with the metacarpal bones but can be **extended** little beyond the line of the metacarpals. In the extended position the fingers can be **adducted** or **abducted** towards or away from the centre line of the middle finger. When the fingers are flexed, sideward movements become impossible because of increased tension of the collateral ligaments, which are fixed to the metacarpals nearer the distal than the palmar surface of their heads, and are also more stretched in flexion owing to the greater width of the palmar aspect of the metacarpal articular surface. The metacarpo-phalangeal joint of the thumb has much less extensive movement than the others—hardly any at all from side to side—though medial rotation occurs at it during the movement of opposition of the thumb to the fingers (p. 370).

Interphalangeal Joints (Fig. 333).—The interphalangeal joints are constructed, as regards ligaments, in exactly the same fashion as the metacarpo-phalangeal joints. But owing to the bi-condyloid shape of the articular surfaces these are pure hinge-joints, capable only of **flexion** and **extension**. Although the fingers are of unequal length, the phalanges are so proportioned that in flexion the finger-tips come into line and meet the palm simultaneously.

Nerve-Supply.—The interphalangeal joint of the *thumb* is supplied by the **median** nerve, with twigs occasionally from the **radial** also; the joints of the *forefinger* and *middle finger* by the **median** nerve; those of the *ring finger* by the **ulnar** nerve and probably **median** also; and those of the *little finger* by the **ulnar** nerve.

The **nerve-supply of the metacarpo-phalangeal and interphalangeal joints** has been specially studied by Stopford (1921), whose principal findings are here summarized. Individual variation in the articular nerve-supply is closely related to variations in the cutaneous distribution of the nerves concerned. The joints of the **thumb** are supplied by the **radial** and **median** nerves—chiefly the radial in the *metacarpo-phalangeal joint*, which, however, in a few cases may be supplied by either nerve alone; and chiefly the median nerve in the *interphalangeal joint*, of which it is often the sole supply. In the **index** and **middle fingers** the *metacarpo-phalangeal joints* are supplied by both **median** and **radial** nerves—chiefly the median—but in some cases either nerve may supply the joint; the *interphalangeal joints* are supplied by the **median** only. The joints of the **ring finger** are supplied by the **ulnar** nerve, probably supplemented by the **median** in most cases. The joints of the **little finger** are supplied by the **ulnar** nerve alone.

JOINTS OF THE PELVIS

The skeleton of the pelvic girdle is joined to the skeleton of the trunk in such a way as to provide great strength in the region of weight transference from trunk to girdle at the sacrifice of almost all mobility. The girdle, formed of a single unjointed piece—the hip-bone—is firmly but not quite immovably joined to the sacrum behind and to its fellow of the opposite side in front. These two joints, sacro-iliac and interpubic, with the sacro-coccygeal union and the lumbo-sacral articulation between the pelvis and the last lumbar vertebra, make up the pelvic joints.

LUMBO-SACRAL AND SACRO-COCCYGEAL JOINTS

Lumbo-Sacral Joint.—At the lumbo-sacral joint the fifth lumbar vertebra is united to the first piece of the sacrum, just as any two typical vertebræ are united, by an intervertebral disc, the anterior and posterior longitudinal ligaments, synovial joints between articular processes, ligamenta flava, and interspinous and supraspinous ligaments. In addition there are two special ligaments that spring from the fifth lumbar transverse process on each side—the ilio-lumbar and the lateral lumbo-sacral ligaments.

The **ilio-lumbar ligament** (Fig. 334) is a strong ligament that spreads laterally from the fifth lumbar transverse process to the posterior part of the inner lip of the iliac crest; it is really the thickened lower border of the anterior layer of lumbar fascia lying in front of the quadratus lumborum muscle.

The **lateral lumbo-sacral ligament**—usually partly blended with the preceding ligament—consists of variable bundles that pass downwards and laterally from the lower border of the fifth lumbar transverse process to the ala of the sacrum, where they intermingle with the anterior sacro-iliac ligament; its attachments indicate its homology with the superior costo-transverse ligaments of the thoracic region.

Sacro-Coccygeal Joint.—At the sacro-coccygeal joint there is an intervertebral disc between the last sacral and first coccygeal segments, reinforced all round by longitudinal strands called the **sacro-coccygeal ligaments** (Fig. 334).

SACRO-ILIAC JOINT

The **sacro-iliac joint** is formed between the auricular facets on the sacrum and on the iliac bone. Reciprocal sinuosities on these two surfaces, or even in some cases more pronounced irregularities in the form of tubercles with depressions opposite to them, cause a certain amount of interlocking between the facets. The shape and the irregularity of the auricular surfaces not only vary considerably in different individuals, but also may show marked differences on the two sides in the same individual. The auricular surface of the sacrum is covered with hyaline cartilage, but the cartilage on the corresponding facet of the ilium is usually of a fibrous type (Schunke, 1938). The joint is a synovial one, with a complete capsular ligament lined with synovial membrane, but movement is greatly restricted by the irregularity of the articular surfaces and the thickness and disposition of the posterior sacro-iliac ligaments. In later life, particularly in males, it is usual to find fibrous or fibro-cartilaginous adhesions between the articular surfaces, with partial or complete obliteration of the cavity of the joint (Brooke, 1924).

The **anterior sacro-iliac ligament** is a broad band, of no great thickness, which closes the joint in front both above and below the pelvic brim. It stretches from the ala and pelvic surface of the sacrum to the adjoining surface of the iliac bone.

The **posterior sacro-iliac ligaments** present a very much stronger and thicker formation. It consists of three strata. The deepest—the **interosseous sacro-iliac ligament**—short, thick, and very strong, fills the narrow cleft between the rough areas on the bones immediately above and behind the articular surfaces (Fig. 335). Occasionally one or two small accessory joint-cavities are found in the substance of this ligament between facets near the posterior superior spine and bosses on the sacrum in the position of transverse tubercles (Jazuta, 1929).

Superficial to the interosseous fibres, longer bands run obliquely medially and downwards between more divergent parts of the bones; these constitute the **short posterior sacro-iliac ligament** (Figs. 334, 335). Still longer fibres, descending almost vertically from the posterior superior iliac spine to the third and fourth sacral segments, behind and lateral to the short ligament, compose the **long posterior sacro-iliac ligament**. The lateral part of the long ligament is indistinguishable from the upper part of the sacro-tuberous ligament.

Nerve-Supply.—The sacro-iliac joint is supplied (1) by twigs directly from the **sacral plexus** and the **posterior primary rami of the first two sacral nerves**, and (2) by branches from the **superior gluteal and obturator nerves**.

Accessory Ligaments.—The gap left in the bony pelvis between the sacrum and the ischial part of the hip-bone is bridged by a system of widespread fibres that form accessory ligaments of the sacro-iliac joint called the sacro-tuberous and sacro-spinous ligaments (Figs. 334, 335).

The **sacro-tuberous ligament** has an extensive attachment to the posterior superior and posterior inferior iliac spines, the back and side of the lower part of the sacrum and the side of the upper part of the coccyx. Thence the fibres converge towards the ischial tuberosity, but, twisting upon themselves, they diverge again to be attached to the medial margin of the ischial tuberosity and the lower margin of the ramus of the ischium. The fibres to the ramus form a sickle-shaped extension of the ligament called the **falciform process**.

The superficial fibres attached to the tuberosity are intimately associated with

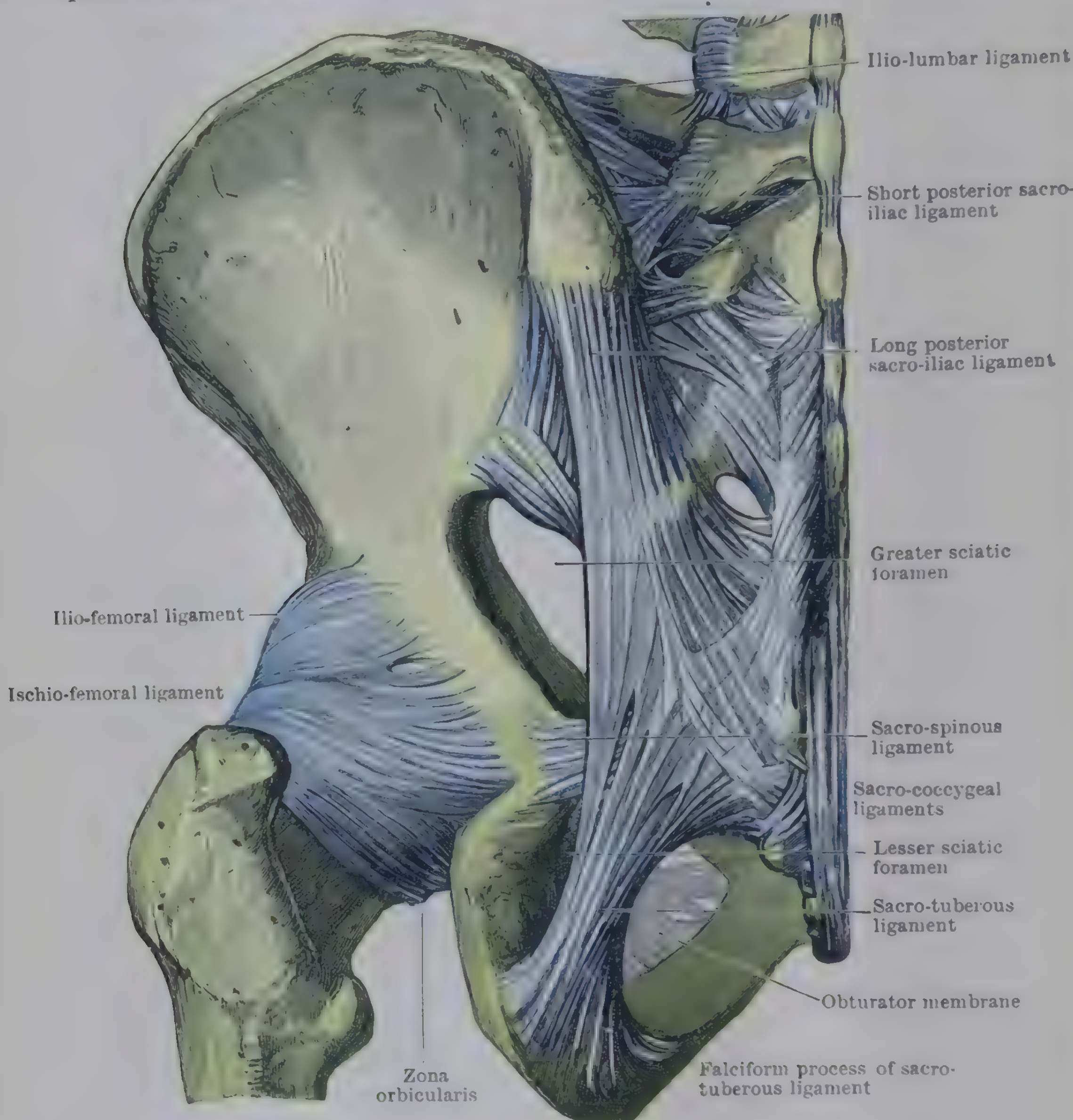

Fig. 334.—Posterior View of Pelvic Ligaments and Hip Joint.

the long head of the biceps femoris muscle; the whole ligament, indeed, is usually regarded as a stranded proximal portion of this muscle.

The **sacro-spinous ligament** lies on the pelvic surface of the sacro-tuberous ligament. It is triangular in outline. Its base is attached to the edge of the lower sacral and upper coccygeal segments, in front of the sacro-tuberous ligament; its apex is attached to the ischial spine. This ligament is closely blended with the coccygeus muscle, and may be regarded as the result of a fibrous degeneration of the dorsal part of the muscle.

Sciatic Foramina.—The sacro-tuberous ligament, by its lateral border stretching between the posterior inferior iliac spine and the ischial tuberosity, converts the greater and lesser

sciatic notches of the hip-bone into foramina separated by the apical part of the sacro-spinous ligament (Figs. 334, 335). The piriformis muscle runs out through the **greater sciatic foramen** with the superior gluteal vessels and nerve above the muscle, and below it the sciatic nerve, the posterior cutaneous nerve of the thigh, the inferior gluteal vessels and nerve, the internal pudendal vessels and the pudendal nerve, and the nerves to the quadratus femoris and obturator internus muscles. The tendon of the obturator internus emerges from the **lesser sciatic foramen**; the nerve to that muscle and the internal pudendal vessels and pudendal nerve enter the perineum above the tendon.

PUBIC SYMPHYSIS

The **pubic symphysis** is a median joint between the bodies of the pubic bones (Fig. 335). Each pubic articular surface is covered with a layer of hyaline cartilage united to the cartilage of the opposite side by a thick fibro-cartilaginous **interpubic disc.** In the upper and back part of this disc a slit-like cavity appears during early life, and it may extend later, in women especially, through the greater part of the fibro-cartilage. There is no true synovial membrane. The joint is therefore of secondary cartilaginous type, modified by the appearance of an imperfect joint-cavity.

Ligaments of Pubic Symphysis.—The perichondrio-periosteal investment of the joint is strengthened all round by the **pubic ligaments.**

The **anterior ligament** is an interlaced decussation across the front of the joint of fibres largely derived from tendons of adjacent muscles, especially the rectus abdominis and external oblique muscles. The **posterior ligament** is represented by a few transverse fibres across the back of the joint. The **superior ligament** crosses the joint between the pubic crests and tubercles. The **inferior ligament** arches across the joint below, between the inferior pubic rami, and so rounds off the subpubic angle; it is separated from the perineal membrane by an interval through which the deep dorsal vein of the penis (or clitoris) enters the pelvis.

Obturator Membrane (Fig. 336).—The obturator membrane, unconnected with any pelvic joint, is an interlacement of ligamentous bundles that close the obturator foramen save in its antero-superior part. It is attached to the margin of the foramen all round except in the neighbourhood of the **obturator canal.** This aperture is bounded above by a rounded part of the margin of the foramen and completed below by the short, free edge of the membrane; it transmits the obturator vessels and nerve. The obturator muscles arise from the surfaces of the membrane.

Pelvic Mechanics

The bony pelvis protects the pelvic viscera and gives attachment to muscles of the trunk and lower limb, but its primary skeletal function is to provide for stable transference of body-weight from the vertebral column to the thigh-bones. From the last lumbar vertebra the weight is transmitted through the upper part of the sacrum and the adjoining part of each iliac bone to the head of the femur; these parts constitute a pelvic arch of thickened bone, the concave border of which corresponds to the posterior half of the pelvic brim. The ventral pelvic bar formed by the superior rami and bodies of the pubic bones acts as a horizontal tie-beam connecting the bases of the pillars of the arch. Owing to the sinuous nature of the sacro-iliac joint-surfaces and the inclination of the long axis of the joint downwards, backwards and medially, the direction of the joint-line varies in sections cut in different planes and also at different levels in the same plane. For example, a section, in the plane of weight transference, through the middle of the joint shows the sacrum to be wedged between the hip-bones with the base above (Fig. 335) but a section near the lower end of the joint and in the same plane shows the sacrum as a wedge with the base below.

The weight of the body tends to displace the sacrum downwards into the pelvis, with separation of the hip-bones. This downward displacement and separation is resisted by the strong ligaments behind the sacro-iliac joints and the reciprocal sinuosities on the auricular surfaces. Any tendency to flattening of the arch, with opening out of the sacro-iliac joints below and in front, is resisted by the tie-beam action of the ventral pelvic bar. The body-weight, superimposed on the upper end of the obliquely-placed sacrum, tends to drive that end downwards and to tilt the lower end upwards and backwards; this is prevented by the strong sacro-tuberous ligaments holding down the lower part of the

sacrum. The ilio-lumbar ligaments help to prevent the last lumbar vertebra from slipping forwards on the oblique upper surface of the body of the first sacral segment. A slight amount of separation or gliding movement is possible at the sacro-iliac joints and the pubic symphysis; the cartilaginous plates in those joints have a cushioning action against jarring shocks. In these ways the pelvic joints provide that element of controlled resilience necessary to perfect function.

The **female pelvis** is modified in association with the requirements of child-bearing. Differences are seen in the joints as in the bones. At the sacro-iliac joint there is less interlocking by reciprocal irregularity of the bones, and more movement is permitted than in the male pelvis; the limitation of movement by fibrous ankylosis in later life is not nearly so marked in women as in men. The larger cavity in the interpubic disc, characteristic of the female joint, allows greater separation of the bones. The coccyx,

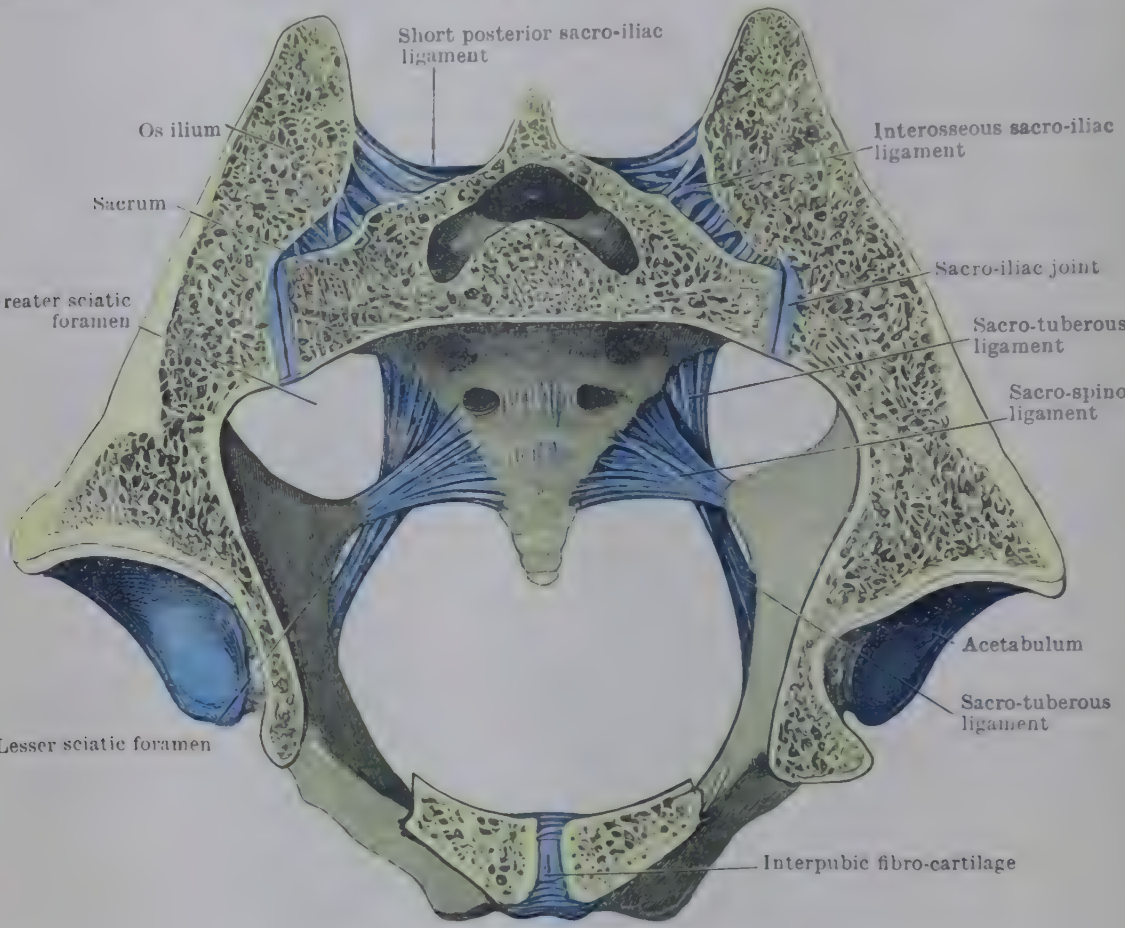

FIG. 335.—CORONAL SECTION OF PELVIS.

which in men is usually fused to the sacrum by synostosis in later life, is more mobile and preserves its mobility longer in women.

During pregnancy a softening and relaxation of the pelvic ligaments occur which allow an increase in the separation of the pelvic bones and an increase in the movements at the pelvic joints. These joint changes were formerly regarded as of importance during child-birth, but radiographic observations indicate that they do not materially affect the diameters of the pelvis (Young, 1940).

JOINTS OF LOWER LIMB

HIP JOINT

At the **hip joint** the globular head of the femur articulates with the cup-like acetabulum of the hip-bone, and provides the most striking example in the body of a ball-and-socket joint.

The mechanical requirements at this joint are severe. It must be capable not merely of supporting the entire weight of the body—as in standing on one leg—but of stable transference of that weight even during movement of the trunk upon the femur such as occurs with rapid alternation at the two hip joints

during walking and running. The joint must therefore possess great strength and stability even at the expense of limitation of range of movement. To this end, the deep socket securely holding the contained ball, the strong, tense capsular ligament, the insertion of the controlling muscles at some distance from the centre of movement, are all in marked contrast to the conditions at the shoulder joint.

Articular Surfaces.—The **femoral articular surface** forms nearly two-thirds of a spheroid. The covering cartilage is interrupted at the pit on the head of the femur, and it ends at the commencement of the neck of the femur along a sinuous line which sometimes makes a scalloped excursion upon the front of the neck. The **acetabular articular surface** is limited to a broad horseshoe-shaped belt which is covered with cartilage and is interrupted below and in front opposite the acetabular notch. The depressed central part of the acetabulum within the horseshoe lodges a pad of fat covered with synovial membrane.

Transverse Ligament and Labrum Acetabulare.—The acetabular notch is bridged by the **transverse ligament** of the acetabulum. The superficial edge of the ligament is flush with the acetabular rim; its deep edge does not reach the bottom of the notch but bounds an aperture which admits articular vessels and nerves. The acetabulum is deepened all round by a fibro-cartilaginous lip, called the **labrum acetabulare,** which is firmly attached to the bony rim and the transverse ligament. The thin, free edge of the labrum forms a slightly smaller circle than its attached base, and so is able to grasp the femoral head (Figs. 336, 337).

Capsular Ligament (Figs. 334, 336).—The capsular ligament encloses the joint and the greater part of the femoral neck as with a cylindrical sleeve. It is very strong and uniformly tense in full extension—in contrast to the thin and lax capsule of the shoulder joint. The tendons of surrounding muscles are much less intimately connected with it, but it does receive expansions from the rectus femoris, the gluteus minimus, and the piriformis muscles.

Proximally, the capsular ligament surrounds the acetabulum and is attached above and behind directly to the hip-bone just wide of the labrum, while below and in front it is fixed to the bone and the outer surface of the labrum and the transverse ligament of the acetabulum. Distally, the ligament is attached in front to the trochanteric line at the junction of the femoral neck and shaft; above and below it is attached to the neck close to its junction with the trochanters; but, behind, it extends over only the medial two-thirds of the neck. Thus, the whole of the neck of the femur is intracapsular in front, but the lateral third is extracapsular behind. The epiphysial line of the head is intracapsular; the trochanteric epiphysial lines are extracapsular.

The fibres of the capsular ligament run for the most part longitudinally from pelvis to femur. Some deeper fibres pass circularly round the joint, constituting the **zona orbicularis**; this is marked only on the back of the capsule, where it appears on the surface, winding round behind the femoral neck (Fig. 334).

Some of the deepest longitudinal fibres, on reaching the neck of the femur, turn upwards upon the neck towards the articular margin; these reflected fibres form bundles, best marked on the upper and lower surfaces of the neck, called *retinacula* or cervical ligaments (Fig. 337).

The main longitudinal fibres of the capsular ligament are massed to form certain thickened bands developed to resist particular stresses to which the capsule is subjected. These bands are specially named after the regions of the acetabulum (iliac, pubic, and ischial) from which they arise—the ilio-femoral, pubo-femoral, and ischio-femoral ligaments.

The **ilio-femoral ligament**, of great strength and considerable thickness, is a triangular band attached proximally by its apex to the lower part of the anterior inferior iliac spine and adjoining part of the acetabular rim, and distally by its base to the trochanteric line. It occupies all the front of the capsule except at the medial side above. Usually the sides of this triangular ligament are stronger than the middle part, so that the stronger bands, diverging below from a common stem above, resemble an inverted Y (⅄). The upper or lateral of the two diverging

bands is attached distally to a special tubercle on the front of the greater trochanter at the upper end of the trochanteric line (Fig. 336).

In full extension of the hip joint the ilio-femoral ligament becomes taut. It therefore resists the strain put upon the anterior part of the capsular ligament in the standing position, when the incidence of body-weight tends to roll the pelvis backwards on the femoral heads.

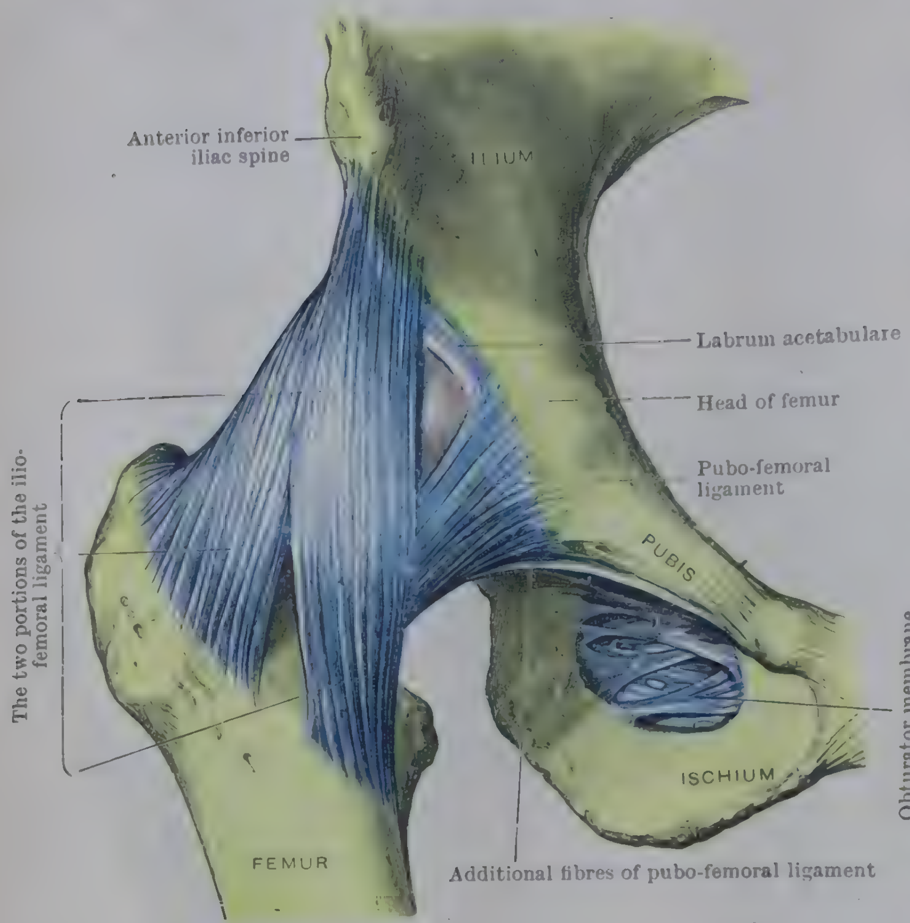

Fig. 336.—Dissection of Hip Joint from the Front.

The **pubo-femoral ligament** arises from the pubic part of the acetabular rim, with additional fibres from the superior pubic ramus overhanging the obturator groove (Fig. 336), and it loses itself distally in the general capsular ligament. Some fibres, however, reach the under part of the femoral neck. This ligament, like the ilio-femoral, becomes taut in extension of the joint and it also helps the adductor muscles in checking excessive abduction of the thigh.

The **ischio-femoral ligament**, less well defined than the others, springs from the ischial wall of the acetabulum on the hinder and lower aspect of the joint (Fig. 334). The upper fibres pass out horizontally across the back of the joint, the lower ones ascend spirally; and both sets of fibres, converging on the upper and lateral part of the femoral neck, are attached to the neck, medial to the root of the greater trochanter, close behind the upper band of the ilio-femoral ligament. The general spiral course of the ischio-femoral ligament upwards and laterally across the back of the joint causes the ligament to be most tense in the position of extension.

Ligament of Head of Femur.—In the hip joint there is also an intra-articular ligament of flattened triangular shape, known as the **ligament of the head of the femur** (Fig. 337). Its base is attached within the joint to the deep border of the transverse ligament and to the margins of the acetabular notch, especially the lower or ischial margin. It then narrows to its apical attachment in the upper part of the pit on the head of the femur. Between these attachments the ligament runs free within the joint-cavity, surrounded by a synovial sheath. It passes round the head of the femur between it and the non-articular part of the acetabular floor (Fig. 337).

The ligament of the head of the femur varies in size, and in rare cases it is absent. Its function is uncertain. It is stretched when the flexed thigh is adducted or rotated laterally, but in many cases it is too weak to have any definite ligamentous action. No appreciable disability results from its rupture or absence. Morphologically, it has been reckoned a relic of the avian *ambiens* muscle or a detached portion of the pectineus. A more feasible ontogenetic explanation of its appearance in Man is that it represents a part of the capsule as first developed which is subsequently included within the joint by the wing-like extension of the femoral head round each side of its femoral attachment and by the increasing size of the ischial contribution to the acetabulum. These developmental changes are associated with provision for increased

rotation in the human joint, which is much specialised in comparison with the simple hinge-like type of joint in lower vertebrates.

A small artery is always found within its substance; this vessel takes little, if any, part in the blood-supply of the femoral head in children, though in adults it may supplement the supply derived from the vessels within the retinacula (*vide infra* and Tucker, 1949).

Synovial Membrane.—The synovial membrane of the hip joint lines the capsular ligament and covers the labrum acetabulare. At the acetabular notch it passes over the inner face of the transverse ligament to cover the fatty tissue in the non-articular part of the acetabulum, and extends as a funnel-shaped sheath upon the ligament of the head of the femur to the edge of the pit on the femoral head. Distally, at the femoral attachment of the capsular ligament, the synovial membrane is reflected upwards on the neck of the femur as far as the edge of the articular cartilage on the head. The retinacula raise this reflected part into prominent folds (Fig. 337), within which blood-vessels run upwards to the head of the bone. At the back of the joint a fold of synovial membrane may protrude beneath the lateral border of the capsular ligament, which is here composed mainly of fibres passing circularly round the femoral neck; the few longitudinal fibres that reach the back of the neck afford some slight support to this synovial protrusion.

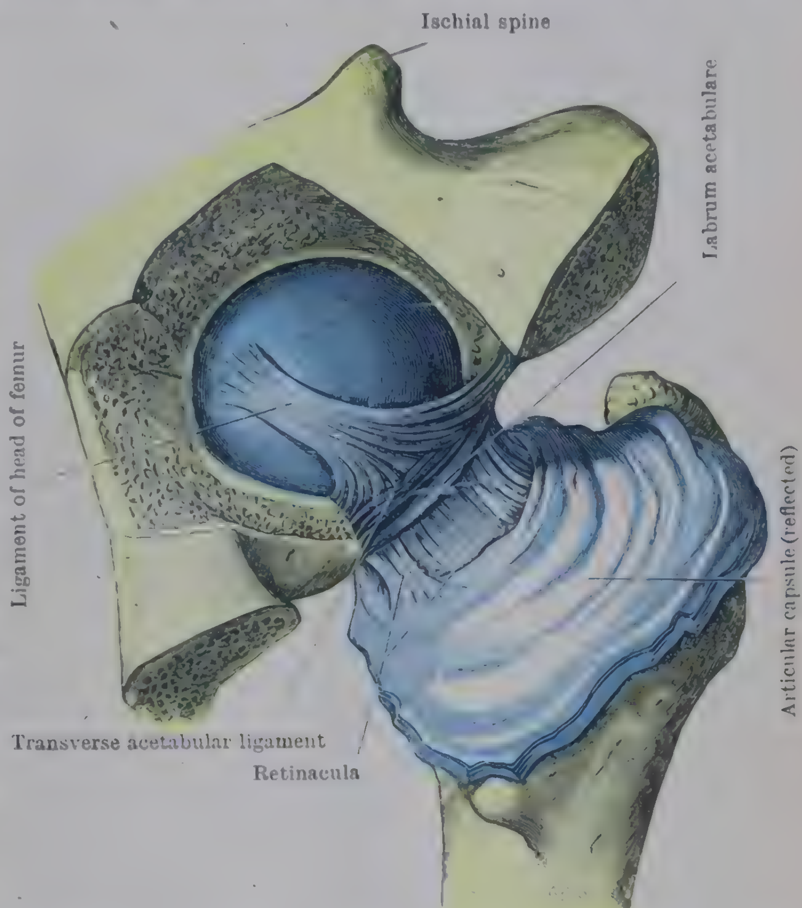

FIG. 337.—DISSECTION OF RIGHT HIP JOINT FROM PELVIC SIDE. The bottom of the acetabulum has been removed, and the capsule of the joint thrown laterally towards the trochanters.

In this joint, where the tense ligaments are, in places, closely applied to the femoral head, the synovial lining is not recognizable as a definite membrane in areas under constant pressure, as on the deep surface of the front of the capsule. The excursion of articular cartilage on to the front of the neck of the femur, already referred to, is probably a reaction to the pressure of the overlying ilio-femoral ligament.

There may be one extra-articular extension of the synovial membrane: the psoas tendon passes over a thin portion of the capsule between the upper ends of the ilio-femoral and pubo-femoral ligaments, with a small bursa intervening; sometimes there is an opening in the capsular ligament under the tendon, and the bursa is then continuous with the synovial membrane of the joint.

Nerve-Supply.—The hip joint is supplied (1) from the lumbar plexus by twigs from the **femoral** and **obturator nerves**, and (2) from the sacral plexus by twigs from the **superior gluteal nerve** and the **nerve to the quadratus femoris muscle** (see Gardner, 1948 *b*).

Movements at the Hip Joint

The movements are those typical of a ball-and-socket joint. They can be analysed as: (1) **flexion** and **extension** around a transverse axis; (2) **abduction** and **adduction** around an antero-posterior axis; (3) **medial** and **lateral rotation** around a vertical axis;

with movements compounded of these around intermediate axes. In the movement of **circumduction**, the limb swings round the side of a cone the apex of which is in the hip joint. All axes intersect at the centre of the head of the femur.

Flexion is limited by the tension of the hamstring muscles when the knee joint is extended; but these muscles are relaxed when the knee is bent, and the thigh can then be brought against the anterior abdominal wall. All parts of the capsular ligament are relaxed in flexion, and dislocation is therefore most liable to occur then. Extension takes place very little beyond the vertical position with the limb in line with the trunk. The limitation of extension is in part due to the tension of the ligaments and in part to the form of the articular surfaces. The head of the femur is not truly spherical but has an ellipsoidal form that is only fully congruent with the acetabulum in the position of complete extension. In bringing the limb into full extension from the position of flexion the capsular ligament becomes increasingly tense and draws the head of the femur more and more tightly against the acetabulum. When the femur has passed about 15° behind the vertical, the articular surfaces of femur and acetabulum are fully congruent, the capsular ligament is taut and no further extension of the joint can take place—the joint is then said to be 'locked' (Walmsley, T., 1928). During this 'screwing home' of the head of the femur, part of the pad of fat in the acetabular fossa is displaced from the fossa and passes outwards between the transverse ligament and the acetabular notch, but when the limb is again flexed the fat is drawn into the acetabulum to help to occupy the potential space that is created by the lateral movement of the head of the femur. A perpendicular line through the centre of gravity of the trunk falls behind a line joining the centres of the femoral heads; hence, in the erect position the pelvis, bearing the trunk, tends to roll backwards on the femora, but is prevented from so doing by the 'locking' that occurs at the hip joints. The 'locked' position is the one in which the body weight is normally borne by the limbs, and it is maintained with the minimum of muscular effort. Abduction is limited by tension of the adductor muscles and the pubo-femoral ligament; adduction, by tension of the abductors and the lateral part of the ilio-femoral ligament. Rotation is termed medial or lateral according to the direction in which the toes are turned; it is rather more free when combined with flexion than in the extended position of the hip. Medial rotation is limited by tension of the lateral rotator muscles and the ischio-femoral ligament; lateral rotation, by the medial rotators and the ilio-femoral ligament. A small amount of rotation at the hip joint occurs automatically in association with the termination of extension and the commencement of flexion at the knee joint (see p. 387).

The difference between average mobility and the extreme mobility possessed by trained contortionists is nowhere more marked than at the hip joint. The greater limitation of movement in the ordinary person is probably largely due to muscle shortening. The final limitation imposed by the impact of the femoral neck on the rim of the acetabulum does not arise in the ordinary use of the joint.

KNEE JOINT

The **knee joint** is the largest joint in the body, and is structurally the most complicated. It is, in the main, a hinge-joint; but, even as such, it is modified in some ways, and, in addition, it is capable of rotation. The human knee joint must possess great stability, especially in extension, and it must at the same time permit full freedom of movement. In the mechanism of joints in general, stability and mobility are to some extent incompatible qualities, and most joints secure one of these at the expense of the other. At the knee joint both are secured to a remarkable degree by such an alliance of muscle and ligament in controlling the joint as prevails nowhere else. Here, to a large extent, the muscles *are* the ligaments.

Articular Surfaces.—Functionally, as well as phylogenetically, the knee joint is compounded of three articulations—an intermediate one between the patella and the patellar surface of the femur, and lateral and medial articulations between the femoral and tibial condyles.

The **articular surface of the femur** comprises: the *condylar areas*, which are opposed to the tibia and are separated behind by the intercondylar notch; and the *patellar surface*, which unites the condyles in front and is opposed to the patella. Each condylar surface is delimited from the patellar surface by a shallow groove on the articular cartilage. On the lateral condyle this groove is almost transverse and is emphasized at each end. On the medial condyle the groove begins farther for-

ward medially, and, passing obliquely backwards across the condyle, disappears before reaching the lateral edge, where a narrow crescentic facet is marked off which engages with the patella in acute flexion. The axis of the medial condylar surface turns laterally in its anterior part; the whole surface is made up of a posterior part which lies parallel to the lateral condylar surface and is equal to it in extent, and an additional wedge-shaped part in front, where the axis turns laterally, which has no corresponding part on the lateral condyle. Each condylar surface is convex from side to side and from before backwards, the antero-posterior curve being much flatter in front than behind. The patellar surface is grooved vertically between two prominent borders—the lateral the more salient (Fig. 338).

The **articular surface of the patella** is broadly oval, and it is divided into a

FIG. 338.—DISSECTION OF RIGHT KNEE JOINT FROM THE FRONT: PATELLA THROWN DOWN.

larger lateral area and a smaller medial area by a rounded vertical ridge apparent even on the macerated bone. The cartilaginous covering reveals a further subdivision of the surface: on each side of the vertical ridge two faint transverse ridges separate three facets paired with the facets on the other side, and another faint vertical ridge delimits a medial perpendicular facet adjoining the medial border of the articular surface. In acute flexion the medial facet rests on the crescentic facet on the medial femoral condyle; the other facets engage in succession from above downwards with the patellar surface of the femur as the joint moves towards full extension. Owing to the angulation of the femur on the tibia the patella tends to be displaced laterally during forced extension of the knee joint, as in rising from a chair. This is prevented by the prominent lateral patellar surface of the femur and by the action of the lower part of the vastus medialis muscle which is inserted into the medial border of the patella.

The **articular surfaces of the tibia** are the cartilage-covered areas on the upper surface of each tibial condyle. These areas are separated by a non-articular intercondylar area formed by the intercondylar eminence in the middle, and rough, triangular depressions in front and behind. The medial articular area is oval and concave. The lateral area, smaller and more circular, is concave from side to side and concavo-convex from before backwards; posteriorly it is prolonged downwards

over the back of the condyle in relation to the popliteus tendon (Fig. 340). A peripheral flattened strip on each condyle underlies a semilunar fibro-cartilage. The tibial articular surfaces are far from congruent with the femoral condyles, which rest upon them; but the effect of this incongruence is lessened by the interposition of the semilunar cartilages.

Articular Capsule.—The capsule of the joint is a complicated structure. There is no complete, independent capsular ligament uniting the bones. Instead, the joint is surrounded by a thick ligamentous formation constructed chiefly of muscle tendons or expansions from them; only here and there is it composed of true capsular fibres running between the articulating bones. Inside the capsule, the synovial lining of the joint is in places separated from the ligamentous stratum by wide intervals occupied by fatty pads or special intra-articular structures.

At the **front of the joint** this ligamentous formation is built up mainly of the fused tendons of insertion of the rectus femoris and vasti muscles. These descend on the patella from above and from each side to a marginal insertion around the upper half of the bone. Superficial tendinous fibres are continued downwards over the front of the bone into the **ligamentum patellæ**. This thick band securely anchors the patella to the tibia, and is in reality the distal part of the quadriceps insertion; it is attached to the apex and the posterior surface of the patella below the articular area, and to the tubercle of the tibia. Other thinner bands pass down from the sides of the patella, diverging slightly, to the front of each tibial condyle; these constitute the **medial** and **lateral patellar retinacula**. Tendinous fibres of the vasti muscles pass obliquely downwards across the patella into the retinaculum of the other side. Other deeper fibres from each side of the patella pass across to the anterior part of each femoral epicondyle.

Superficial to all these bands there are strong expansions of the fascia lata. The ilio-tibial tract descends across the antero-lateral aspect of the joint to be inserted into the lateral tibial condyle. A strong band diverges anteriorly from this tract to be attached to the upper part of the lateral edge of the patella, forming a *superior patellar retinaculum*. Less definite fascial expansions sweep down over the patella, and on each side of it, towards the upper part of the tibia; some fibres form U-shaped loops in front of the ligamentum patellæ.

The whole of this anterior covering of the knee joint, with the patella inset on its deep aspect, is kept tense by the tone of the extensor muscles, and is tightly braced up when these muscles contract in extension. In the ordinary type of hinge-joint the extensor portion of the capsule must be loose in the extended position to permit the possibility of flexion. But at the knee this part of the capsule is, as it were, continued into muscle above, instead of being attached directly to the proximal bone, and can be kept taut in all positions.

The **back of the joint** is covered over by a ligamentous feltwork of intersecting bands which form a **posterior ligament**. True *capsular fibres* descend over the upper part of the joint from a femoral attachment along the base of the popliteal surface and invest the back of each condyle with a thin covering overlain by the corresponding head of the gastrocnemius, which in part arises from it. Distally, other capsular fibres ascend from the posterior border of the proximal end of the tibia, leaving an opening laterally for the escaping popliteus tendon. The stronger central portion of the posterior ligament is formed by a well-marked expansion from the semimembranosus tendon which turns obliquely upwards and laterally to blend with the general capsular fibres over the lateral condyle of the femur. This expansion is called the **oblique posterior ligament**. The lower lateral part of the back of the joint is strengthened by the **arcuate ligament of the knee**, which springs from the back of the head of the fibula, arches upwards and medially over the popliteus tendon as it emerges from the joint, and spreads out on the back of the capsule. Sometimes the most lateral fibres of the arcuate ligament are specially developed as a separate band that runs from the head of the fibula to the back of the lateral femoral condyle (Fig. 339).

At the **sides of the joint** there are true capsular fibres which descend from the sides of the femoral condyles to the sides of the tibial condyles. They blend posteriorly with the ligamentous feltwork, and anteriorly with the various

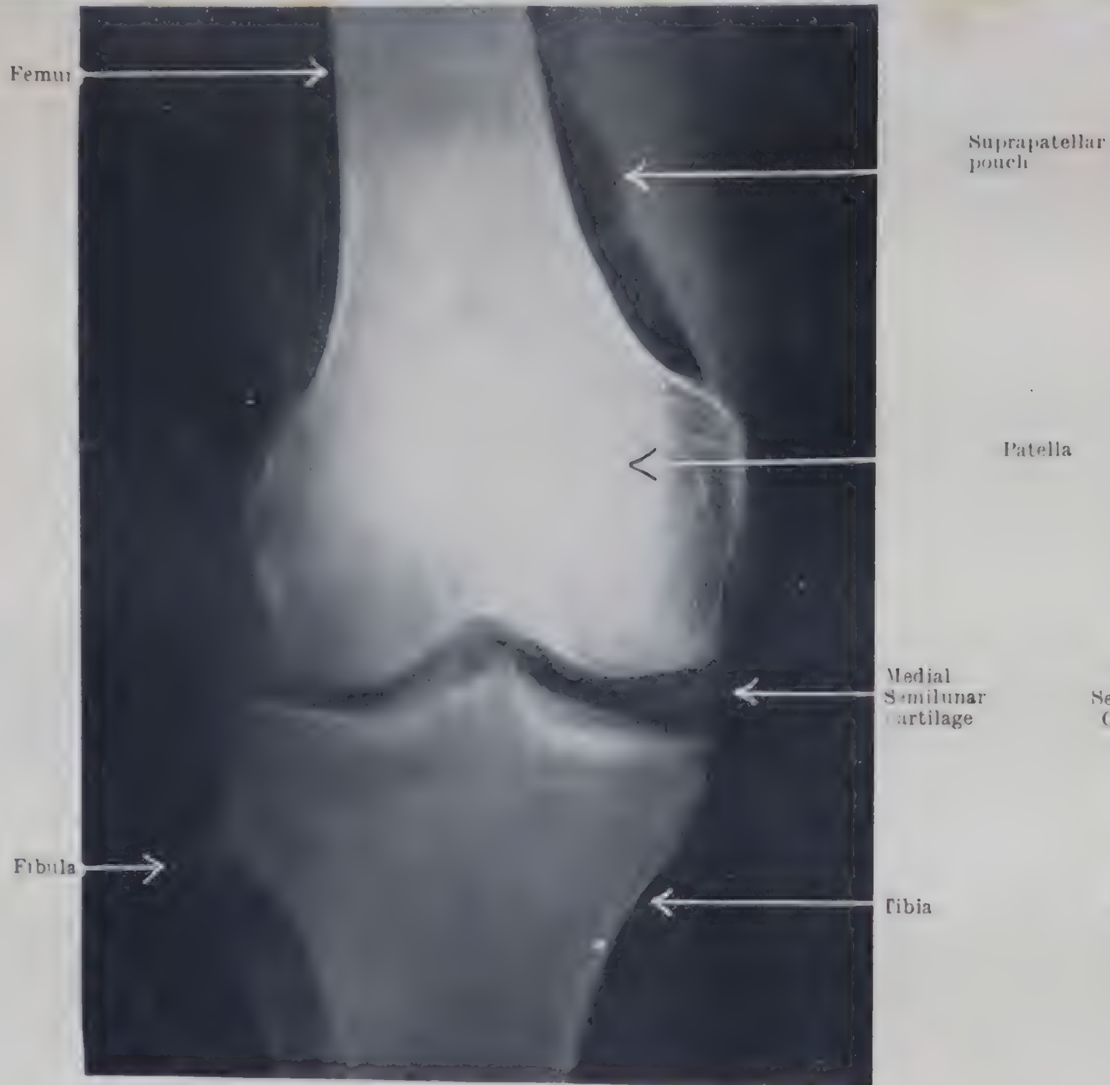

Fig. 1.—Anterior view to show the shadows of the Medial Semilunar Cartilage and the Articular Cartilage on the Medial Femoral Condyle.

Fig. 2.—Oblique Anterior view to show the shadow of the Lateral Semilunar Cartilage.

Plate XXXV. Radiographs of Adult Right Knees after injection of Air into the Cavity.

Note the extension of the air into the suprapatellar pouch.

[Facing p. 382]

PLATE XXXVI

Fig. 1.—Radiograph of Right Foot in Position of Full Inversion.

See inset, and note the movement at the transverse tarsal joint (p. 397 and Plate XXVII, p. 320).

Fig. 2.—Radiograph of Right Foot of Subject standing with Muscles Contracted. (See Fig. 472, footprint 2 and contrast with footprints 1 and 3.)

Fig. 3.—Radiograph of Right Foot of Subject standing with Muscles Relaxed as fully as possible. (For footprint see Fig. 472, 3, p. 547.)

[Facing

tendinous expansions already described. Here are found the special *medial* and *lateral ligaments* characteristic of hinge-joints, but the ligaments of the two sides differ greatly in form and relations.

The **medial ligament** is a broad, flat band in the true capsular plane. Its upper end has an extensive attachment on the medial epicondyle of the femur; some fibres may be traced upwards into the adductor magnus tendon, and the ligament has been regarded as formed, in part at least, from an original tibial

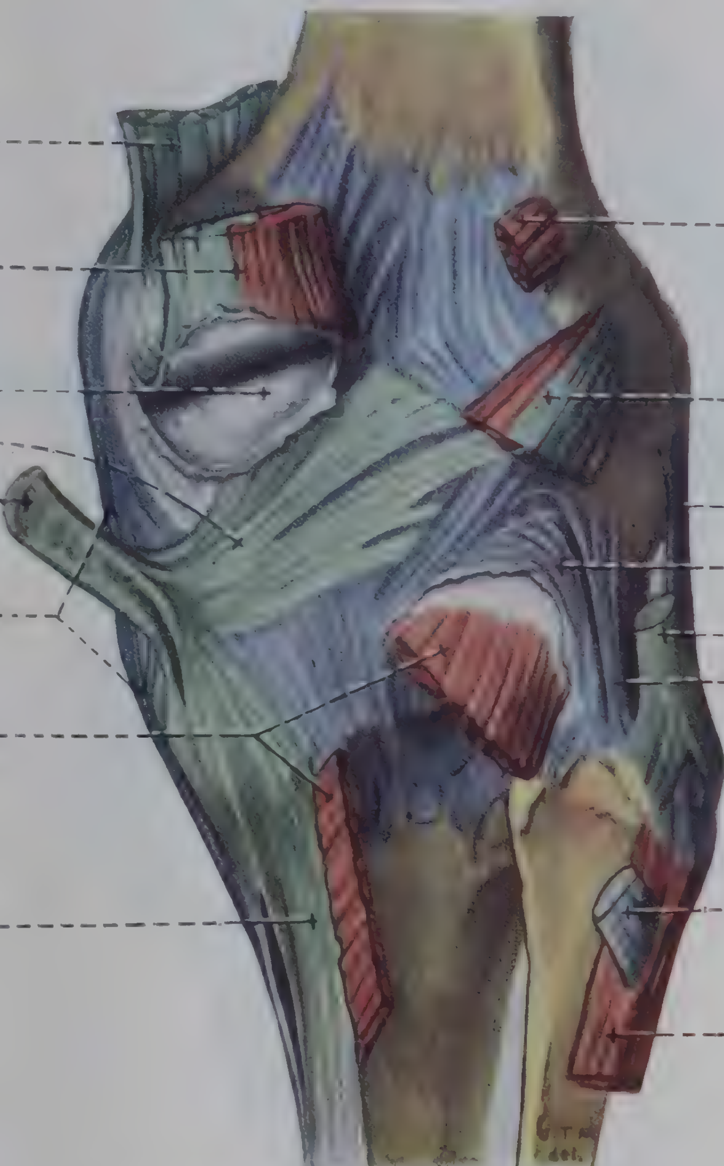

FIG. 339.—RIGHT KNEE JOINT FROM BEHIND.

In the specimen the lateral part of the *arcuate ligament* was present as a separate band; and the continuity between the lateral ligament of the knee and the peroneus longus muscle was specially well marked.

insertion of this muscle. The ligament passes downwards and slightly forwards and is attached at its lower end to the medial surface of the tibia: the superficial fibres descend to below the level of the tibial tubercle; deeper fibres have a shorter course from femur to tibia, the deepest of all having an intermediate attachment to the medial semilunar cartilage. Posterior to the upper part of the main band, shorter fibres reach the edge of the tibial condyle immediately above the principal insertion of the semimembranosus tendon. A downward expansion from this tendon reaches the shaft of the tibia, partly under cover of the posterior border of the main band (the medial inferior genicular vessels and nerve running forwards between them) and partly blending with this border of the ligament.

The **lateral ligament** (Figs. 338, 339), round and cord-like, stands altogether clear of the capsular ligament, and is wrapped round by an expansion of the

fascia lata. It is attached above to the lateral epicondyle of the femur; below, it reaches the head of the fibula in front of its highest point, splitting the tendon of the biceps as it does so. As in the specimen drawn in Fig. 339, the ligament is sometimes partly continued into the upper end of the peroneus longus muscle, and may be regarded as a stranded femoral tendon of this muscle.

On the lateral side of the joint the true capsular fibres are short and weak; they bridge the interval between the femoral and tibial condyles, and some of them

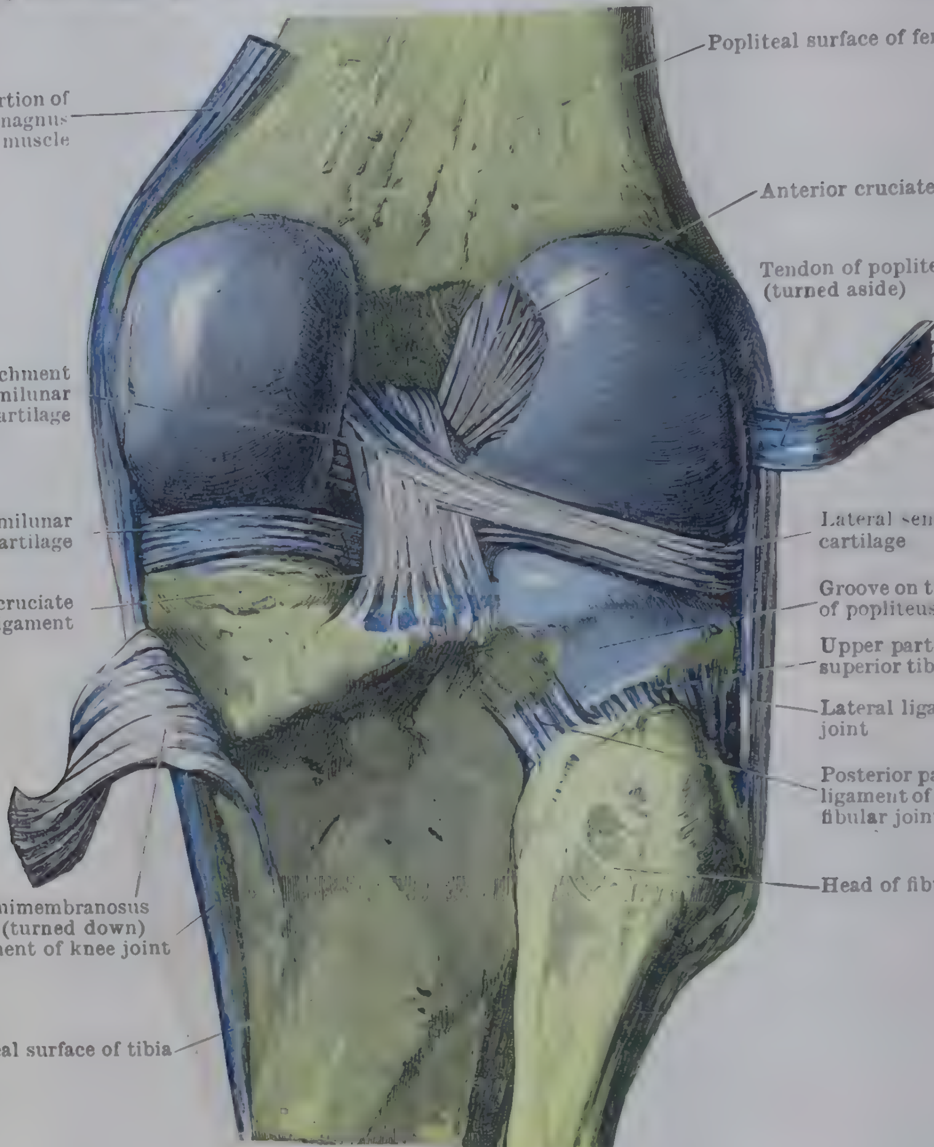

FIG. 340.—RIGHT KNEE JOINT OPENED FROM BEHIND BY REMOVAL OF THE POSTERIOR LIGAMENT.

are separated from the lateral semilunar cartilage by the popliteus tendon. There is a distinct interval between these capsular fibres and the lateral ligament: through the interval the lateral inferior genicular vessels and nerve run forwards.

The medial and lateral ligaments prevent disruption of the joint at the sides. They are most tightly stretched in extension, and then their direction—the fibular ligament downwards and backwards, the tibial downwards and forwards—is such as to prevent rotation of the tibia laterally or of the femur medially.

Intra-Articular Ligaments (Figs. 338, 340, 341).—In addition to the capsular ligamentous formation, there are two intra-articular ligaments that stretch between the tibia and femur. These are the **cruciate ligaments**—strong, rounded bands named from the way in which they cross each other between their attachments, and distinguished as **anterior** and **posterior** from their relative positions on the tibia, from which they ascend to the sides of the intercondylar notch of the femur. The **anterior cruciate ligament** extends obliquely upwards and backwards from the rough, non-articular area in front of the intercondylar eminence of the tibia to the back part of the medial side of the lateral femoral condyle. The **posterior cruciate ligament** passes upwards and forwards on the medial side of the other; it extends

from the sloping, non-articular surface behind the eminence to the lateral side of the medial condyle. The attachments of the cruciate ligaments are such that the anterior cruciate prevents posterior displacement of the femur on the tibia and the posterior ligament prevents anterior displacement. In flexion the ligaments are less taut than in extension and they then allow a small amount of passive antero-posterior movement of the tibia on the femur if the thigh is fixed and the leg is forcibly moved. Furthermore, the ligaments become taut when the flexed leg is rotated medially and they become less taut when the leg is rotated laterally and the ligaments tend to become uncrossed.

Semilunar Cartilages (Figs. 338, 340, 341).—Two **semilunar cartilages** also are found within the joint, interposed between the femoral and tibial condyles, and help to compensate for their incongruence. The name is rather misleading because they are formed almost entirely of fibrous tissues with relatively few cartilage cells interspersed. Each is a flattened pad of crescentic form (hence the name "meniscus" formerly used) and is wedge-shaped in cross-section, with the edge of the wedge at the concave border.

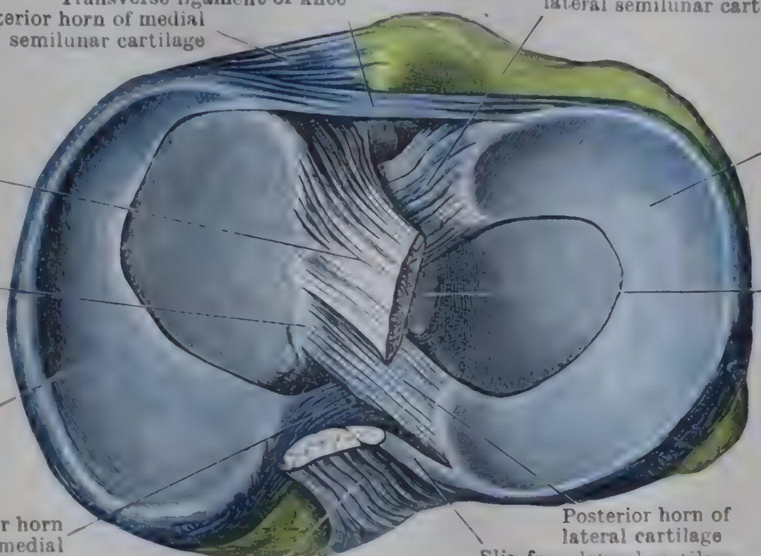

FIG. 341.—UPPER END OF TIBIA WITH SEMILUNAR CARTILAGES AND ATTACHED PORTIONS OF CRUCIATE LIGAMENTS.

The thick, convex border of each cartilage is bound down to the peripheral margin of the tibial condyle by short ligamentous fibres, and is also fused to the deep surface of the capsular ligament. This means that the **medial cartilage** is much more firmly anchored, for through its capsular attachment it is fixed to the medial ligament of the knee, whereas the **lateral cartilage** is attached only to the weak fibres which represent the capsular ligament on the lateral side of the joint and not at all to the lateral ligament of the joint. At one point—where it is crossed by the popliteus tendon—the peripheral edge of the lateral cartilage is quite free from capsular attachment.

The extremities of each cartilage are prolonged into fibrous horns which are firmly attached to the intercondylar area on the top of the tibia (Fig. 341). The *anterior horn* of the **medial semilunar cartilage** is fixed to the fore-part of this area in front of the anterior cruciate ligament; its *posterior horn* is fixed towards the back, between the posterior cruciate ligament and the posterior horn of the lateral cartilage. The *two horns* of the **lateral semilunar cartilage** are attached close together, in front of and behind the intercondylar eminence, so that this cartilage comes much nearer to completing a circle than the other one does.

The anterior parts of the two cartilages are joined by a variable fibrous band called the **transverse ligament** of the knee (Figs. 338, 341). The posterior horn of the lateral cartilage gives off a ligamentous slip which joins the posterior cruciate ligament (Figs. 340, 341); this slip may split into two, one part joining the back of the cruciate ligament and the other joining the front.

The connexion between the lateral cartilage and the posterior cruciate ligament recalls the typical lower mammalian condition where the lateral semilunar cartilage is attached posteriorly not to the tibia but to the medial femoral condyle behind the posterior cruciate ligament.

Synovial Membrane.—The synovial cavity of the knee joint is very extensive. The central part lies between the patella in front and the femur (patellar surface) and cruciate ligaments behind, and passes laterally and medially between the femoral and tibial condyles, where the cavity is partially divided into upper and lower compartments by the semilunar cartilages. In the anterior wall of this central part the synovial membrane passes from the edges of the articular surface of the patella in all directions on the deep aspect of the anterior wall of the joint. Below the patella, the membrane is carried towards the tibia over a mass of fatty, fibrous tissue, called the **infrapatellar pad of fat**, which fills up the angle between the deep surface of the patellar ligament and the front of the tibia above the tubercle. From the synovial surface of this pad a vertical, crescentic fold of

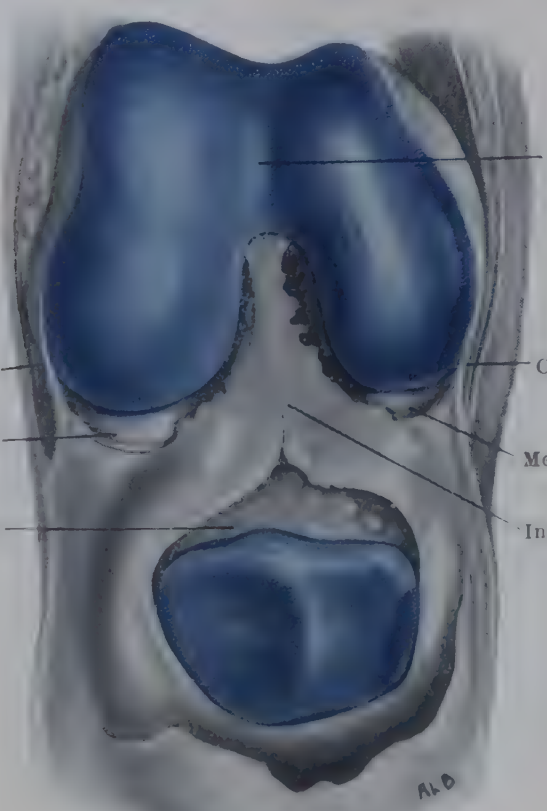

FIG. 342.—RIGHT KNEE JOINT OPENED FROM THE FRONT TO SHOW THE INFRAPATELLAR AND ALAR SYNOVIAL FOLDS.

The joint is flexed to a right angle and the patella turned down (cf. Fig. 338). Articular cartilage, *blue*.

synovial membrane, called the **infrapatellar fold**, runs towards the cruciate ligaments. Similar folds, called the **alar folds**, run horizontally across the fatty pad, one from each side of the vertical fold (Fig. 342). These synovial folds are vestiges of the original partitions that separated the three components of the cavity of the knee joint

Three recesses open off the central part of the cavity. One is median, and is called the **suprapatellar synovial pouch**. It lies above the level of the patella between the quadriceps muscle and the lower part of the shaft of the femur; it develops as a bursa separate from the joint, with which it eventually communicates. The articularis genu muscle, composed of fleshy slips that arise from the femur above the pouch, is inserted into its wall and draws it upwards in extension of the joint. The other recesses lie one behind the posterior part of each femoral condyle; in this situation the capsular ligament is overlain by the gastrocnemius muscle, and there is usually a bursa between the muscle and the ligament, especially on the medial side (Fig. 339), where the bursa sometimes communicates with the joint-cavity through an opening in the capsule. These posterior recesses are separated from each other by a thick, median septum which

projects into the joint-cavity from behind and is formed by the cruciate ligaments carrying forward a broad, vertical fold of synovial membrane which clothes them in front and at the sides.

The **synovial relations of the popliteus tendon** are important. As the tendon passes backwards from its origin deep to the lateral part of the capsular ligament, the synovial membrane is wrapped round its medial side, separating it from the edge of the lateral semilunar cartilage. When the tendon leaves the joint through the opening in the posterior part of the capsule, a *synovial pouch* is carried down on its deep surface across the back of the superior tibio-fibular joint. In some cases the cavity of this joint communicates with the bursa-like pouch which accompanies the tendon, and therefore also with the cavity of the knee joint.

Additional Bursæ.—In addition to the bursæ mentioned, numerous others are found in the vicinity of the knee joint. The more constant of these others are: the *subcutaneous prepatellar bursa*, under the skin over the lower part of the patella; the *subfascial prepatellar bursa*, between the fascial and tendinous expansions in front of the patella; the *subtendinous prepatellar bursa*, between the superficial and deep layers of the tendinous fibres that cross the patella; the *deep infrapatellar bursa*, between the upper part of the tibia and the lower part of the ligamentum patellæ, separated from the knee joint by the infrapatellar pad of fat; a bursa between the medial ligament of the knee and the overlying tendons of the sartorius, gracilis and semitendinosus; bursæ between the semimembranosus tendon and the medial ligament of the knee and between that tendon and the medial head of the gastrocnemius; and a bursa between the biceps tendon and the lateral ligament of the knee.

Nerve-Supply.—The knee joint is supplied by several branches from the **femoral** nerve and from both divisions—**medial** and **lateral popliteal**—of the sciatic nerve, and by a filament from the **obturator** nerve (see Gardner, 1948 *a*).

Movements at the Knee Joint

These are primarily **flexion** and **extension** around a transverse axis as in an ordinary hinge-joint, but with these differences: that the axis changes its position during movement owing to the different curvature of different parts of the femoral condyles, and that the end of extension or beginning of flexion is accompanied by a special **rotatory movement**. (For details of the mechanism of the knee joint, consult Goodsir, 1858.)

In voluntary flexion the leg may be moved through 130° or more from the position of full extension, but this may be increased by forced movement or by the adoption of the squatting position. In full flexion the posterior surfaces of the femoral condyles articulate with the posterior part of the articular surface of the tibia and the corresponding parts of the semilunar cartilages, but, as the joint passes from flexion to extension, if the tibia is fixed as in rising from a chair with the feet planted on the floor, the femoral condyles roll and glide forwards upon the tibia. The curvatures of the femoral condyles become progressively less as they are traced forwards and they therefore have an increasingly greater contact with the tibia as the femur passes into full extension, and for the same reason the curvatures of the semilunar cartilages tend to be opened. Just before full extension is reached, the tibial surface of the lateral femoral condyle is almost exhausted, although the anterior, oblique part of the surface on the medial condyle has still to be brought into play. While the lateral condyle completes its forward roll, the medial condyle rolls forward equally but at the same time glides backwards—until the oblique part in front is exhausted—in a horizontal arc centred in the lateral condyle, which is therefore twisted vertically and a medial rotation of the femur results. This terminal rotatory movement tightens the medial and lateral ligaments of the knee and the joint is then, as it were, 'screwed home'. In the fully extended position the other ligaments of the knee joint, most notably the posterior oblique, are also taut, and as the articular surfaces of the femur and tibia are then in maximal contact, the joint is said to be 'locked'. Before flexion can take place the rotatory movement must be undone, and this is accomplished by the action of the popliteus muscle. At the end of extension, before the terminal rotation takes place the anterior cruciate ligament is at its tightest; the rotation lessens its tension sufficiently to prevent it checking the initial opposite (*i.e.*, lateral) rotation of the femur at the beginning of flexion. These rotations of the femur on the tibia occur when the tibia is fixed during the movement at the knee. But if, as in the extension movement of kicking, the tibia as well as the femur is free to rotate, the rotation may be partly of the tibia on the femur—laterally at the end of extension, medially at the beginning of flexion.

When the body is erect, the axis of gravity of the body falls in front of a line between

the knee joints; gravity therefore tends to produce a 'locking' at the knee joint. When standing in the natural upright position, however, the knee joint is not usually 'locked' but is maintained in a position a little short of full extension. In such a position the quadriceps muscle is relaxed and the patella can be moved freely from side to side on the femur. The hamstring and gastrocnemius muscles, on the other hand, are in such a degree of contraction as just to maintain the joint in this position against the action of gravity. In reaching forwards, however, the knee joint often becomes fully extended and 'locked', and in this position also the quadriceps is relaxed.

The relation of the patella to the femur during flexion-extension movement has already been mentioned (p. 381).

In addition to the hinge movements of flexion and extension, some **rotation** of the leg around a vertical axis can take place except when the joint is fully extended. In full extension, apart from the special, small rotatory movements already described, all rotation is prevented by the tension of the medial and lateral and cruciate ligaments. Rotation is most free when the knee is flexed to about a right angle; for neither cruciate ligament is then very tight and the tension of the medial and lateral ligaments, slightly reduced by the special rotatory movement at the beginning of flexion, is further lessened during flexion by descent of their femoral attachments.

The **semilunar cartilages**, as already explained, compensate for the incongruity of the opposed femoral and tibial surfaces and, by slight movement, accommodate themselves to the differently shaped parts of the femoral condyles that rest upon them in different positions of the joint. They shift slightly forwards in extension and open out their curve under the 'flatter' anterior parts of the condyles then opposed to them. In flexion they shift backwards and curl in upon the more rounded posterior parts of the femoral condyles. The attachment of the medial cartilage to the medial ligament causes this cartilage to be drawn medially when the ligament tightens in extension. In a sudden, unguarded movement, the cartilage may at that moment be pinned between femur and tibia before its normal opening out has occurred. The pull of the medial ligament may then split the cartilage in its long axis, producing one form of the commonest derangement of the knee joint—torn medial semilunar cartilage.

According to MacConaill (1932) the semilunar cartilages play an important part in relation to efficient lubrication in the joint. No easy movement can take place between the congruent surfaces of a bearing unless they are separated by a layer of viscous fluid, which must maintain a wedge-shaped space between them; as the surfaces roll over one another they squeeze out in advance of their approximation a diminishing wedge of lubricating fluid. The necessity for this 'wedge' of lubricant is greater where, as in the knee joint, there is a considerable thrust transmitted from one joint-surface to the other, and here the interposed fibro-cartilages separate the intervening synovial fluid into two 'wedges', thereby increasing the efficiency of the mechanism. The slight mobility of the fibro-cartilages permits them to assume the proper angulation to the joint-surfaces necessary for the maintenance of the wedge-shaped synovial films.

TIBIO-FIBULAR JOINTS

The fibula is closely bound to the tibia by a joint at each end; and the shafts of the two bones are connected by an interosseous membrane.

Superior Tibio-Fibular Joint (Figs. 338, 341).—This is a small synovial joint, of plane type, between a flat, circular or oval facet on the head of the fibula and a similar facet on the tibia placed postero-laterally on the under aspect of the overhanging lateral condyle. The **capsular ligament** surrounding the joint is strengthened in front and behind by fibres directed upwards and medially from the fibula to the adjoining part of the tibia.

The tendon of the popliteus muscle is intimately related to the postero-superior aspect of the joint; and the pouch of synovial membrane prolonged under the tendon from the knee joint sometimes communicates with the synovial cavity of the tibio-fibular joint through an opening in the upper part of the capsule.

Nerve-Supply.—The superior tibio-fibular joint is supplied by twigs from the **lateral popliteal nerve** and from the branch of the **medial popliteal nerve** to the popliteus muscle.

Inferior Tibio-Fibular Joint (Figs. 343, 346).—This is a fibrous joint. The rough, triangular, opposed surfaces of the bones are united by a strong **inter-**

osseous ligament. In addition, the joint is strengthened in front and behind by longer bands called the **anterior** and **posterior inferior tibio-fibular ligaments.** These bands stretch from the lower border of the tibia, in front and behind, to the back and front of the distal end of the fibula, each inclined laterally and downwards. Under cover of the posterior ligament there is a longer band, called the **transverse tibio-fibular ligament**, which is attached to the whole length of the posterior edge of the inferior surface of the tibia and to the upper end of the malleolar fossa on the fibula. This band closes the posterior angle

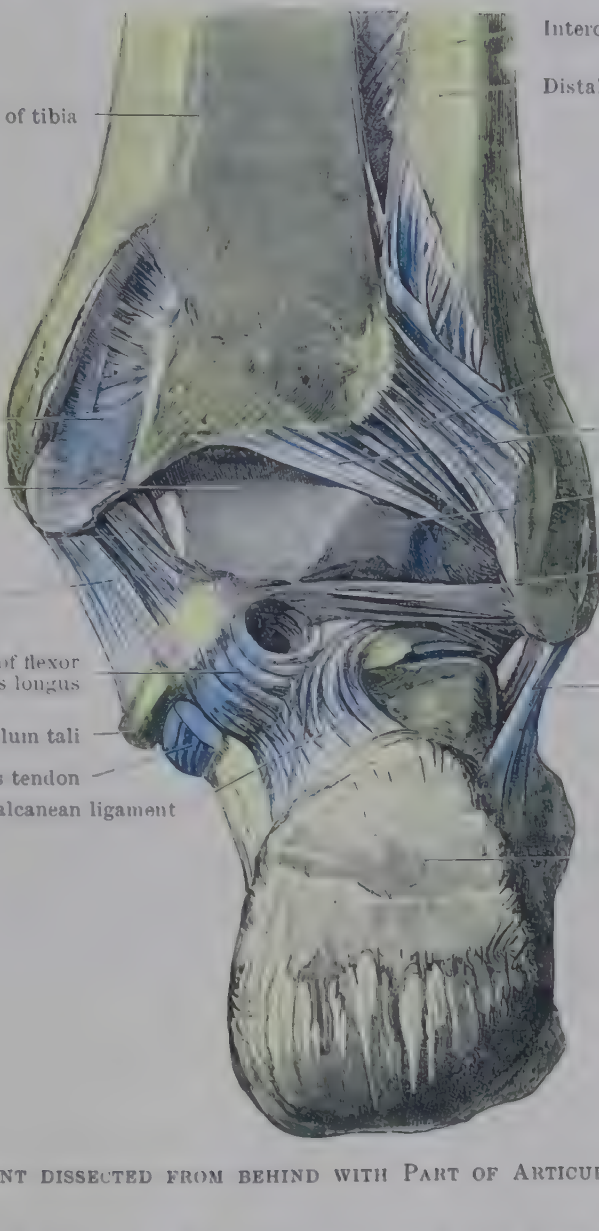

FIG. 343.—ANKLE JOINT DISSECTED FROM BEHIND WITH PART OF ARTICULAR CAPSULE REMOVED.

between the tibia and fibula and articulates with the bevelled posterior half of the lateral border of the trochlea tali (Fig. 343).

A recess of the cavity of the ankle joint usually extends upwards between the tibia and fibula for about a quarter of an inch. It is blocked above by the base of the interosseous ligament and is occupied by a fold of synovial membrane of the ankle joint. Sometimes the articular cartilage on the lower ends of the tibia and fibula extends upwards for a little way on the walls of this recess.

Nerve-Supply.—The inferior tibio-fibular joint is supplied by twigs from the **anterior** and **posterior tibial nerves.**

Interosseous Membrane.—The interosseous membrane of the leg is tightly stretched between the interosseous borders of the two bones: its fibres in great part run downwards and laterally from tibia to fibula. The membrane reaches up to the under aspect of the superior joint and downwards to blend with the upper edge of the interosseous ligament of the inferior joint. There is an

oval aperture near the upper end of the membrane through which pass the anterior tibial vessels (Fig. 338), and a smaller one at the lower end for the perforating branch of the peroneal artery (Fig. 343).

Movement at the tibio-fibular joints is slight and entirely passive. It is occasioned by changes in the ankle joint, with which it will be described (p. 392).

ANKLE JOINT

The **ankle joint** is a synovial joint of typical hinge pattern. The lower ends of the tibia and fibula provide a socket in which the upper part of the talus rocks around a transverse axis. The only special feature of the hinge is an arrangement whereby the sides of the socket come to exercise a positive 'grip' upon the moving member of the joint as an aid to increased stability.

Articular Surfaces.—The **proximal articular surface** provides the socket (Fig. 344). It is formed by the cartilage-covered areas on the lower ends of the leg bones. The roof of the socket, wider in front than behind, is the *distal surface of the tibia,* concave from before backwards and slightly convex from side to side. The medial wall is the *lateral surface of the medial malleolus,* the cartilage here being continuous with that on the roof at a rounded angle. The lateral wall is the triangular facet on the fore part of the *medial side of the lateral malleolus.* The angle between this wall and the roof corresponds to the narrow cleft between the tibia and fibula distal to the interosseous ligament between these bones; but, posteriorly, this angle is filled up by the *transverse tibio-fibular ligament.*

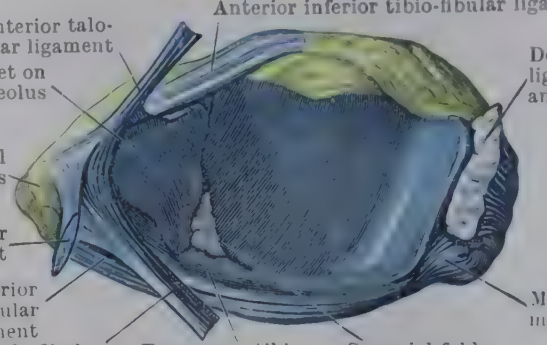

Fig. 344.—Articular Surfaces of Tibia and Fibula which are opposed to the Talus in the Ankle Joint.

The **distal articular surface** is formed entirely by the upper part of the body of the talus—the *trochlea tali*—which is shaped like the upper part of a short cylinder placed transversely. The cylinder is square-cut medially, but obliquely cut laterally, in such a way that the cylindrical surface is broader in front than behind. This surface articulates with the distal surface of the tibia—the roof of the socket—which also is broader in front. A shallow, wide antero-posterior groove on the upper trochlear surface corresponds to the convexity on the tibial surface. The cartilage on top of the trochlea is continued on to its sides—the 'ends' of the cylinder. The medial articular surface or 'end' is vertically set, and is shaped like a comma laid on its side, tail backwards: it is opposed to the medial malleolar wall of the proximal articular surface. The lateral articular area or 'end' of the trochlea is triangular, corresponding to the opposed facet on the lateral malleolus; it is obliquely set, inclining laterally below and medially behind. The angle between the upper and lateral surfaces of the trochlea is bevelled off posteriorly where it articulates with the transverse tibio-fibular ligament (Fig. 343).

Capsular Ligament.—The capsular ligament surrounds the joint. As is usual in a hinge-joint, it is weak in front and behind but is strengthened at the sides by special medial and lateral ligaments.

The **anterior** and **posterior ligaments of the ankle** are membranous and weak. They are attached proximally to the anterior and posterior borders of the lower end of the tibia, and distally to the upper surface of the talus in front of and behind the articular area.

Medial and Lateral Ligaments.—These ligaments have in common an upper attachment to the corresponding malleolus, a middle band descending to the

calcaneum, and anterior and posterior bands to the talus; the medial ligament has other parts in addition. The medial ligament is fused with the medial part of the capsule; the anterior and posterior bands of the lateral ligament are fused with the lateral part of the capsule, but the middle band is not.

In the **lateral ligament** (Figs. 343, 346) the three bands are quite distinct from one another. The middle one—the **calcaneo-fibular ligament**—runs from in front of the tip of the lateral malleolus downwards and slightly backwards to the middle of the lateral surface of the calcaneum, a little above and behind the peroneal tubercle. The **anterior talo-fibular ligament** runs from the anterior border of the lateral malleolus forwards and medially to the neck of the talus. The **posterior talo-fibular ligament** is attached to the fibula at the bottom of the malleolar fossa and passes medially and slightly backwards to the upper surface of the posterior tubercle of the talus.

The **medial ligament** (Figs. 343, 345) is made up of several bands which, however, are differentiated only by their distal attachments. They are fused in a

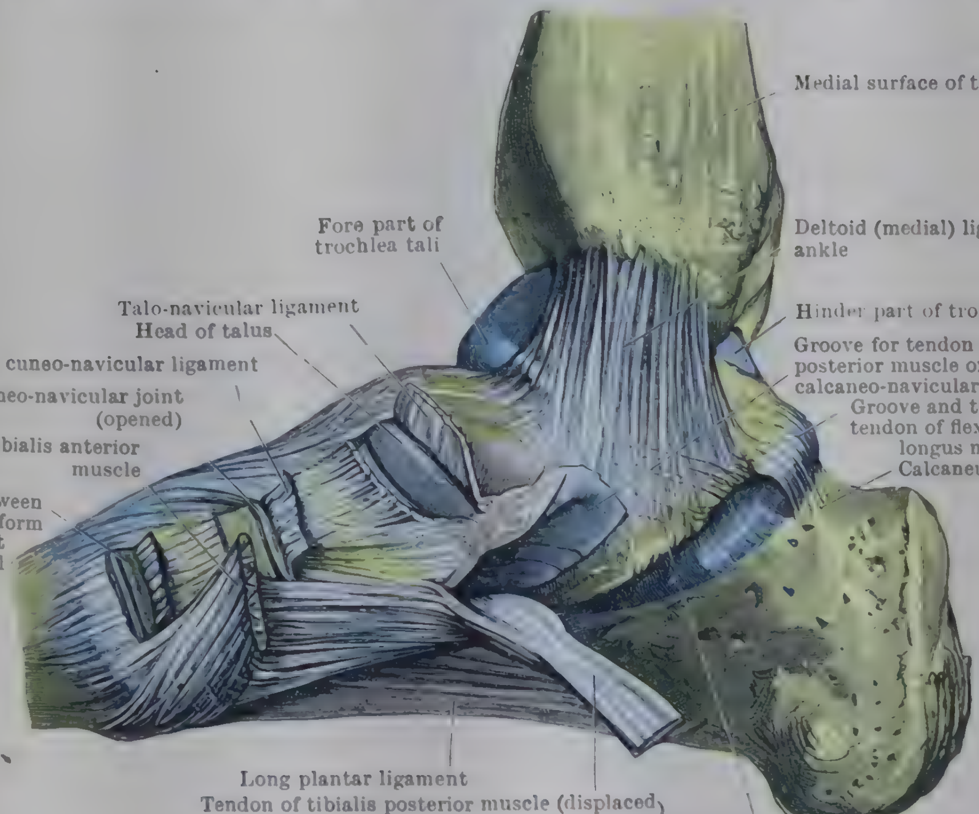

FIG. 345.—ANKLE JOINT AND TARSAL JOINTS FROM THE TIBIAL SIDE.

strong ligamentous formation which, on account of its triangular shape, is usually called the **deltoid ligament**. The apical part of this structure is attached to the pit on the lower border of the medial malleolus. Its thick base has a continuous attachment—to the rounded upper and medial part of the navicular bone (*tibio-navicular fibres*), to the medial part of the neck of the talus (*anterior talo-tibial fibres*), to the plantar calcaneo-navicular ligament and the medial border of the sustentaculum tali (*calcaneo-tibial fibres*), and to the medial side of the talus, under the "tail" of the comma-shaped facet (*posterior talo-tibial fibres*). The talo-tibial fibres are on a deeper plane than the others; the tibio-navicular and calcaneo-tibial portions are continuous over the superficial aspect of the anterior talo-tibial fibres.

Synovial Membrane.—The synovial membrane of the joint lines the capsular ligament and covers well-marked fatty pads that lie in relation to the anterior and posterior ligaments. A synovial fold (Fig. 344) occupies the cleft between the tibia and fibula below the base of the interosseous tibio-fibular ligament; the sides of this cleft may be covered in part by an extension of the articular cartilage on the tibia and fibula.

Nerve-Supply.—The ankle joint is supplied by twigs from the **anterior** and **posterior tibial** nerves.

Movements at the Ankle Joint

Movement takes place around a transverse axis on a level with the tip of the lateral malleolus and slightly below the level of the medial malleolus. In the normal, standing position the foot makes a right angle with the leg. Considerable confusion has resulted in the past from the use of the terms 'flexion' and 'extension' in describing the movements that occur at the ankle joint, and for that reason the terms **'dorsi-flexion'** and **'plantar-flexion'** are to be preferred. In *dorsi-flexion* the foot is drawn upwards, the trochlea tali turning backwards in its socket; movement in the opposite direction is *plantar-flexion*. The range of plantar-flexion is greater than that of dorsi-flexion but there is considerable individual variation in the extent of the movements.

In **dorsi-flexion**, the broader, anterior part of the trochlea tali is forced back into the

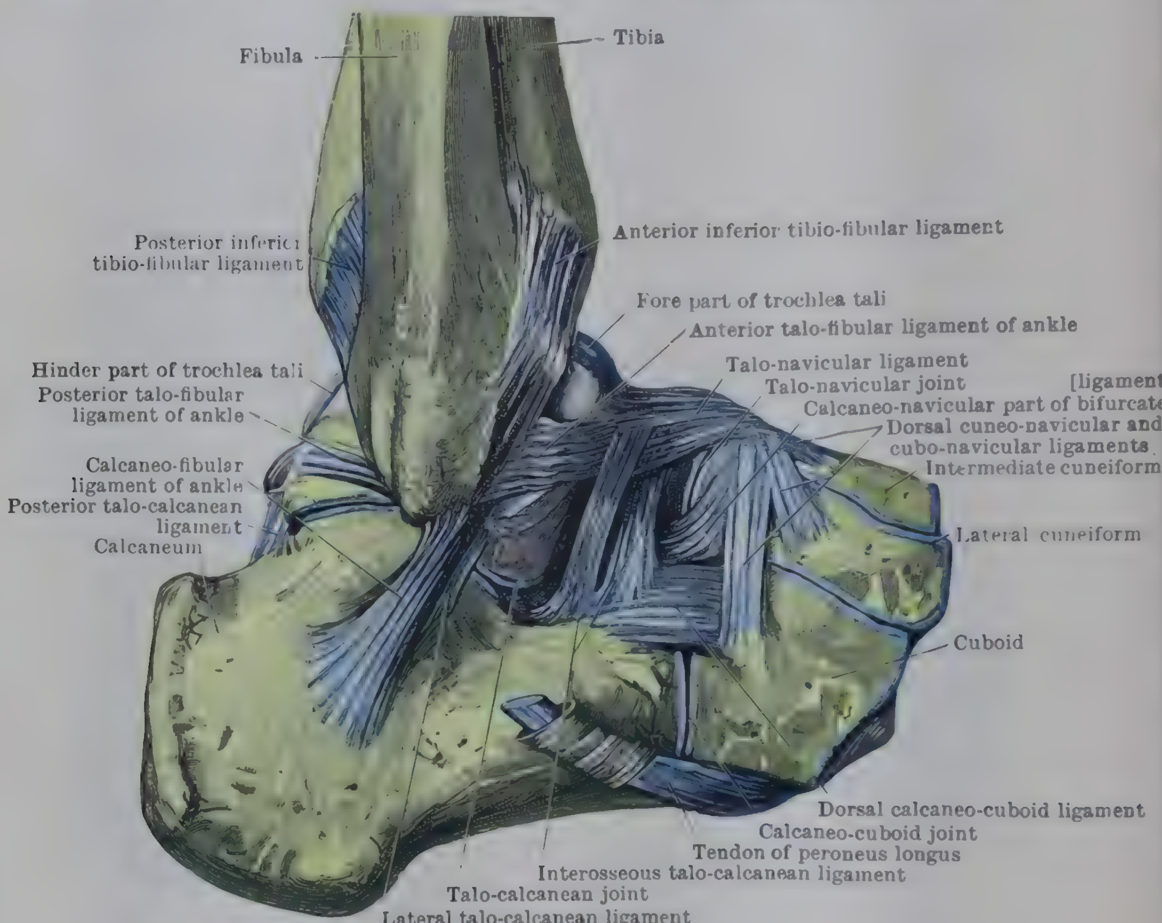

FIG. 346.—LIGAMENTS ON LATERAL SIDE OF ANKLE JOINT AND ON DORSUM OF TARSUS.

narrower, posterior part of the tibio-fibular socket; this causes slight separation of the tibia and fibula, with increased tension of the interosseous and transverse tibio-fibular ligaments. The talus is then most securely held between the malleoli. In **plantar-flexion,** as the narrower part of the trochlea turns forward into the broader part of the socket, the malleoli spring together again, so retaining up to a point their grasp upon the sides of the talus; but in full plantar-flexion a little side-play can be demonstrated in the joint. The wedge-shaped form of the joint-surfaces helps to prevent backward displacement of the foot on the leg when coming to a sudden stop in running or jumping. The maintenance of this positive grasp upon the talus is the function of the *inferior tibio-fibular joint*, the strong ligaments of which provide the spring mechanism involved. The *superior tibio-fibular joint* permits slight gliding movement in association with the displacement of the lower ends of the bones of the leg.

When the body is erect, muscular effort, mainly soleus and gastrocnemius, is needed to prevent falling forwards, owing to the incidence of body-weight in front of the ankle joints. But this effect of gravity is minimized in so far as the feet are usually turned a little laterally, and the axes of the two ankle joints are inclined to each other so as to make an angle pointing forwards.

The ankle joint is strongly supported by the tendons of the muscles of the leg which

descend in close relation to it. In front, the tendons of tibialis anterior, extensor hallucis longus, extensor digitorum longus and peroneus tertius pass over the anterior ligament in that order medio-laterally; posteriorly and medially are the tibialis posterior and flexor digitorum longus tendons; posteriorly is the tendon of the flexor hallucis longus; and posteriorly and laterally are the tendons of the peroneus longus and peroneus brevis.

JOINTS OF THE FOOT

The joints between the tarsal bones, between metatarsal bases, and between tarsus and metatarsus are intricate in their arrangement and several of them are complicated in their movements. The significance of the structure of these joints and of the movements that occur at them can only be understood in the light of the architecture of the foot as a whole. The account of the foot in this text is, of necessity, curtailed, and for further study the reader is advised to consult the works of Wood Jones (1944 *a*) and Morton (1937).

Arches of the Foot

The human foot is a structure that is highly specialized for the support of the body in the erect posture and for the propulsion of it during movement. To subserve these functions efficiently it must be able to adapt itself to the ground in many different positions and must be capable of absorbing mechanical shocks. This is achieved by the presence of a series of resilient arches, convex above, which become slightly flattened by the incidence of the body-weight in standing or during progression, and resume their original curvature when the pressure on them is relieved. The arches are formed by the tarsal and metatarsal bones, and are disposed both longitudinally (Pl. XXVII, p. 320) and transversely (Fig. 294, p. 319).

The **longitudinal arch** is higher on the medial side than on the lateral, and on account of the arrangement of the tarsal and metatarsal bones in two columns (p. 322) it is customarily described in two parts called the **lateral** and **medial arches**. The posterior part of the calcaneum forms a common posterior pillar for both arches (Pl. XXXVI, p. 383). The **lateral arch** proceeds from this through the anterior part of the calcaneum, which forms a joint with the cuboid bone; the arch is continued through the cuboid into the lateral two metatarsal bones, which articulate with the cuboid. This arch is a very low one and receives the weight of the body through the talus at the talo-calcanean joint. The **medial arch** is higher and more important. The posterior pillar is continued into the sustentaculum tali, and the summit of the arch is then formed by the head of the talus placed above and between the sustentaculum tali and the navicular bone. The anterior pillar is formed by the navicular bone, the three cuneiform bones, and the medial three metatarsal bones.

The **transverse arch** is placed across the anterior part of the tarsus and the posterior part of the metatarsus, and is best marked along the line of the tarso-metatarsal joints. The arch is gradually lost as the metatarsals are traced forwards towards their heads which are all in functional contact with the ground.

For the preservation of these arches the integrity of the tarsal, tarso-metatarsal, and intermetatarsal joints is important, for at them the bones are held in their proper relationship as segments of the arches. For this purpose certain ligaments of the joints are much more important than others. The important ligaments are specially strengthened to resist undue yielding of the joints and consequent collapse of the arches; they are therefore found on the plantar aspect of the joints (that is, on the concave side of the arches) or, especially in the joints of the transverse arch, in interosseous positions. But it must be emphasized once more that unsupported ligaments will, in time, stretch under continuous strain, and the arches of the foot are in every case supported by muscles as well.

The body-weight is transmitted from the bones of the leg to the longitudinal arches through the talus. The talus forms two joints with the rest of the tarsus (Fig. 347), each being more particularly concerned in the transference of weight to one of these arches. The more posterior joint—the *talo-calcanean*—is specially associated

with the lateral arch and at the more anterior joint—the *talo-calcaneo-navicular*—the weight is transmitted to the medial arch. At both joints the talus rests on the calcaneum, and between the joints there is the canalis tarsi (see below) to the walls of which parts of the capsular ligaments of the two joints are attached.

INTERTARSAL JOINTS

Talo-Calcanean Joint (Figs. 346, 347).—This joint is formed between the facet on the under surface of the body of the talus and the posterior facet on the upper surface of the calcaneum; each facet is approximately cylindrical in curvature—that on the talus concave, the other convex.

The **capsular ligament** surrounding the joint is made up of short fibres attached close to the articular surfaces all round. Slightly stronger portions, specially named

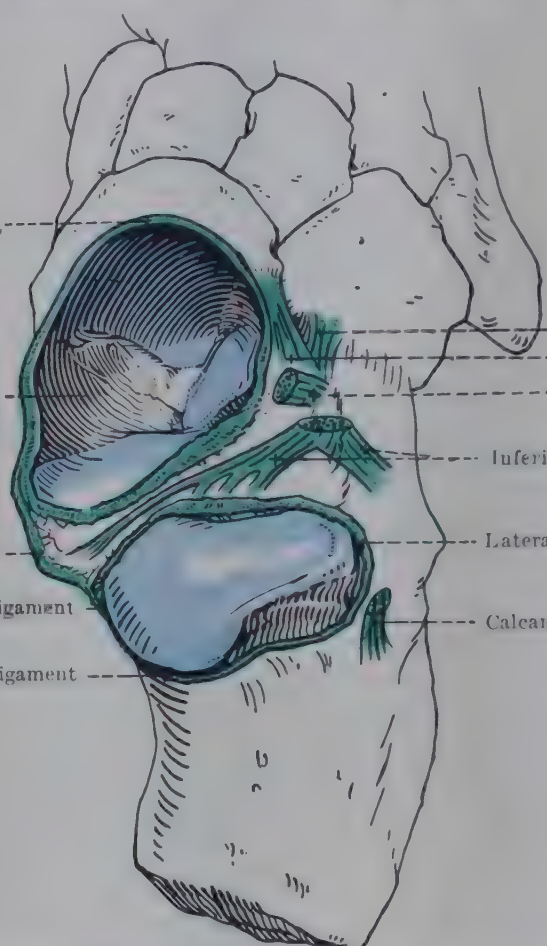

FIG. 347.—LIGAMENTS AND INFERIOR ARTICULAR SURFACES OF TALO-CALCANEAN AND TALO-CALCANEO-NAVICULAR JOINTS (seen from above after removal of the Talus).

the *posterior*, *medial*, and *lateral talo-calcanean ligaments*, are situated in corresponding parts of the capsule.

The anterior part of the capsular ligament is thin and is attached to the roof and floor of the canalis tarsi. The *canalis tarsi* is a narrow tunnel which is bounded by the grooves on the talus and the calcaneum and runs obliquely forwards and laterally in front of the articular facets of this joint; at its antero-lateral end the canal expands to form the *sinus tarsi*. In addition to the anterior ligament of the talo-calcanean joint the canalis tarsi gives attachment to the posterior part of the capsule of the talo-calcaneo-navicular joint (p. 396), and these two ligaments together constitute the *interosseous talo-calcanean ligament* which forms a weak connexion between the two bones. Between the two parts of the interosseous ligament lies the deep extension of the lateral limb of the inferior extensor retinaculum which is attached to the floor of the canalis tarsi (Barclay Smith, 1896) (Figs. 347, 349). Lying in the sinus tarsi is a strong discrete band that is attached above to the neck of the talus and below to the calcaneum; this ligament has been termed by Wood Jones (1944 *b*) the *ligamentum cervicis*, and it is of importance because it forms the only strong

ligamentous bond between the two bones and because movement of the bones occurs around it in inversion and eversion (Fig. 347).

The calcanean parts of the medial and lateral ligaments of the ankle joint act as accessory ligaments of the talo-calcanean joint.

The articular capsule is lined with **synovial membrane**; the synovial cavity does not communicate with any other joint (Fig. 349).

Talo-Calcaneo-Navicular Joint (Fig. 347).—At this joint a large facet on the head and the lower surface of the neck of the talus articulates with a deep and extensive socket that is formed partly by bone and partly by ligaments. The anterior part of

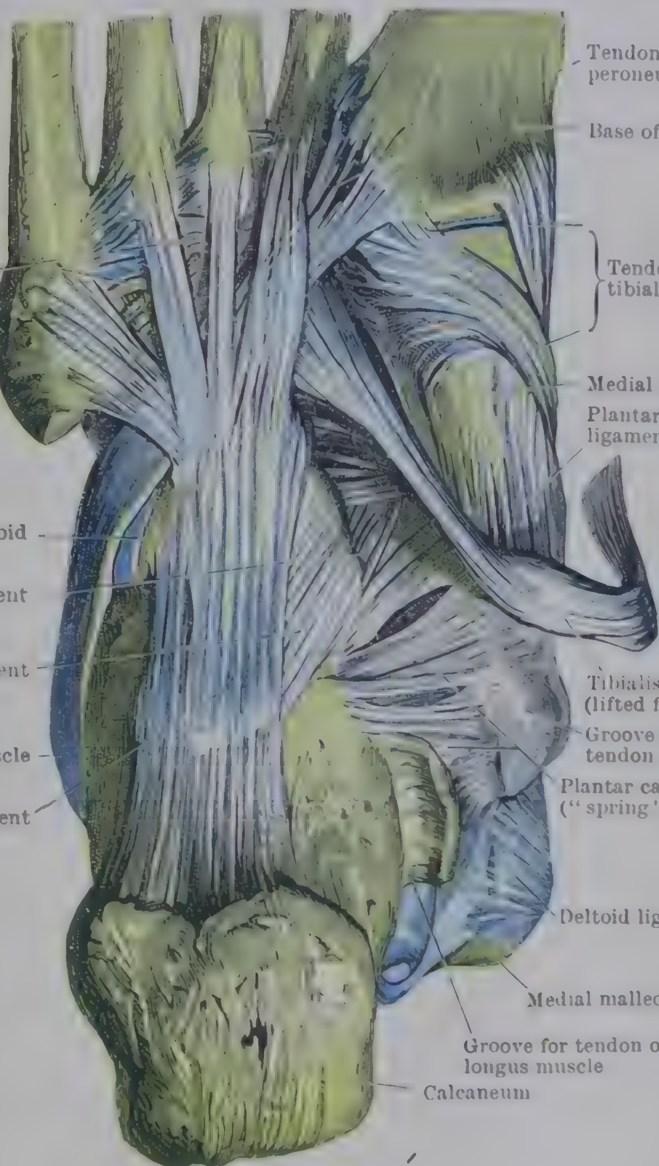

FIG. 348.—PLANTAR ASPECT OF TARSAL AND TARSO-METATARSAL JOINTS.

the **socket** is formed by the concave articular surface of the navicular bone, and the posterior part by the upper surface of the sustentaculum tali and a facet that is usually present on the upper surface of the calcaneum antero-lateral to the sustentaculum. Between the navicular and the calcaneal articular surfaces there is an appreciable interval that is greatest in its medial part. The medial part of this interval is occupied by the *plantar calcaneo-navicular ligament* and the much smaller lateral part by the *calcaneo-navicular* fibres of the *bifurcated ligament*.

The **plantar calcaneo-navicular ligament** articulates with the medial and inferior surfaces of the head of the talus and is a fibro-cartilaginous band of great strength (Figs. 345, 347, 348). It is attached behind to the anterior end and medial border of the sustentaculum tali; in front it spreads out on to the plantar, the medial, and the adjacent part of the upper surface of the navicular bone; its medial part is joined and supported by fibres of the deltoid ligament of the ankle joint. The tendon of the tibialis posterior muscle turns down into the sole under the ligament and acts as a

sling for it and for the head of the talus (Figs. 345, 348). The tension of the plantar calcaneo-navicular ligament, supported by the tibialis posterior muscle, resists the tendency of the weight of the body to drive the head of the talus downwards between the bones which it braces together, and the resilience it imparts to the medial arch is recognized in its common appellation—the *spring ligament*.

The **calcaneo-navicular part of the bifurcated ligament** completes the socket on the lateral side. It is composed of short fibres that pass from the upper surface of the anterior end of the calcaneum to the adjacent lateral surface of the navicular bone (Figs. 346, 347). Sometimes the part of the articular head of the talus in contact with this band is faceted by it.

The rounded **head of the talus** has a continuous covering of articular cartilage that is continued on to the under surface of the neck and the body. This articular surface conforms in shape to the socket and is marked off by faint ridges into a facet for the navicular bone in front, one for the sustentaculum tali below, and between these, a third for the plantar calcaneo-navicular ligament.

Capsule.—On account of the extensive form of the bony and ligamentous socket a true capsular ligament is present only on the posterior and the dorsal aspects of the joint.

The posterior part of the capsular ligament is relatively weak. It is to be regarded as the anterior component of the interosseous ligament (p. 394).

The capsular ligament is completed round the dorsal aspect of the joint, between the two calcaneo-navicular bands, by a thin sheet, called the **talo-navicular ligament** (Figs. 345, 347), which extends from the neck of the talus to the dorsal surface of the navicular bone. It blends medially with the anterior fibres of the deltoid ligament that go to the navicular bone.

The **synovial cavity** of this joint makes no communications with neighbouring articulations (Fig. 349).

Calcaneo-Cuboid Joint (Figs. 346, 347).—The calcaneo-cuboid joint is the highest point in the lateral longitudinal arch, which, as already mentioned, is formed by the calcaneum, the cuboid bone, and the lateral two metatarsal bones. The body-weight falls on this arch behind its summit, at the talo-calcanean joint, and the strain is most felt at the joint immediately in front of the calcaneum—the calcaneo-cuboid joint. This joint, like the talo-calcaneo-navicular joint at the summit of the medial arch, must therefore be specially reinforced on its under aspect, and here are placed the strong bands called the long and short plantar ligaments. In addition, the tendon of the peroneus longus, passing under the cuboid bone in front of the articulation, acts as a sling after the manner of the tibialis posterior tendon under the medial arch.

The **articular facets** on the opposed surfaces of the calcaneum and cuboid bone are quadrilateral and reciprocally concavo-convex.

Capsule.—An articular capsule completely surrounds the joint, and certain special ligaments are to be described in connection with it.

Applied to the dorso-medial aspect of the joint is the **calcaneo-cuboid part of the bifurcated ligament**, which springs from the upper and fore part of the calcaneum in common with the calcaneo-navicular part of the ligament, and is attached to the adjacent dorso-medial angle of the cuboid bone (Fig. 347).

On the plantar aspect of the joint are two special ligaments, superficial and deep, separated by areolar tissue (Fig. 348). The deep one is the **short plantar ligament**. It is a broad band of short fibres immediately applied to the joint; it runs from the anterior part of the inferior surface of the calcaneum to the cuboid bone behind the ridge that bounds the peroneal groove. The superficial and much longer band is the **long plantar ligament**. It arises from the whole length of the rounded, keel-like ridge on the plantar surface of the calcaneum and stretches to the ridge on the cuboid bone, to which its deep fibres are attached. The more superficial fibres pass on over the peroneus longus tendon to the bases of at least the lateral three metatarsal bones. This ligament therefore stretches under nearly the whole length of the lateral arch and strengthens the plantar aspect of all the joints in the arch. As this arch has little height, a long band of this nature stretching, like a tie-beam, from

pillar to pillar is more effective in preserving the arch than short ties between adjacent segments of the arch.

Synovial membrane covers the inside of the capsular ligament. The joint cavity is self-contained, making no communication with any other (Fig. 349).

Transverse Tarsal Joint. — The talo-calcaneo-navicular joint and the calcaneo-cuboid joint, although they do not communicate with each other, together extend right across the tarsus in an irregular transverse plane, between the talus and calcaneum behind and the navicular and cuboid bones in front (Fig. 349). This articular plane is termed the *transverse tarsal joint.*

The anterior two bones involved—navicular and cuboid—are bound together by **dorsal** (Fig. 346) and **plantar cubo-navicular ligaments** between adjacent parts of the corresponding surfaces, and by an **interosseous cubo-navicular ligament** between their contiguous sides (Fig. 349). Sometimes there is a synovial cavity amidst these ligaments, between cartilage-covered facets on the bones, which opens anteriorly into the cuneo-navicular joint.

The remaining intertarsal joints—*cuneo-navicular, intercuneiform*, and *cuneo-cuboid*—frequently share a common synovial cavity, but the cuneo-cuboid may have a cavity separate from that of the others. The intercuneiform and cuneo-cuboid joints are placed between the tarsal segments of the transverse arch of the foot.

Cuneo-Navicular Joint.—This is the joint between the convex anterior surface of the navicular bone and the concave articular surface provided by the posterior ends of the three cuneiform bones. The navicular **articular cartilage** (Fig. 349) is faceted by the opposed cuneiform bones, and is continued on to the medial wall of the cavity of the cubo-navicular joint when such is present.

The joint is surrounded by a **capsular ligament** distinct on all sides except laterally, towards the cuboid bone, where the joint may communicate with the cuneo-cuboid joint and always with a cubo-navicular joint when present. Distally, the joint-cavity forms recesses between the cuneiform bones (Fig. 349). In the upper and medial parts of the capsule there are short bands, relatively weak, passing from the navicular to each cuneiform bone ; these are the **dorsal cuneo-navicular ligaments** (Figs. 345, 346). Similar stronger bands on the under aspect of the joint, inseparable from slips of insertion of the tibialis posterior tendon, constitute the **plantar cuneo-navicular ligaments.**

Intercuneiform Joints.—At the intercuneiform joints the three cuneiform bones are bound together by weak, transverse **dorsal ligaments** and much stronger **interosseous** and **plantar ligaments**. The last two limit, in front, small joint-cavities between articular facets placed behind and above on the contiguous surfaces of the bones. These cavities are continued from that of the cuneo-navicular joint (Fig. 349), and usually the medial intercuneiform joint extends forwards over the interosseous ligament to open into the middle tarso-metatarsal joint.

Cuneo-Cuboid Joint.—This is a joint between oval or circular facets on the lateral cuneiform bone and the cuboid bone. It is surrounded by a weak **dorsal cuneo-cuboid ligament** between the dorsal surfaces of the bones, by a **plantar cuneo-cuboid ligament** (Fig. 348) between their adjacent plantar borders, and by a strong **interosseous cuneo-cuboid ligament** (Fig. 349) which closes the cavity anteriorly. Posteriorly, the joint may or may not open into the cuneo-navicular joint.

The cuboid and cuneiform bones, placed side by side across the distal part of the tarsus, form the tarsal part of the *transverse arch of the foot*. The strong interosseous and plantar intercuneiform and cuneo-cuboid ligaments maintain the segments of the arch in position, and additional strength is obtained from the peroneus longus tendon as it passes across the foot between the two pillars of the arch (Fig. 348).

Nerve-Supply.—The tarsal joints are supplied on the dorsal aspect by the **anterior tibial** nerve, and on the plantar aspect by the **medial** and **lateral plantar** nerves.

Movements in the Tarsus

The movements of dorsi-flexion and plantar-flexion occur at the ankle joint and have been described on page 392. In these movements the talus rotates in the tibio-fibular socket and the tarsus and metatarsus move as a unit. In the other movements of the foot the calcaneum and navicular, carrying with them the more distal tarsal bones (between which movements also occur), move on the talus.

The movements that occur at the tarsal joints produce, in summation, the characteristic changes of inversion and eversion.

In **inversion**, the foot is adducted and twisted so that the medial border is raised and the lateral border depressed until the sole is turned slightly medially (Pl. XXXVI, p. 383, Fig. 1). Inversion is usually accompanied by plantar-flexion, and the composite movement is sometimes referred to as *supination*. In **eversion**, the foot is abducted, the lateral border is raised and the medial border lowered, so that the sole is turned slightly laterally. Eversion is usually accompanied by dorsi-flexion and the total movement is sometimes referred to as *pronation*. Inversion and eversion occur principally at the talo-calcanean and talo-calcaneo-navicular joints, and Inkster (1938) has shown that fixation of the calcaneum greatly limits these movements. The talo-calcanean and talo-calcaneo-navicular joints have a common axis of movement which runs obliquely forwards, upwards and medially through the sinus tarsi, in the region of the ligamentum cervicis (p. 394), and the complicated movements that occur at these joints have been described in detail by Manter (1941). Movement occurs also at the other tarsal and tarso-metatarsal joints during inversion and eversion, but this diminishes in amount in a proximo-distal direction (MacConnaill, 1945).

TARSO-METATARSAL AND INTERMETATARSAL JOINTS

Tarso-Metatarsal Joints (Fig. 349).—The anterior members of the tarsus —the cuboid and three cuneiform bones—articulate with the bases of the metatarsal bones along an irregular line which "presents the outline of an indented parapet both on its tarsal and its metatarsal aspects".

The *first* metatarsal bone articulates only with the anterior surface of the

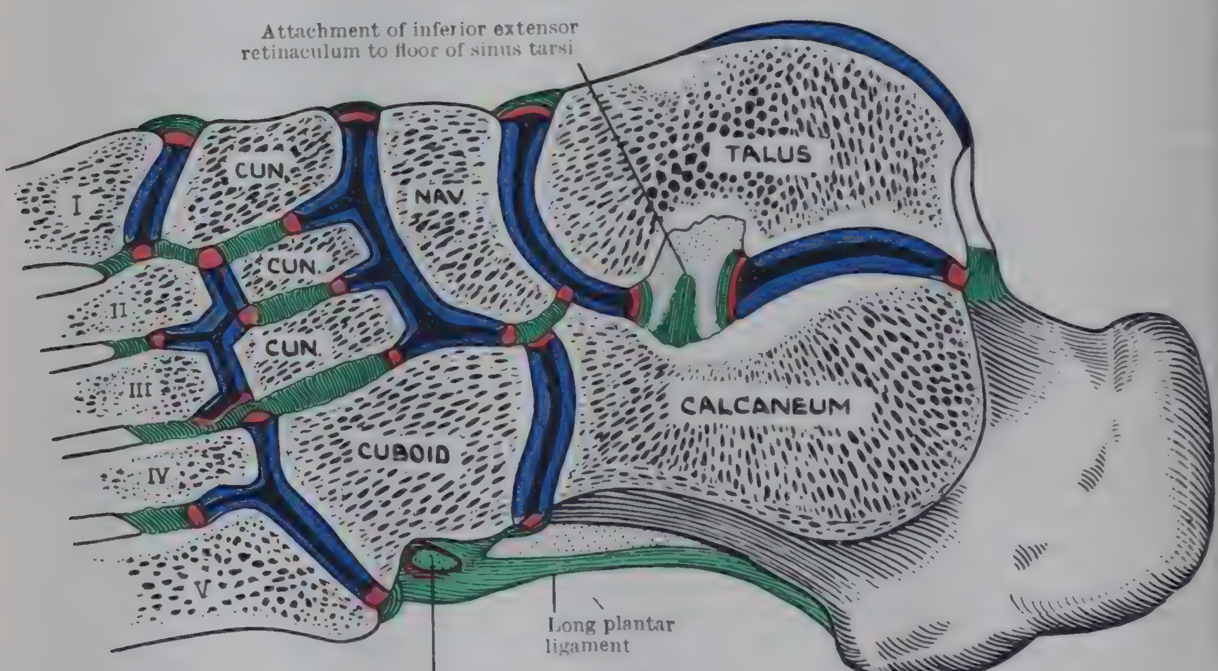

Fig. 349.—Oblique Section of Left Foot to show the Synovial Cavities of the Tarsal and Tarso-Metatarsal Joints.

The foot was in strong inversion when sectioned and does not reveal the communication that exists between the cuneo-navicular and intermediate tarso-metatarsal joints. An unusually large cubo-navicular joint-cavity was present. Articular cartilage, *blue*; synovial membrane, *pink*; ligaments and tendon, *green*.

medial cuneiform bone. The *second* metatarsal articulates in a socket with all three cuneiform bones—the lateral side of the medial bone, the anterior end of the intermediate, and the medial side of the lateral bone. The *third* metatarsal articulates with the lateral cuneiform bone. The *fourth* metatarsal articulates with the cuboid and to a small extent with the lateral cuneiform bone. The *fifth* metatarsal articulates with the cuboid bone only.

The articulations are all synovial joints of gliding type, closed over by dorsal

and plantar ligaments. In addition there are certain interosseous ligaments which delimit three separate synovial cavities.

The **dorsal tarso-metatarsal ligaments** are short slips that pass between the adjoining dorsal surfaces of the tarsal and metatarsal bones, each metatarsal bone receiving a slip from each tarsal bone with which it articulates.

The **plantar tarso-metatarsal ligaments** are similar bands on the under aspect of the joints, but are less regularly disposed. Those for the medial two metatarsal bones are the strongest, but the lateral tarso-metatarsal joints are strengthened underneath by fibres from the long plantar ligament. The tarso-metatarsal joint of the big toe is strengthened below by the insertion into the articulating bones of the tibialis anterior medially and the peroneus longus laterally. Slips from the tibialis posterior tendon are applied to the under aspect of the joints of the middle three metatarsal bones. (See Fig. 348.)

Two strong **interosseous tarso-metatarsal ligaments** are always present (Fig. 349). One passes from the anterior and lateral part of the medial cuneiform bone to the contiguous medial side of the second metatarsal base. The other passes from the antero-lateral angle of the lateral cuneiform to the adjacent medial surface of the fourth metatarsal base. These two ligaments separate **three tarso-metatarsal synovial cavities.**

The **medial** cavity is entirely confined to the joint between the first metatarsal and medial cuneiform bones. The **intermediate** cavity separates the second and third metatarsals from the intermediate and lateral cuneiform bones; this cavity is prolonged forwards for a little way between the second and third, and third and fourth metatarsal bases; posteriorly, it usually communicates, between the medial and intermediate cuneiform bones, with the cuneo-navicular joint. The **lateral** joint-cavity separates the cuboid from the fourth and fifth metatarsal bones, and is prolonged forwards between these two metatarsal bases. Sometimes the intermediate cavity is partially divided by a third interosseous ligament that passes between the adjacent angles of the lateral cuneiform and second metatarsal bones; this band was absent in the specimen drawn in Fig. 349.

The indented nature of the tarso-metatarsal joint line adds strength to the *transverse arch* of the foot. This arch is built of two spans placed side by side, the one formed by the cuboid and cuneiform bones, the other formed by the metatarsal bases. These two spans are interlocked by the indentations and tied together by the ligaments of the tarso-metatarsal joints.

Intermetatarsal Joints.—The intermetatarsal joints are small synovial joints between cartilage-covered facets on the contiguous sides of the bases of the lateral four metatarsal bones. The joint-cavities (Fig. 349) are prolonged from the tarso-metatarsal cavities—that between the fourth and fifth bones from the lateral tarso-metatarsal joint, those on each side of the third bone from the intermediate joint.

Above, below, and in front, the little joints are closed by **dorsal, plantar**, and **interosseous intermetatarsal ligaments**, composed of short, transverse fibres between corresponding surfaces of the bases of the metatarsal bones. The interosseous ligaments are very strong, and play an important part in holding together the metatarsal bases as segments of the metatarsal span of the transverse arch of the foot.

The first metatarsal bone is connected to the second by interosseous fibres only. Sometimes a bursal sac is formed amidst these fibres, between indistinct facets on the bones; its cavity may communicate with the medial tarso-metatarsal joint.

Nerve-Supply.—The tarso-metatarsal and intermetatarsal joints are supplied by twigs from the anterior tibial and the lateral and medial plantar nerves.

Metatarsal Movements.—The interlocking of the bones at the tarso-metatarsal joints and the intermetatarsal interosseous ligaments preclude, except at the first tarso-metatarsal joint, anything beyond small gliding movements of the metatarsal bones by which they contribute very slightly to the inversion and eversion movements of the foot. The fourth and, more particularly, the fifth, owing to the oblique line of their basal joints, have a slight capability of flexion accompanied by adduction. At the first tarso-metatarsal joint a slight rotary movement may occur in addition to a limited amount of up and down gliding. Such movements of the first metatarsal take place during the adaption of the foot to the ground in varying degrees of inversion and eversion.

METATARSO-PHALANGEAL AND INTERPHALANGEAL JOINTS

Metatarso-Phalangeal Joints.—These joints closely resemble the metacarpo-phalangeal joints in the shape of the articular surfaces and the disposition of the

ligaments. At the base of each toe the cupped posterior end of the proximal phalanx is applied to the rounded metatarsal head.

The **capsular ligament**, lined with synovial membrane, is formed at the sides by strong, fan-shaped **collateral ligaments** attached to neighbouring parts of the bones, and, on the plantar aspect, by a thick, pad-like **plantar ligament**; dorsally, the capsule is completed by an expansion of the extensor tendon.

The plantar ligament is grooved by the flexor tendons. In the big toe this ligament has two fairly large sesamoid bones developed in it; they are covered with cartilage on their upper surfaces, which articulate with grooves scored on the under surface of the head of the first metatarsal bone. The plantar ligaments of all the joints are connected by the **deep transverse ligaments of the sole,** which are arranged like the deep transverse ligaments of the palm, except that in the hand this connexion does not involve the joint of the thumb, whereas in the foot the joint of the big toe is linked up with the others.

Nerve-Supply.—The metatarso-phalangeal joints are supplied on their **dorsal** and **plantar** aspects by the corresponding **digital** nerves.

Movements.—The movements of these condyloid joints are similar to the movements at the corresponding joints in the hand but are less extensive. In the foot, however, **extension** of the proximal phalanges can be carried beyond the line of the metatarsal bones; and **abduction** and **adduction** are centred on the second toe because of the slightly different arrangement of the interossei muscles. In **flexion** the toes are at the same time drawn together; in **extension** they are spread apart and inclined slightly in the lateral direction.

Interphalangeal Joints.—The interphalangeal joints also are similar to the corresponding joints in the hand. At each articulation the proximal bone presents a double convexity within the joint and the distal bone a double concavity.

Collateral ligaments at the sides, a thick **plantar ligament** and the expansion of the extensor tendon dorsally complete the **articular capsule**, lined with synovial membrane. The second interphalangeal joint of the little toe is often obliterated by synostosis.

Nerve-Supply.—These joints are supplied by the **dorsal** and **plantar digital** nerves.

Movements.—These are hinge-joints. Movement is limited to **flexion** towards the sole of the foot and **extension** in the opposite direction, around a transverse axis.

Mechanism of the Foot

The foot is specialized to support the body in the erect position, alike in standing and in progression. Its skeletal parts are arranged in arches, longitudinal and transverse, in the manner already described. The presence of the joints in the arches introduces a spring mechanism, so that the arches resemble the half-elliptical springs of a carriage. They yield slightly when weight is put upon them, and recoil when it is removed (Fig. 350). The medial longitudinal arch is higher than the lateral and has more joints, which give to the corresponding part of the foot a greater resilience. This is in accordance with the propulsive function of the medial part of the foot in walking and running, whereas the lateral part of the foot is more concerned with the actual static support of the body. The arched form of the foot is established in early foetal life, but the height of the arches shows considerable individual variation.

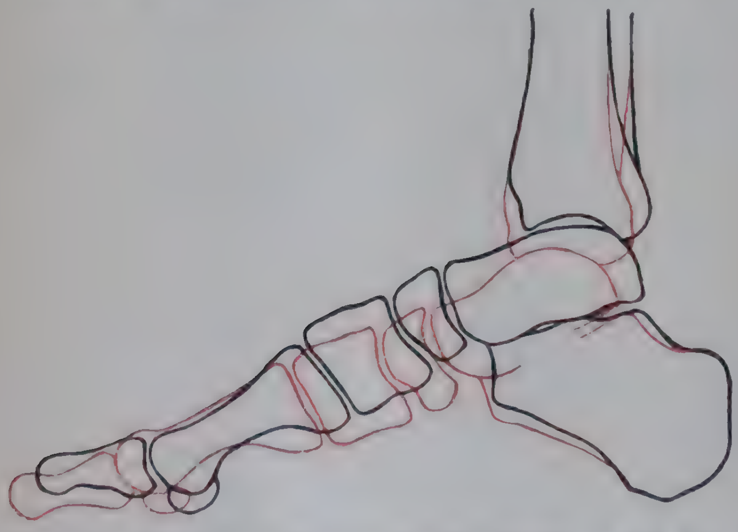

FIG. 350.—TRACING OF RADIOGRAPHS (Pl. XXXVI, p. 383, Figs. **2** and **3**). Superimposed to show the position of the Longitudinal Arch of the Foot during Relaxation (red) and Contraction (black) of the muscles. (See also Fig. 472, Footprints **2** and **3**.)

Attention has been drawn to the ligaments which specially support the arches,

and to the prime importance of the muscles in safeguarding the ligaments from over-stretching. The tendon of the tibialis posterior muscle passes as a sling below the summit of the medial arch, and, because of the insertion of that tendon on the plantar aspect of nearly all the tarsal and metatarsal bones, the contraction of the muscle must tend to increase the general concavity of the sole. The peroneus longus acts similarly as a sling beneath the lateral arch and also as a contractile tie-beam between the extremities of the transverse arch. The tibialis anterior and peroneus tertius muscles pull upon the medial and lateral arches from above. The long flexors of the toes act as contractile ties to the longitudinal arches. The muscles of the sole help to brace all the arches, according to their disposition.

In walking, the weight is first applied to the common posterior pillar of the two longitudinal arches as the heel strikes the ground. As the body moves forward the weight falls on the lateral border of the foot along the lateral arch, is rapidly transferred across the metatarsal heads to the medial arch as the heel leaves the ground, and a final propulsive thrust is obtained by flexion of the joints of the big toe. In running, the weight reaches the ground at the distal ends only of the longitudinal arches, which then act as quarter-elliptical springs, and, by their recoil, reinforce the final thrust derived from flexion of the medial toes.

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MYOLOGY

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The **skeletal muscles** alone are considered in this Section. They constitute the 'red flesh' of the body, and account for 42 per cent of its weight in the male, 36 per cent in the female. They execute movements initiated by the will, for which reason the tissue concerned is known as voluntary muscle. It is termed also **striated** muscle on account of its characteristic transverse striations, alternately dark and pale, seen under the microscope. It differs from the two other varieties of muscle-tissue, namely, **unstriated** or **plain** muscle found in the walls of viscera, blood-vessels, ducts of glands, and elsewhere; and the distinctive type of striated muscle confined to the heart, and hence termed **cardiac** muscle (Fig. 351). Both these varieties are under the control of the involuntary nervous system.

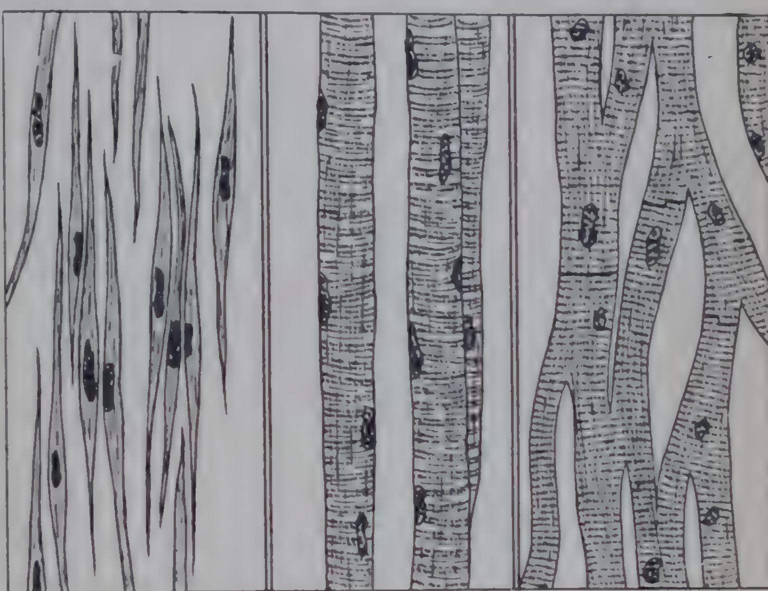


Fig. 351.—The Three Varieties of Muscle-Tissue. (Drawn from human muscle × 250.)

A. Plain muscle-fibres from prostate gland.
B. Striated. C. Cardiac.

All three varieties of muscle-tissue are derived from mesoderm, the cells of which acquire the characteristic power of contractility and become specialized to form muscle-fibres.

A typical skeletal muscle consists of a number of *fasciculi* or muscle-bundles, enveloped in a sheath of fibrous tissue termed *fascia*, and usually connected, at one or both extremities, with bundles of white fibrous tissue which constitute some variety of *tendon*.

Each fasciculus is surrounded and bound to its neighbours by areolar tissue called the **perimysium externum**; and each consists of a number of elongated muscle-fibres, held together in their turn by areolar tissue called the **perimysium internum**. The perimysium internum is connected on the one hand to the **sarcolemma** (or cell-wall of the muscle-fibre) and on the other to the perimysium externum, by which it is brought into connexion with some part of a tendon.

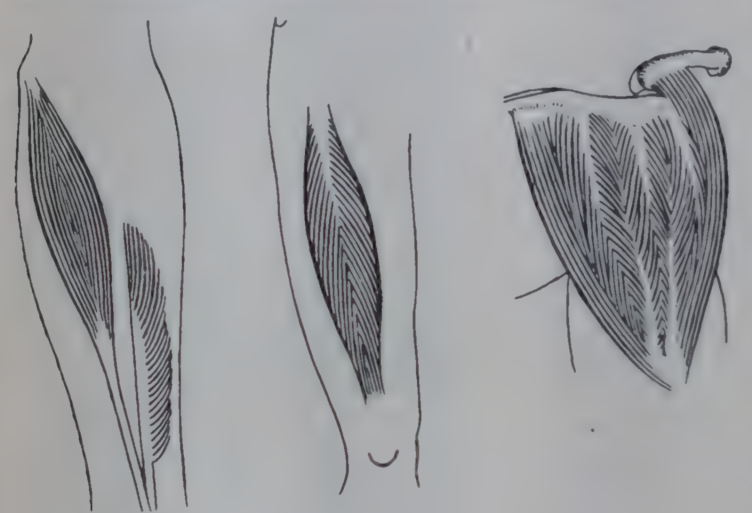
Attachments.—In order that a muscle may effectively exercise its power of contractility, it must possess (1) a relatively fixed point of attachment, termed the **origin**, usually nearer the median plane of the body, or proximal in a limb, and (2) a movable point of attachment, termed the **insertion**, usually farther from the median plane, or distal in a limb. Skeletal muscles are usually attached at both ends to bone, not directly by contractile muscle substance but by intervening non-contractile fibrous tissue. Some muscles have extensive attachments to bands of deep fascia and thereby to the bones, while such varied structures as tendons,

cartilages, fibrous raphes, ligaments, and skin may also be the site of origin or insertion.

Muscular attachments show marked individual variation in their extent and character and may be (1) fleshy, (2) tendinous, or (3) a combination of both. In the first case, *e.g.*, vastus intermedius, the fleshy fibres appear to spring directly from the bone, but the actual union is by perimysium to periosteum. In the second case, a varying extent of white fibrous tissue is interposed between the attachment and the fleshy belly. This intermediary is termed a **tendon**; and the shape and appearance of tendons vary greatly, the extremes being represented by the narrow, ribbon-like tendon of the palmaris longus and the broad, sheet-like tendon of the obliquus externus abdominis. A sheet-like tendon is usually referred to as an **aponeurosis.**

In some cases a muscle consists of two bellies connected by an *intermediate tendon.* Such muscles are termed "digastric" or "biventral". The fleshy bellies may be set at an angle to each other (*e.g.*, digastric and omo-hyoid), and in that event the intermediate tendon is anchored to some part of the skeletal system by a fascial sling. On the other hand, the two bellies may be placed in the same line.

The tendon, whether of origin or insertion, usually sends prolongations into the substance of the muscle—an arrangement which is not only efficient, but is also economical in the use of highly specialized tissue such as muscle, since it obviates the need for long muscle-fibres when the required movement may be produced by short fibres.



A B C

FIG. 352.—DIAGRAMS OF TYPES OF MUSCLES.

A. Fusiform (flexor carpi radialis) and Unipenniform (flexor pollicis longus). Cf. Fig. 421, p. 494.
B. Bipenniform (rectus femoris). Cf. Fig. 448, p. 522.
C. Multipenniform (deltoid).

Muscular Form.—The phylogeny and the function of a muscle determine its general form, and its detailed structure depends upon the number, arrangement, and length of its fibres. The greater the range of movement produced the longer are the fibres in the muscles concerned (Jansen, 1913). Various statements have been made regarding the length of muscle-fibres, from 1 mm. to 15 cm., but it seems probable that fibres may run the whole length of a muscle. Fibres of the adult sartorius 34 cm. long—and incomplete at that—have been isolated by dissection and fibres have been found to run from the tendon of origin to the tendon of insertion in the sartorius at birth and in the eye-muscles of the adult. (Lockhart & Brandt, 1938.) The more powerful a muscle the greater is the number and the shorter the length of its fibres; and the more extensive also is the use of tendinous fibres for their attachment. For example, the arrangement in the **penniform** types permits a greater number of fibres to be used and confers greater power.

In **unipenniform** muscles, the fibres are placed parallel to one another but not to the long axis of the muscle. This arrangement permits the use of short powerful fibres, and the longer the muscular belly the greater the number of these fibres, and the stronger the muscle (*e.g.*, vastus medialis). In **bipenniform** (*e.g.*, rectus femoris) and **multipenniform** muscles (*e.g.*, deltoid) still greater power is obtained by modifications of the same arrangement. In some muscles the fibres run parallel (or nearly parallel) to the long axis. They are termed **fusiform.** When the points of attachment of a fusiform muscle are widely separated, a long tendon of insertion is provided—again an efficient arrangement economical of muscle-tissue (Fig. 352).

Nomenclature of Muscles.—Muscles have received their names from a variety of circumstances, such as—their shape, *e.g.*, trapezius, quadratus; their structure, *e.g.*, triceps, digastric; their situation, *e.g.*, pectoralis, tibialis; their points of attachment, *e.g.*, sterno-mastoid, pubo-coccygeus; their direction, *e.g.*, rectus, obliquus; or their function, *e.g.*, flexor, abductor, etc. The names of most muscles combine two characteristics, *e.g.*, pronator teres, flexor digitorum sublimis. It is an interesting (and instructive) exercise for the student, as he studies Myology, to note the reasons for the names of individual muscles.

Variations.—The muscular system is remarkable for the numerous variations in its members. Individual muscles may possess additional heads of origin, *e.g.*, the biceps brachii; some muscles are frequently absent, *e.g.*, palmaris longus; while, in addition to the variations of muscles which we speak of as 'normal', a large number of 'abnormal' muscles or muscular slips have been described. Many of the latter, on account of the regularity of their position and attachments, have received special names. In a student's text-book it is not possible to deal with this aspect of Myology; but references to a few of these anomalous muscles will be found at the appropriate places in the description of the 'normal' muscles. Those who desire further information should consult Bryce (1923) or the special work of Le Double (1897).

Types of Muscle-Fibres.—Human muscles and the muscles of all other vertebrates are composed of several kinds of fibres:—(1) Pale, thin, rapidly contracting, easily fatigued, and metabolically expensive fibres—the first to be called upon in the production of active movements; (2) red, thick, slowly contracting, difficult to fatigue, and metabolically inexpensive fibres, that are harnessed in the work to increase and maintain the effort; (3) several intermediate types of fibres. Invertebrates and some vertebrates (*e.g.*, the rabbit) possess muscles composed exclusively of either the first or second types of fibre; but in man the fibres are mixed, though the red kind are considered to predominate in certain muscles, for example, the soleus, and the pale in others, for example, the gastrocnemius. Fibres of the same speed of contraction are usually grouped together. The deeper heads of a muscle are said to have more of the slowly contracting fibres.

Slight stimuli (caused, for example, by a stretching of the muscle) conveyed by its sensory nerves to the central nervous system produce a reflex state of contraction or muscle-tone *via* the motor nerves to the muscle. Red and pale fibres both function in this respect in maintaining *tone* and *posture*. There is no example of a purely postural muscle in Man. The greater the stimulus, the more fibres are called to function; and there is no basic difference in the production of the contraction maintaining postural tone, and that causing any active voluntary movement.

Contraction of Muscle-Fibres.—The amount of shortening which any muscle undergoes is directly proportional (nearly 1 : 2) to the length of its constituent fibres. Haines (1934) states that a muscle-fibre contracts by about 57 per cent of its length when fully stretched. If all the fibres of a given muscle are the same length and run from the tendon of origin to the tendon of insertion, then the extent of the muscle's contraction may be associated with the range of movement possible at a joint or joints; Haines considers that in movements not habitual, such as full flexion at the knee with full extension at the hip, the fibres of certain muscles, *e.g.*, the long head of the biceps femoris, are too short to perform the dual movements fully, and consequently that such muscles can act fully on only one joint at a time.

MUSCULAR ACTION

The essential virtue of muscle—its contractility—is displayed in producing movements of the body. Muscular action is therefore the basis of physical culture, an underlying principle of treatment in orthopædic surgery, and very frequently the secret of diagnosis in affections of the nervous system when the muscles are made to yield tell-tale evidence of the condition of their nerve-supply. Physical fitness may be assessed by the general tone of the muscular system; for example,

the poise of the shoulders, which depends mainly on the trapezius muscles, is a good general indication of well-being. Great emphasis must therefore be placed on the value of practical and experimental study of the function of muscles in the living human body. The following paragraphs dealing with the action of muscles should, indeed, be frequently consulted throughout the study of Myology. For discussion beyond the scope of this text see the detailed yet engrossing works of Duchenne (1867) and Beevor (1904).

Most skeletal muscles function by producing movements at the joint or joints over which they pass on their way from origin to insertion; and it is important to note that the muscles most powerfully concerned may act either by contraction or by relaxation, according to whether the movement is made against gravity or resistance, or with gravity in the absence of resistance. For example, the deltoid contracts when the arm is raised, but in Fig. 1, Pl. XLI, p. 512, the lengthening muscle is still firm and active, as shown by the weight riding upon it, while the arm is being lowered. The deltoid thus controls the gravitational descent of the arm, as a crane would pay out rope in lowering a weight, but when the arm is being lowered against resistance, as in Fig. 2, Pl. XLI, such activity of the deltoid is useless; other muscles, antagonists to the deltoid, such as the pectoralis major and the latissimus dorsi, have to pull the arm downwards, and the deltoid itself becomes flaccid, as is shown by the weight sinking into it. It is therefore essential to consider the influence of gravity and resistance in determining muscular action, and to note that the relaxation of muscles is as important as their contraction; modern physical training methods exercise both functions to obtain harmony in development.

The terms '**concentric action**' and '**excentric action**' are sometimes used in this connection to distinguish the shortening and lengthening respectively of a muscle as it works. It must be emphasized that a muscle may work equally hard in each kind of action, *i.e.*, there may be '*active* lengthening' as well as the more obvious 'active shortening'. On the other hand, a muscle may shorten or lengthen, in co-operation with more active muscles, without working hard at all; this may be termed '*adaptive* shortening or lengthening'.

Muscular relaxation may be the important feature in certain exercises. For example, the hip joint may be fully flexed, and then again the knee joint may be fully extended, but not both together unless the "hamstring" muscles acquire a special power of relaxation through practice; extreme relaxation of the hamstrings is essential for the accomplishment of the 'high kick', and a lesser degree is required in touching the toes without bending the knees.

Muscles may be voluntarily contracted without movements occurring and without appreciable shortening. This condition is known as **isometric contraction**, and occurs, for example, in the quadriceps femoris maintaining the erect posture, when the knee joint is held extended against the flexing force of gravity. The length remains constant but the tension is increased. In the opposite condition, **isotonic contraction,** the muscle shortens but its tension is constant. This occurs in voluntary movements.

The more powerful the action of a muscle the greater is the number of fibres stimulated to function. It is not necessary for all the fibres of a muscle to contract at the same time for gentle movements; indeed, muscle-fibres work by groups in relays to avoid fatigue. When examining a patient, the physician, in order to bring more fibres into play, adopts the method of **reinforcing** muscular action by opposing the patient's movements; this is a practice which will afford the student of anatomy also, as he carefully palpates living limbs, valuable practical information concerning muscles.

When a muscle contracts, its insertion is, as a general rule, approximated to its origin, but when both attachments are movable, the insertion may on occasion be relatively more fixed than the origin. Thus, in Fig. 1, Pl. XL, p. 457, in which the subject pulls down a weighted rope towards the body, the insertion of the latissimus dorsi into the arm is brought towards its origin from the trunk; but if the subject were to raise the body by means of the rope, the origin would be approximated to the insertion.

Most skeletal muscles utilize the bones as levers, and in the limbs the muscles are usually attached just beyond the joint upon which they mainly act; one advantage of this is that a small movement at the knee or the elbow, for instance, produces, with economy of muscle-contraction, a much wider excursion of the foot or the hand. The particular action of any muscle is a problem in mechanics, depending on the position of the two attachments and the relation of the muscle to the axes of the movements which are possible at the joint or joints over which it passes. Thus, in the case of the elbow joint where movements occur around a transverse axis only, all muscles which pass anterior to the joint can act as flexors, and all muscles which pass posterior to the joint can act as extensors. But such questions are not of great importance.

Movements, and not individual muscles, are represented in the cerebral cortex—that is, we are aware of the execution of a movement but not of the executive muscles. In fact, we may hardly even be aware of certain movements that initiate or are accessory to the chief movement. Even the simplest movements require the co-ordinated action of many muscles in different functional capacities to ensure precision of performance. Although some persons may appear to have the power to contract a particular muscle at will, probably other muscles are also employed, and it is justifiable to say that, from a functional point of view, there is no such thing as the isolated action of a muscle. Control of the muscles producing any given voluntary movement is an automatic function of the central nervous system.

The different capacities in which individual muscles may function in any given movement are as follows:—1. Prime movers; 2. Antagonists; 3. Fixation muscles; 4. Synergists; but the same muscles appear in different capacities for different movements.

The **prime movers**, as the term implies, are the muscles which by their active contractions, and the consequent approximation of their attachments, are responsible for the actual movements which take place. When the fist is clenched, for example, the prime movers are the flexors of the fingers and the thumb.

The **antagonists** in any movement are those muscles which are capable by contraction of producing the reverse movement, and by their relaxation enable the movement to be effected. The extensors of the fingers and thumb, for example, would prevent the clenching of the fist, but for the law of *reciprocal innervation* between two groups which causes antagonists to relax as prime movers contract. It has been shown experimentally that the same areas of the motor cortex of the brain are responsible for the contraction of the one and the inhibition or relaxation of the other. The term 'antagonists' belies the function of muscles in that capacity, for they do everything to secure harmony in the movement, 'paying out' just as much as, and no more than, is required, thus securing guidance and precision. For example, the deltoid remains taut when the arm is lowered against slight resistance but becomes flaccid when severe resistance is encountered.

Precision in the performance of any desired movement, or effective action against resistance, is possible only if the muscles concerned have a stable basis from which to act. It is the function of **fixation muscles** to provide this stable basis by steadying a part or a joint. For example, if the scapula is not adequately steadied and guided by the trapezius and serratus anterior muscles, disharmony in elevation of the arm by the deltoid will result. The trapezius and serratus anterior are prime movers in securing the rotation of the scapula upon the chest-wall necessary for elevation of the arm, but are also fixation muscles in providing a firm base upon which the humerus is turned by muscles of the arm. During the exercise, in the supine position, of raising both legs from the floor, the rectus abdominis, though it does not act upon the limbs, soon becomes painfully cramped, because of the heavy and exhausting work required of it in fixing the pelvis for the pull of the limb-muscles and the support of the weight of the limbs.

Synergists [σύν (syn) = together, ἔργειν (ergein) = to work] might well be classed as special examples of fixation muscles, since they control the position of intermediate joints so that prime movers which pass over several joints may exert their power in a desired movement of a distal joint. In clenching the fist the synergists are the extensors of the wrist. If the wrist were not held extended,

then the flexors of the fingers would be powerful enough to produce flexion of the wrist. Now, flexion of the wrist added to flexion of the fingers stretches the tendons of the extensors of the fingers until they can yield no more, whereupon the continued flexion at the wrist causes the fingers to open out and the grip to slacken. This is the explanation of the success of the common trick of forcibly flexing an opponent's wrist to compel him to drop a weapon from his hand. Similarly the synergic action of the flexor carpi ulnaris and the extensor carpi ulnaris, acting together as adductors of the wrist, is essential for the apparently simple movement of abducting the thumb.

Group-Action of Muscles.—A movement may require the simultaneous co-operation of teams of muscles from all four of the above classes, namely prime movers, antagonists, fixation muscles and synergists, and such activity is sometimes cited as an example of the group-action of muscles. But the term is more accurately applied to the common or related action of a group of muscles usually with common sources of nerve-supply ; for example, the muscles that flex the ankle work together as a team, and surgeons, appreciating this fact, are careful to select a muscle from the same team when they try to mitigate the disability due to paralysis of a muscle, by transplanting another member of the team to act as substitute. Obviously, a muscle transferred from a rival side would be by nature an antagonist, although, eventually, it might be trained to play a new part among its former opponents. Such reversal is more efficient in the upper limb than in the lower. In the lower limb, individualism is suppressed in the well-nigh automatic group-actions of locomotion, and such a practice as replacing a paralysed tibialis anterior by an antagonist —the peroneus longus—is usually unsatisfactory. In the upper limb, however, with its universal movements and more diverse and refined functions, muscles are more accustomed to the need for varied uses and individual specialization, and an extensor can be educated to take the part of a flexor (a normal action of the extensors upon the pronated forearm, p. 492) much more easily than in the lower limb (Dunn, 1920).

Associated Actions.—Muscles of one region may act in harmony with remote muscle-groups ; in walking, as the foot leaves the ground, the post-vertebral muscles of that side and the gluteus medius and minimus of the opposite side can be felt contracting to maintain the balance of the body. Again, in turning to look backwards we are mainly conscious of the movement of the head, and seldom realize the harmonious activity of the muscles of the eyes, trunk, limbs and feet ; indeed every large movement is preceded and accompanied by movements of which we are not aware until we study the concerted action carefully and analyse its different phases. Owing to these associations, paralysis of a single muscle affects the general co-ordination as well as the chief movement in which it is concerned. The defect resulting from paralysis of a muscle is not necessarily a full indication of its action as a component of the movement.

Dual Action of Muscles.—Apart from voluntary actions, some striated muscles also perform involuntary movements ; and in certain lesions of the central nervous system it is a point of clinical interest that a muscle, though intact, cannot execute its voluntary movement although it may retain its function for involuntary *bilateral* acts—*e.g.*, a paralysed upper limb is moved with its fellow in the stretching that accompanies a yawn, and a latissimus dorsi, paralysed for voluntary unilateral movement, contracts in the instinctive bilateral act of coughing (Beevor, 1904). Further, a muscle which participates in more than one voluntary movement (*e.g.*, biceps, flexor and supinator) may be paralysed for the one movement and not the other, as the movements are not represented in the same part of the cerebral cortex.

Ligamentous Action of Muscles.—The ligaments of a joint would require to be much stronger and bulkier were it not for the aid given by muscles. All the activities of muscles, from gentle muscle-tone to vigorous contraction, prevent undue strain being thrown on the ligaments ; and, indeed, ligaments stretch rapidly when the muscular safeguard is removed or diminished. But muscles have a more truly ligamentous effect through their inability to relax sufficiently to allow free movement of a joint in all circumstances. For example, when the

knee is straight the hamstring muscles, unable to relax enough to permit full flexion of the hip joint, play the part of restraining ligaments at that joint (cf. pp. 529, 543).

Postural Action.—Even at rest, during consciousness, all voluntary muscles are under slight tension, called *tone* or *tonus*. This is well marked in muscles which habitually maintain and regain the normal posture of the body against gravity, and such muscles, sometimes termed the anti-gravity muscles, may be said to possess a postural function. For the main part, the extensor muscles of the lower limb, trunk and neck exercise this function which may be easily demonstrated by the following methods. Stand erect with one hand placed upon the back, lean slightly forwards, and the increased tension of the extensors to maintain the balance will be felt at once. Instead of leaning forwards, the mere raising of one arm forwards, disturbs the delicate postural balance and produces the same effect upon the extensors. In the erect position, a slight inclination forwards and then backwards causes alternate tension and relaxation of the extensors and flexors of the trunk easily detected by one hand on the back and the other on the abdomen. Other instances of postural muscular activity—a function, be it noted, which is carried out for long periods without appreciable signs of fatigue—are the sitting posture, the clenched position of the teeth by the elevators of the mandible, the suspension of the upper limb by supraspinatus (aided by infraspinatus, teres minor and subscapularis) and the action of the deep muscles of the calf not only in helping to keep the posture erect but also in maintaining the arches of the foot.

The student must be careful to appreciate that this postural play upon particular muscles is controlled by the central nervous system through reflexes in the spinal cord, initiated by impulses from other muscle-groups, the skin, the labyrinth and higher centres in the brain. Slowly contracting muscles are not radically different from their fellows except for the predominance of their red fibres as against the pale fibres in the rapidly contracting muscles. In some groups the superficial muscles may be of the pale type and the deep of the red variety; for example, the superficial, pale, rapidly contracting gastrocnemius and the deep, red, slowly contracting postural soleus. As both gastrocnemius and soleus act posturally as well as in rapid and exhausting voluntary movement, there is no vital difference between the types.

Action-Currents in Muscle.—The activity of a muscle produces action-currents which may be recorded by electrical apparatus—a valuable method of determining the active and inactive muscles in a movement; the activity of the internal intercostal muscles in expiration has been demonstrated in this way.

Nerve-Supply.—Each muscle is supplied by one or more nerves, which in their course through it separate into smaller and smaller branches. Ultimately their terminal filaments (axons) give off numerous collaterals, each of which forms a special end-plate in relation to a muscle-cell.

It has been estimated that of the fibres contained in a nerve of supply to a muscle three-fifths are motor and two-fifths are sensory; the reciprocal action of these has already been described under muscle-fibres. In addition, all muscles receive sympathetic nerve-fibres, which have been shown to diminish and delay the occurrence of fatigue in skeletal muscle, but the details of their action are not yet fully determined.

Vascular Supply.—*Blood-vessels* enter muscles with the nerves along a line which is frequently definite enough to receive the name of *neuro-vascular hilum* (Brash, 1947). Striated muscles may be said not to possess *lymph-vessels* since these are not found between the individual fibres. But a capillary network is present in the sheath of a muscle and between the fasciculi. (Aagaard (1913) states that there is a lymph-capillary plexus around the fibres of striated muscle.)

FASCIÆ AND SYNOVIAL SHEATHS AND BURSÆ

Beneath the skin there are two layers of connective tissue to be considered in relation to the muscular system—the superficial fascia [panniculus adiposus] and the deep fascia. The panniculus carnosus (rudimentary in man) lies in the substance of the superficial fascia.

The cells of the mesoderm, not differentiated into muscles, vessels, and bones are utilized to form connective tissue or fascia which ensheaths these structures.

Superficial Fascia.—The superficial fascia is a continuous sheet of areolar tissue which underlies the skin of the whole body. It is closely adherent to the corium; and, except beneath the skin of the eyelids, penis, and scrotum, it is usually more or less impregnated with fat. The fat of the superficial fascia is scanty in the healthy adult male, but tends to increase on the abdomen, breast, and buttocks; it forms a thicker subcutaneous layer in women and children, and is thus mainly responsible for the more rounded contours of their bodies. Its relative amount is indeed a secondary sex-character, since in the average it accounts for about 18 per cent. of the body-weight in men and 28 per cent. in women. The cutaneous vessels and nerves ramify in this fascia; and its deep surface—membranous in character—is in loose connexion with the deep fascia. It is chiefly in this layer that dropsical effusions occur.

Deep Fascia.—Underneath the skin and superficial fascia there is a fibrous membrane, bluish-white in colour, devoid of fat, and in closest relation to skeleton, ligaments, and muscles. This is the deep fascia. It covers and invests the various muscles, and in some cases is the means of their attachment. It has a special tendency to become attached to all subcutaneous bony prominences, and to be continuous with the ligaments. Laminæ from its deep surface extend inwards among the deeper structures; these sheets enclose glands and viscera, provide nerves and vessels with sheaths, and form **intermuscular septa** which separate groups of muscles and individual muscles—affording them additional means of attachment.

In the distal portions of the limbs, where the various joints are close to one another, special thickenings of the deep fascia called **retinacula** are present for the purpose of retaining the tendons in position when their muscles contract. These fascial bands act as pulleys round which the tendons work, and they serve to prevent waste of power. There is a further modification on the flexor aspects of the digits for the same purpose; the fibrous bands are connected to one another and to the phalanges in such a way as to form osteo-fascial tunnels in which the tendons lie.

It is important for the student to appreciate the function of the undifferentiated mesoderm which remains as a living packing-material to embed those structures (vessels, muscles, bones) that are of mesodermal origin. This conception clarifies the fact that where muscles or vessels cross each other, or lie in contact, the fascial bed makes a common wall for the separate tunnel or tube each structure occupies. This arrangement of the investing fascia, the texture of which may vary from a dense sheet to a thin membrane, is evident in the living subject; but in the dissecting-room a wrong impression may be obtained from the preserved subject by an artificial cleavage that splits up the fascial bed, like a slate slab, into numerous planes and sheaths. These points should be kept in mind particularly in dealing with the fasciæ of the neck and pelvis (cf. Fig. 380).

Synovial Sheaths.—In the situations just described, where tendons are retained in place by localized thickenings of the deep fascia, synovial sheaths are provided to facilitate their movements. Such sheaths may be related to one or more tendons. They are always closed sacs, with a parietal layer lining the walls of the space in which the tendon lies and a ‘visceral’ layer closely applied to the tendon itself, so that the two synovial surfaces are in apposition with each other.

In the digital synovial sheaths, continuity is established between the parietal and visceral layers by means of **vincula tendinum** (p. 496), as well as at the extremities of the sheaths. The vincula tendinum transmit small blood-vessels, and they may be regarded as incomplete ‘meso-tendons’.

Synovial Bursæ.—Simple, closed synovial sacs are placed between a tendon (or an aponeurosis) and a bony point or ligament over which it plays, or between the distal ends of two or more tendons, when they are inserted in close proximity to one another.

DESCRIPTION OF THE MUSCLES

In the study of the muscular system it is necessary to note the following characters in reference to each individual muscle: (1) The *shape* of the muscle—flat, cylindrical, triangular, rhomboidal, etc.; and the character of its extremities—membranous, tendinous, or fleshy. (2) The *attachments* of the muscle. (3) The *relations* of the surfaces and borders of the muscle to bones, joints, muscles, and other important structures. (4) Its *vascular* and *nervous supply*. (5) The *movements* in which it takes part.

The skeletal muscles may be divided into two series: axial and appendicular. The **axial muscles** comprise the muscles of the trunk, neck, head, and face; they are more or less segmental in arrangement, and are grouped around the axial skeleton. The **appendicular muscles** are the muscles of the limbs; they are grouped around the appendicular skeleton, and they are not segmental in arrangement.

AXIAL MUSCLES

MUSCLES OF VERTEBRAL COLUMN

The muscles of the vertebral column are arranged in two main groups—post-vertebral and prevertebral—on the dorsal and ventral aspects of the column respectively. The post-vertebral or dorsal group is by far the more extensive and the more complex in its attachments. It extends from the sacrum to the head, forming a cylindrical fleshy column in the loin, filling up the vertebral groove in the thoracic region, and giving rise to the muscular mass at the back of the neck. It is attached not only to the vertebral column but also to the pelvic girdle below, the posterior part of the base of the skull above, and, by means of numerous slips of its component parts, to all the ribs.

The prevertebral or ventral group, on the other hand, is interrupted. It extends from the base of the skull, in front of the foramen magnum, to the upper thoracic region, and reappears again in the lumbar region as the psoas major and minor.

It is evident that the physiological antagonists of the powerful dorsal group, whose main action, taken as a whole, is to extend the vertebral column, are to be found not merely in the true prevertebral group directly in relation to the vertebral column, but also and mainly in the ventral and lateral muscles of the abdominal wall, which, through their attachments to the thorax, are in a position to bend the vertebral column forwards on the pelvis.

The muscles of the back, from the topographical point of view, may be conveniently divided into two main groups—(1) the *superficial* and (2) the *deep*.

The **superficial muscles of the back** are described with the muscles of the upper limb, which they connect to the axial skeleton.

DEEP MUSCLES OF BACK

The **deep muscles of the back**—the post-vertebral or dorsal group of the vertebral column—may be classified according to their attachments in three series — vertebro-costal, vertebro-cranial, and intervertebral. It is, however, more convenient to describe them as they are met with in irregular strata in the dissection of the back. On this basis, and having regard to serial repetition of attachments and the general direction taken by the muscular fibres, the greater part of this complex musculature—so bewildering at first to the student, subdivided as it has been into many parts, separately named and largely artificial—may be resolved into two main systems: a superficial, longitudinal *sacro-spinalis* system and a deeper, oblique *transverso-spinalis* system. These form the basis of the first two of the following three groups into which the deep muscles of the back may be divided: (1) the sacro-spinalis system and the splenius muscle; (2) the transverso-spinalis system (semispinalis thoracis and cervicis, multifidus and rotatores) with

the semispinalis capitis; and (3) the interspinal, intertransverse, and suboccipital, muscles.

The general regional disposition as indicated in Figs. 353, 354, should be studied rather than the details of attachments.

It should be noted that the component parts of the more superficial group are arranged in more or less separate longitudinal columns and stretch between their attachments over many vertebræ; the component parts of the deeper muscles are shorter, passing over fewer vertebræ; and in the deepest layer the attachments of the individual parts are between contiguous vertebræ only.

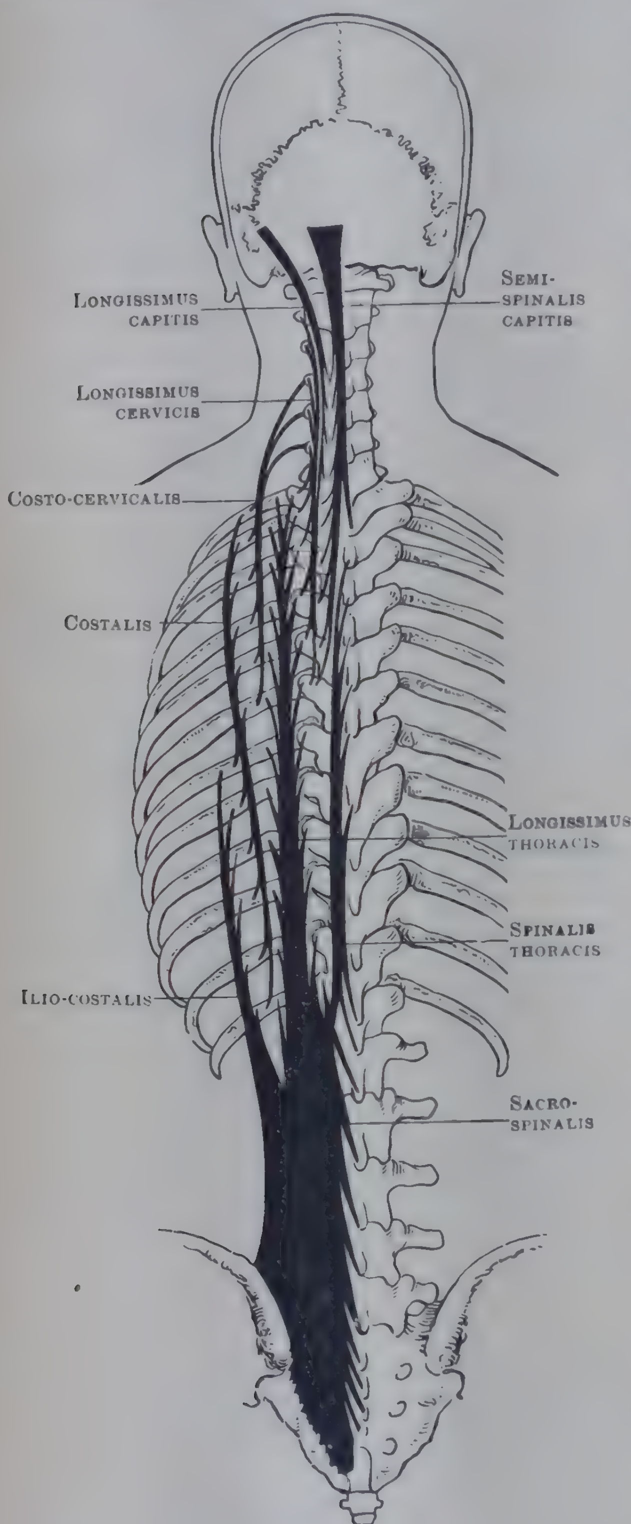


Fig. 353.—Schematic Representation of the Parts of the Left Sacro-Spinalis Muscle.

In general also, the differentiation of the muscular systems described increases from below upwards. All three groups are continued to the head, and, in the cervical region, portions of each become definitely individualized in relation to the finer movements of the head and the cervical part of the vertebral column as compared with the more generalized movements of the column as a whole.

Two small muscles called the *serrati posteriores, superior* and *inferior*, situated between the superficial and the deep muscles of the back, are described with the muscles of the thorax, to which they properly belong.

First Group

This group includes the sacrospinalis with the spinalis thoracis (usually described as its medial column), and the splenius (capitis and cervicis) muscle, which lies in a more superficial plane in the upper thoracic and cervical regions.

Splenius.—The splenius muscle, situated in the back of the neck and the upper part of the thoracic region, is a broad band which straps down the underlying muscles. It **arises** from the ligamentum nuchæ (from the level of the fourth cervical vertebra downwards) and from the spines of the last cervical and higher (four to six) thoracic vertebræ.

Its fibres extend upwards and laterally into the neck, separating in their course into an upper and a lower part. The upper part is the **splenius capitis**, which is **inserted** into the mastoid portion of the temporal bone and the lateral part of the superior nuchal line of the occipital bone (Fig. 356). The lower part is the **splenius cervicis**, which is **inserted** into the posterior tubercles of the transverse processes of the upper three or four cervical vertebræ, under cover of the origin of the levator scapulæ.

The greater part of the muscle is concealed by the trapezius and the sterno-mastoid, but a portion of the splenius capitis appears between them in the floor of the posterior triangle of the neck. It is covered also by the rhomboid muscles, levator scapulæ, and serratus posterior superior, and, itself, helps to conceal the cervical prolongations of the sacro-spinalis and the semispinalis capitis.

Sacro-Spinalis.—The sacro-spinalis possesses vertebral, vertebro-cranial, and vertebro-costal attachments. It is an elongated mass composed of separate slips extending from the sacrum to the skull. Simple at its origin, it becomes more and more complex as it is traced upwards towards the head, its continuity as a whole being maintained at higher levels by relays of fibres arising as the lower fibres are inserted.

Its primary origin is: (1) by a strong tendinous sheet fused with the posterior layer of the lumbar fascia and continuous below, as it narrows to a pointed extremity, with the posterior sacro-iliac, the sacro-tuberous, and the sacro-coccygeal ligaments, from the iliac crest and posterior superior iliac spine, the transverse tubercles and spinous crest of the sacrum and the lumbar and lower two thoracic spines; and (2) by fleshy fibres massed beneath the lateral border of the tendon just above the posterior superior iliac spine, where they obtain a powerful direct attachment to the upper half of the iliac tuberosity and to the inner lip of the iliac crest. Below this level the tendon is spread over the underlying multifidus muscle, which is separated from it for the most part by a layer of areolar tissue containing some fat. The sacro-spinalis muscle extends upwards through the loin, in which it forms the main muscular mass posterior and lateral to the multifidus, and it splits into three columns—**a lateral,** called the **ilio-costo-cervicalis,** derived from the lateral part of the fleshy origin, an **intermediate,** called the **longissimus,** and a **medial,** called the **spinalis thoracis.**

Ilio-costo-cervicalis.—The **ilio-costalis** is **inserted** by six slender slips into the lower six ribs.

Medial to the insertion of each of these slips is the origin of the **costalis** which, **arising** from the lower six ribs medial to the ilio-costalis, is **inserted** in line with it by similar slips into the upper six ribs.

The **costo-cervicalis arises** in the same way by six slips from the upper six ribs, medial to the insertions of the costalis. It forms a narrow band that extends into the neck to be **inserted** into the posterior tubercles of the transverse processes of the fourth, fifth, and sixth cervical vertebræ behind the scalenus posterior.

The three subdivisions of the ilio-costo-cervicalis form together a continuous muscular column, and constitute the most lateral group of the component elements of the sacro-spinalis.

Longissimus.—The longissimus is the largest element in the sacro-spinalis system. Mostly tendinous on the surface at its **origin,** it becomes fleshy in the upper part of the loin. It is thickest in the loin, and becomes thinner as it passes upwards in the back, as the longissimus thoracis, between the columns formed by the ilio-costo-cervicalis laterally and the spinalis thoracis medially. It is continued up into the neck as the longissimus cervicis and longissimus capitis.

The **longissimus thoracis** is **inserted** by two series of slips—laterally into nearly all the ribs, and medially into the transverse processes of the thoracic vertebræ and the accessory processes of the upper lumbar vertebræ.

The **longissimus cervicis** has an **origin** from the transverse processes of the upper six thoracic vertebræ, medial to the insertions of the longissimus thoracis. Extending upwards into the neck, it is **inserted** into the posterior tubercles of the transverse processes of the second, third, fourth, fifth, and sixth cervical vertebræ. In the neck it is concealed by the costo-cervicalis and splenius cervicis muscles.

The **longissimus capitis arises,** partly by an origin common to it and the previous muscle, from the transverse processes of the upper six thoracic vertebræ, and partly by an additional origin from the articular processes of the lower four cervical vertebræ. Separating from the longissimus cervicis, the muscle ascends through the neck as a narrow band which is **inserted** into the mastoid portion of the temporal bone, deep to the splenius capitis muscle. In the neck the muscle is placed between the splenius capitis and semispinalis capitis.

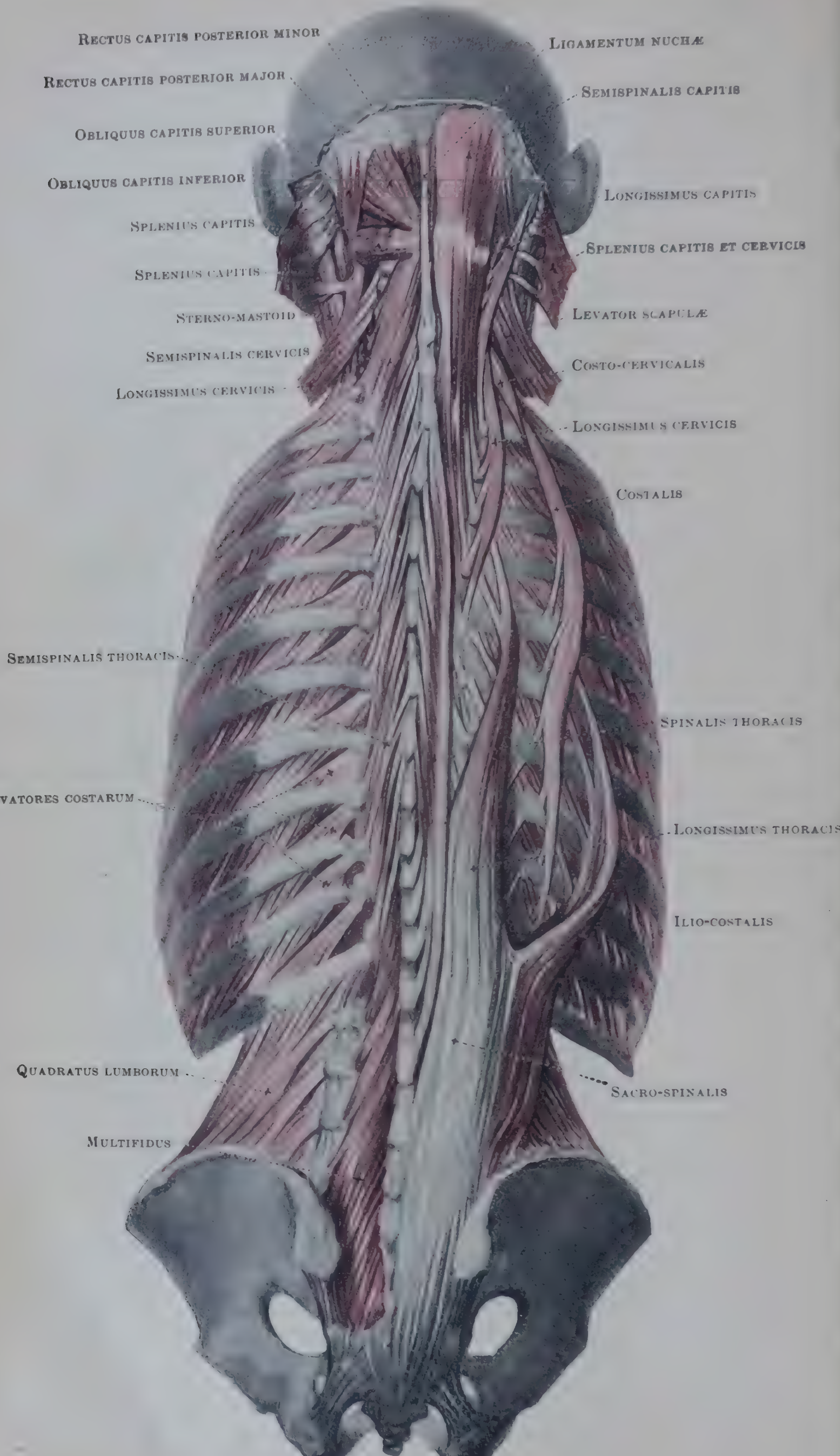


Fig. 354.—Deep Muscles of the Back.

Spinalis Thoracis.—The spinalis thoracis **arises** by tendinous fibres from the lower two or three thoracic and upper two or three lumbar spines, the lower slips being in common with the upper origins of the longissimus thoracis.

It is a narrow muscle which lies close to the thoracic spines medial to the longissimus thoracis, and it is **inserted** into the upper four to eight thoracic spines. It is not as a rule prolonged into the neck, though a **spinalis cervicis** and a **spinalis capitis** (joining the semispinalis) may both be present.

Second Group

This group comprises the multifidus (with the deep-lying rotatores) and the semispinales muscles (thoracis, cervicis, and capitis). The multifidus occupies the

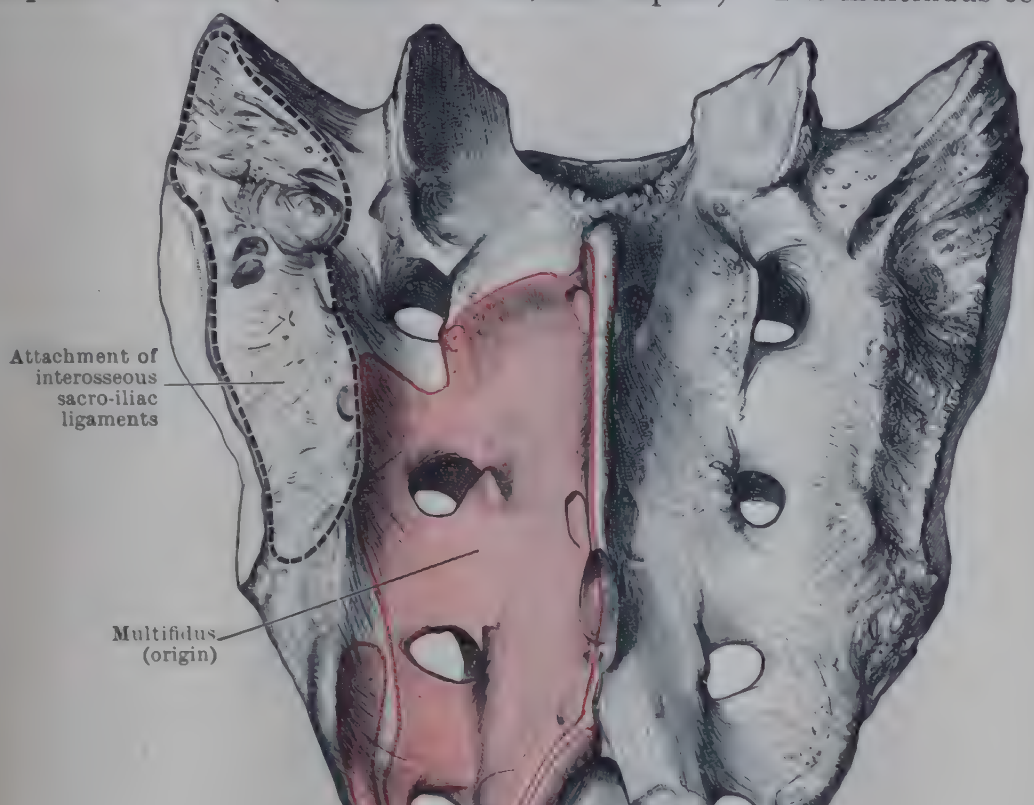


Fig. 355.—Muscle-Attachments to the Sacrum (Dorsal Surface).

The tendinous origin of the sacro-spinalis is represented by the thick line on the medial and lateral sides of the area of the origin of the multifidus.

whole length of the vertebral furrow; it is under cover of the sacro-spinalis below, while in the upper thoracic and cervical regions the semispinales form more superficial and overlapping strata partially concealed by the splenius. The more superficial muscles have the longer fibres; the fibres of the multifidus pass over fewer vertebræ.

In general, these muscles extend obliquely upwards from the transverse processes to the spines, thus constituting a "transverso-spinal" system; the semispinalis capitis, related to this system as the splenius is to the sacro-spinalis, with a similar origin, but extending to the base of the skull, is a corresponding "transverso-occipital" muscle. The general contrast between the directions of the fibres of this and the previous group should be noted as an indication of a real distinction between them; the fibres of the sacro-spinalis system pass upwards and laterally from spines to transverse processes, while those of the transverso-spinalis system pass upwards and medially from transverse processes to spines.

Semispinalis.—The semispinalis muscle extends from the loin to the skull. It is described as three muscles—the **semispinalis thoracis**, the **semispinalis cervicis**,

and the **semispinalis capitis**—but the separation between S. thoracis and S. cervicis is artificial.

The **semispinalis thoracis arises** from the transverse processes of the lower six thoracic vertebræ and is **inserted** into the spines of the first four thoracic and last two cervical vertebræ.

The **semispinalis cervicis arises** from the transverse processes of the upper six thoracic and the articular processes of the lower four cervical vertebræ, and it is **inserted** into the spines of the cervical vertebræ from the second to the fifth.

The **semispinalis capitis** is very similar in its attachments to the longissimus capitis, but it is a very much larger muscle and the direction of its fibres is different. It takes **origin** from the transverse processes of the upper six thoracic and the articular processes of the lower four cervical vertebræ medial to the longissimus

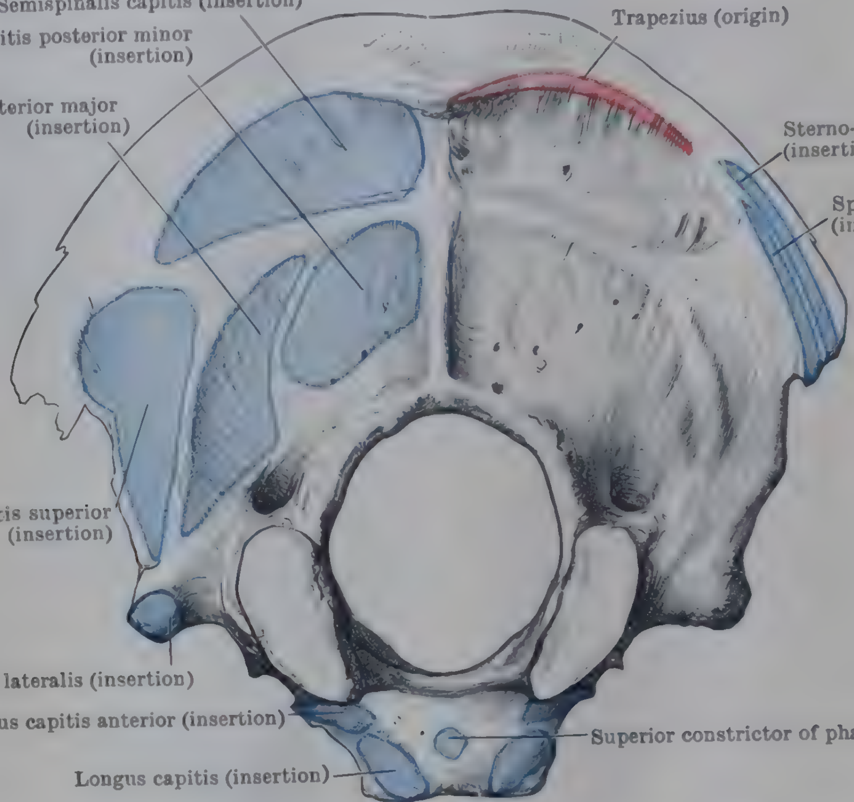


Fig. 356.—Muscle-Attachments to the Occipital Bone.

cervicis and longissimus capitis. It may have an origin also from a variable number of the spines of the lower cervical and upper thoracic vertebræ (**spinalis capitis**).

It forms a broad muscular sheet which extends upwards in the neck to be **inserted** into the medial impression between the superior and inferior nuchal lines of the occipital bone (Fig. 356). The medial portion of the muscle is separate; it consists of upper and lower muscular parts with an intervening tendon placed vertically in contact with the ligamentum nuchæ; this tendon is not to be confused with a tendinous intersection which may traverse the upper portion (Fig. 354). The muscle, covered by trapezius and, deep to that, mainly by the splenius and longissimus capitis muscles, forms the muscular mass that bounds the nuchal furrow. It conceals the semispinalis cervicis and the medial part of the suboccipital triangle, and its vertical fibres are usually visible at the upper angle of the posterior triangle of the neck above the splenius capitis.

Multifidus.—The multifidus differs from the semispinalis in extending from the sacrum to the second cervical vertebra, and in the shortness of its fasciculi, which pass over fewer vertebræ to reach their insertion.

It **arises** successively from the sacrum (Fig. 355) under cover of the tendon of the sacro-spinalis, from the posterior sacro-iliac ligaments, from the mamillary processes of the lumbar vertebræ, from the transverse processes of the thoracic vertebræ, and from the articular processes of the lower four cervical vertebræ. It is **inserted** into the spines up to and including the second cervical.

Lying in contact with the vertebral laminæ and, in the thoracic region, with the rotatores, the muscle is covered in the neck and back by the semispinalis, and in the loin by the sacro-spinalis muscle.

Rotatores.—The rotatores are eleven pairs of small muscles that occupy the vertebral groove in the thoracic region, deep to the multifidus, of which they form the deepest fibres. Each is a small slip which **arises** from the transverse process of one vertebra and is **inserted** into the lamina of the vertebra directly above.

Third Group

This group comprises several series of small muscles which are vertebro-cranial or intervertebral in their attachments, and include the special group of sub-occipital muscles.

Interspinales.—The interspinales are bands of muscular fibres that connect

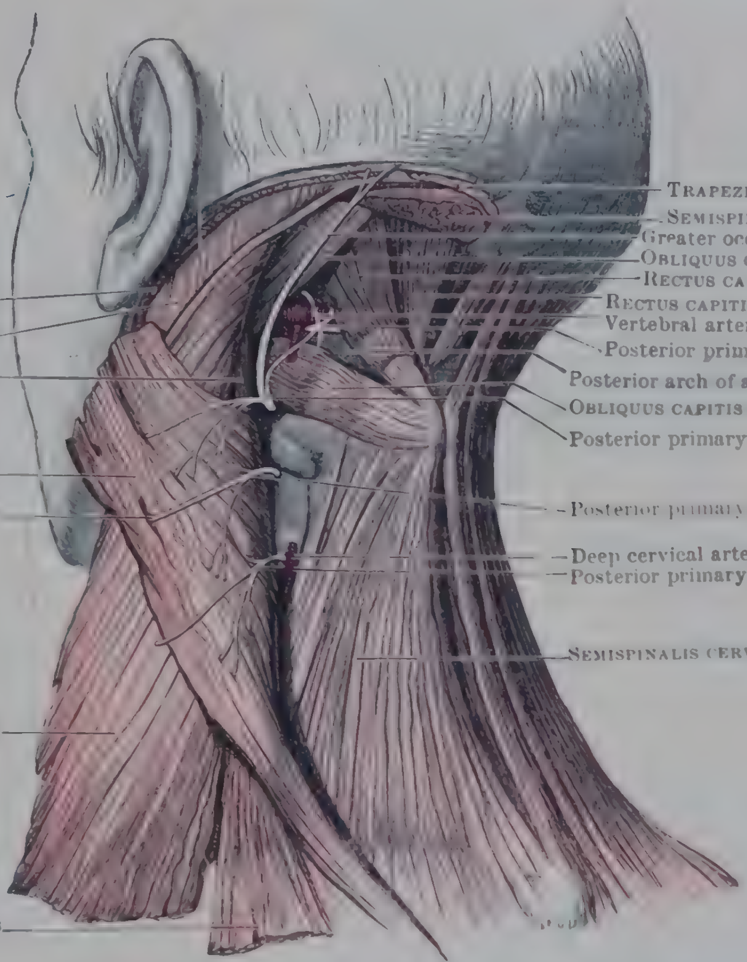


FIG. 357.—SUBOCCIPITAL TRIANGLE OF THE LEFT SIDE.

together the spines of the vertebræ from the second cervical downwards. They are well-developed in the cervical and lumbar regions, where they lie one on each side of the corresponding interspinous ligament, but they are poorly developed and may be absent in the thoracic region.

Intertransverse Muscles.—The intertransverse muscles are slender slips that extend between the transverse processes.

In the cervical region, with certain exceptions, an anterior intertransverse muscle extends from costal element to costal element in front of the emerging anterior primary ramus of the corresponding spinal nerve, and a posterior intertransverse muscle extends from transverse element to transverse element behind the nerve. Above the atlas, the rectus capitis lateralis is in series with the posterior intertransverse muscles, and the rectus capitis anterior may represent the anterior group. Between the atlas and the second cervical vertebræ, the posterior muscle is well developed and is situated, like the rectus capitis lateralis, posterior to the emerging nerve, but the anterior muscle in this space is frequently absent.

In the thoracic region the intertransverse muscles are absent, except in the lower three or four intervals, where their arrangement corresponds to that found in the lumbar region.

In the lumbar region lateral and medial intertransverse muscles are present. The lateral pass between the extremities of the transverse processes, while the medial connect the mamillary tubercles to the accessory tubercles of the vertebræ above.

Suboccipital Muscles.—These muscles are four in number—obliquus capitis inferior and superior, and rectus capitis posterior major and minor (Fig. 357). They are concealed by the semispinalis capitis, longissimus capitis, and splenius capitis, and enclose a triangular space (the suboccipital triangle) which contains the vertebral artery, the posterior primary ramus of the first cervical nerve, the posterior arch of the atlas, and the posterior atlanto-occipital membrane.

The **obliquus capitis inferior,** the stoutest of the group, **arises** from the spine of the axis vertebra and passes upward and laterally to be **inserted** into the transverse process of the atlas. The greater occipital nerve curls round the inferior border of this muscle.

The **obliquus capitis superior arises** from the transverse process of the atlas and passes backwards, upwards and medially to be **inserted** into the occipital bone, deep and lateral to the semispinalis capitis, above the inferior nuchal line (Fig. 356). The upper border of the muscle is closely related to the posterior belly of the digastric at its origin, and the occipital artery runs backwards between them.

The **rectus capitis posterior major arises** from the spine of the axis and **is inserted** into the occipital bone, deep to the obliquus capitis superior and semispinalis capitis, below the inferior nuchal line (Fig. 356).

The **rectus capitis posterior minor arises** deep to the preceding muscle from the posterior tubercle of the atlas and **is inserted** into the occipital bone below the inferior nuchal line, medial and deep to the rectus major (Fig. 356).

Nerve-Supply.—The deep muscles of the back are, in general, all supplied by the **posterior primary rami** of the **spinal nerves** according to their situation. The medial intertransverse muscles in the lumbar and lower thoracic region are supplied by posterior primary rami, but (as exceptions to the general statement) the lateral intertransverse muscles in the same regions, and both anterior and posterior intertransverse muscles in the cervical region, are supplied by **anterior primary rami.**

The four suboccipital muscles are supplied by branches of the **posterior primary ramus** of the **first cervical nerve.**

Actions of the Deep Muscles of the Back.—These muscles act upon the vertebral column, head, ribs, and pelvis, producing, according to circumstances, flexion, extension, lateral bending and rotation. It is of special importance, in connection with the many disabilities that arise from faulty posture, injuries to the back, "muscular strains", etc., to remember that they are in constant action against gravity in maintaining the erect and sitting postures. Like all other muscles they pass readily into reflex contraction to prevent painful movements; the difficulty experienced in performing *any* muscular action efficiently when the muscles of the back are thus in rigid contraction emphasizes strongly the principle of the co-operation of all the muscles of the body in the simplest action.

The deep muscles of the back not only control the gravitational descent of the body in bending forwards (flexion), but also act powerfully in regaining the erect position (extension). The extensor muscles of the vertebral column are therefore twice as massive as the flexors—just the opposite of the proportions found in anthropoid apes (Fick, 1911). If extension is continued beyond the erect position—backward bending (Pl. XXIX, p. 342, Fig. 2)—the important action is the relaxation of the sterno-mastoid and the abdominal and prevertebral groups to permit and control the movement. If flexion of the column is resisted, or is performed against gravity as in getting up from the supine position, then the prevertebral muscles, to which the sterno-mastoid and the abdominal groups functionally belong, are called into action. Gravitational control is again concerned in lateral flexion. The oblique parts of the post-vertebral and prevertebral muscles, the oppositely-directed fibres of the two sides working in unison, produce rotation—a movement that occurs also in the lumbar region. The muscles that produce lateral flexion act with those that produce rotation, which must also occur during side-bending. Although relaxation of the post-vertebral group secures forward bending (flexion) of the body, it should be noted that the greater part of this movement is executed not so much by the vertebral column as by relaxation of the hamstring muscles to allow flexion of the hip.

The association of the post-vertebral muscles with the limb-muscles in walking (p. 408) and also their postural action (p. 409) have already been mentioned. The muscles acting upon the head, particularly those of the suboccipital group, may be associated

with the muscles of the eyeballs; for example, when the eyes are turned to one side, the head also is turned to that side.

The student will appreciate therefore that the following statement of isolated muscle actions is merely a summary of mechanical deductions and is of little clinical value.

Splenius cervicis—Extension and lateral flexion of vertebral column to the same side.
Splenius capitis—Extension of head, and lateral flexion and rotation to the same side.
Sacro-spinalis, multifidus and semispinalis—Extension, lateral flexion, and rotation of column; extension and lateral movement of pelvis in walking.
Longissimus capitis and semispinalis capitis—Extension, lateral flexion and rotation of the head.
Inferior oblique—Extension, lateral flexion and rotation of the atlas (with the head) on the axis.
Superior oblique—Extension, lateral movement and rotation of the head on the atlas.
Rectus capitis posterior major—Extension, lateral flexion and rotation of the head.
Rectus capitis posterior minor—Extension and lateral flexion of the head.

FASCIÆ OF THE BACK

The **superficial fascia** of the back is thick and tough, and contains a quantity of granular fat.

The **deep fascia** is attached to the superior nuchal line of the occipital bone and in the median plane to the ligamentum nuchæ, and, below this level, to the supraspinous ligaments and vertebral spines—thus extending from the skull to the back of the sacrum and coccyx. Its fibres are mainly transverse. It ensheaths the superficial muscles of the back and becomes continuous with the fascia of the neck, axilla, thorax, and abdomen (cf. Fig. 412, p. 483). In the shoulder region it is attached to the spine and acromion of the scapula and to the clavicle, and sweeps over the deltoid into the arm. Below and laterally it is attached to the iliac crest.

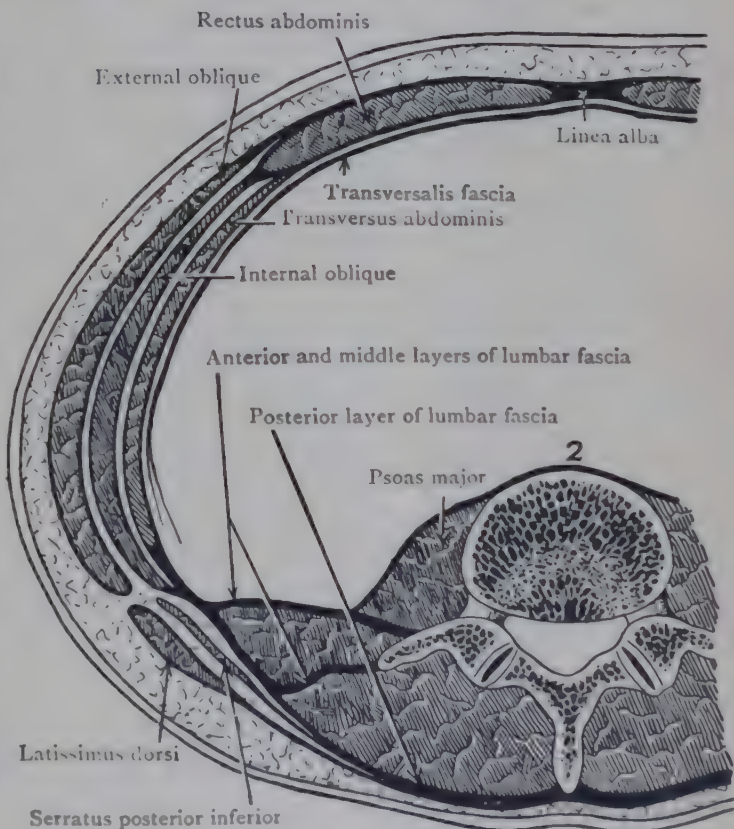


FIG. 358.—TRANSVERSE SECTION THROUGH THE ABDOMEN AT LEVEL OF SECOND LUMBAR VERTEBRA.

In the loin, the deep fascia is specially named the **lumbar fascia** and is divided into three layers—posterior, middle, and anterior—which enclose muscles between them; but the posterior layer is the only one of the three that is continuous with the deep fascia above the loin. In the course of development the deep muscles of the back, within their fascial sheaths, become covered by muscles derived from myotomes developed in other situations, for example, by the trapezius, rhomboid and latissimus dorsi muscles. The sheet that covers the posterior surface of the deep muscles of the back therefore runs upwards under the superficial muscles, becomes attached to the angles of the ribs lateral to the ilio-costo-cervicalis, and blends with the aponeurosis of serratus posterior superior in its course. In the sacral and lumbar regions, because of the interweaving of this sheath with the tendinous expansion of the latissimus dorsi and serratus posterior inferior, it becomes a strong, glistening aponeurosis termed the **posterior layer of the lumbar fascia**. This layer is attached medially to the lumbar and sacral

spines and supraspinous ligaments, laterally to the iliac crest; it covers the sacro-spinalis muscle, and is continuous round the lateral border of this muscular column with another fascial plane—the **middle layer of the lumbar fascia.** The middle layer is the continuation of the posterior aponeurosis of the transversus abdominis. It extends medially to be attached to the tips of the lumbar transverse processes. It covers the posterior surface of the quadratus lumborum and separates its medial part from the sacro-spinalis. Its upper border, between the twelfth rib and the first lumbar transverse process, blends with the lumbo-costal ligament. The **anterior layer** is the thinnest of the three. It covers the front of the quadratus lumborum and separates its medial part from the psoas major. Medially, it is attached to the fronts of the lumbar transverse processes. Laterally, it blends with the middle layer at the lateral margin of the quadratus to form a narrow band that stretches from the last rib to the iliac crest. Its upper border, between the twelfth rib and the first lumbar transverse process, forms the lateral arcuate ligament, which gives origin to part of the diaphragm and behind which the subcostal nerve and vessels pass from the thoracic to the abdominal wall.

MUSCLES AND FASCIÆ OF HEAD AND NECK

Deep Lateral and Prevertebral Muscles of Neck

There are three series of muscles in this group: (1) vertebro-costal (scalenus anterior, medius and posterior), (2) vertebro-cranial (longus capitis and rectus capitis anterior and lateralis), and (3) intervertebral (longus cervicis). They clothe the antero-lateral borders of the cervical portion of the vertebral column, and are in relation anteriorly with the pharynx and œsophagus, and the large vessels and nerves of the neck.

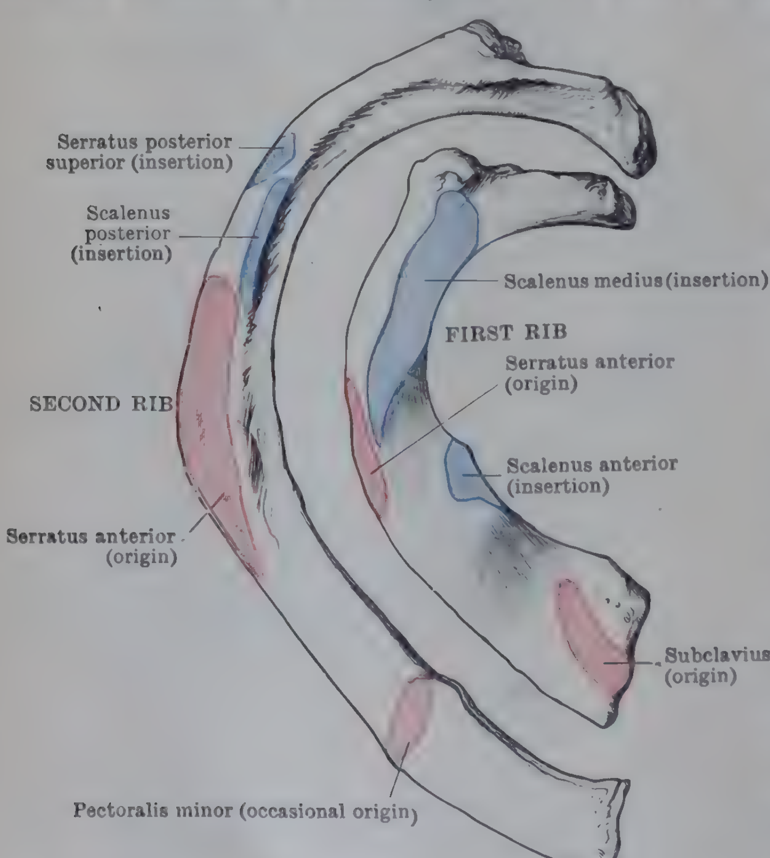


Fig. 359.—Muscle-Attachments to Upper Surface of First Rib and Outer Surface of Second Rib (Right Side).

Scalenus Anterior.—The scalenus anterior **arises** from the anterior tubercles of the transverse processes of the third, fourth, fifth, and sixth cervical vertebræ. It runs downwards and laterally to be **inserted** into the scalene tubercle and ridge on the first rib (Figs. 359, 360, 381).

The phrenic nerve is formed at the upper part of the lateral border of the scalenus anterior, runs vertically downwards on its anterior surface, and leaves its medial border a little above its insertion. The pre-vertebral fascia covers the muscle and binds down the phrenic nerve to its surface. With the exception of its insertion, which lies behind the clavicle, the muscle is completely covered by the sterno-mastoid, but the inferior belly of the omo-hyoid and the internal jugular vein intervene between them. It is separated posteriorly from the scalenus medius by the roots of the brachial plexus and the subclavian artery, while just anterior to its insertion the subclavian vein grooves the rib. Spasm of

the scalenus anterior with consequent elevation of the first rib may cause irritation of the fibres of the plexus that cross the rib, and section of the tendon has been successful in relieving the symptoms.

Scalenus Medius.—The scalenus medius **arises** from the posterior tubercles of the transverse processes of all the cervical vertebræ—occasionally omitting the first or the seventh. It descends in the posterior triangle, behind the brachial plexus and the subclavian artery, to be **inserted** into the rough impression on the first rib behind the subclavian groove (Fig. 359). The nerve to the rhomboids and the upper two roots of the nerve to the serratus anterior pierce the muscle, and descend on its lateral aspect under cover of the fascia.

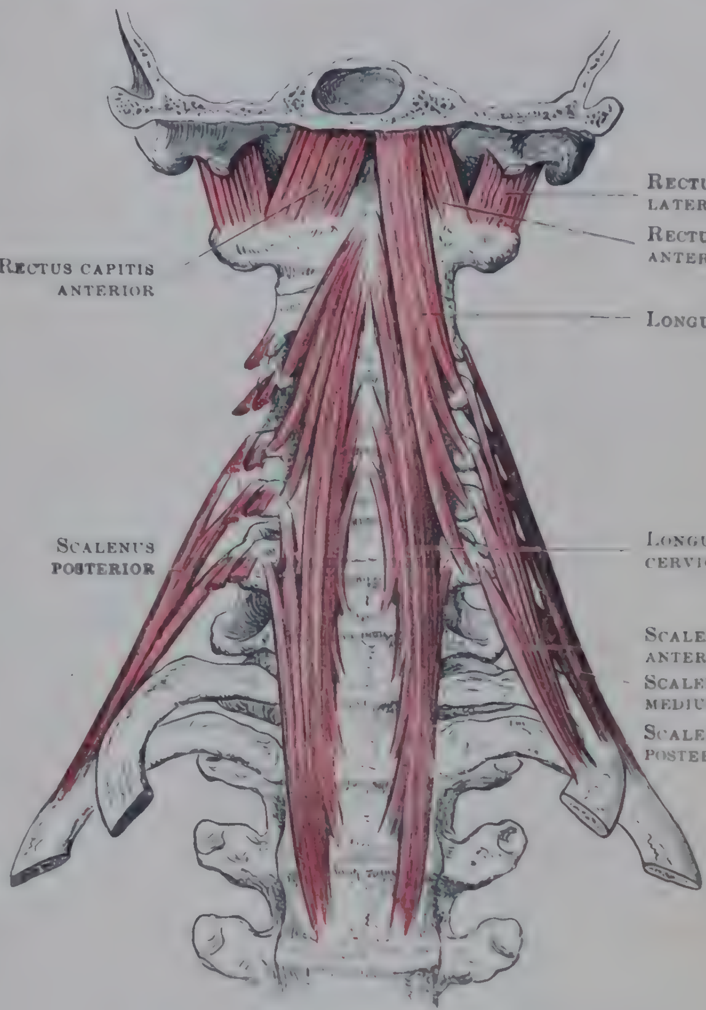


Fig. 360.—Prevertebral Muscles of the Neck.

Between these scalene muscles laterally and the longus cervicis medially, there is a pyramidal space into the base of which the pleura projects, capped by a fascial membrane that may be strengthened by a few slips from the scalene muscles and their fascial sheaths. The vertebral vessels run to the apex of this pyramid.

Scalenus Posterior.—The scalenus posterior **arises**, behind the scalenus medius, from the posterior tubercles of the fourth, fifth, and sixth cervical transverse processes. It is **inserted** into an impression on the outer side of the second rib behind the origin of serratus anterior.

At first completely hidden by the scalenus medius, the scalenus posterior appears in the lowest part of the floor of the posterior triangle in the angle between the scalenus medius and the levator scapulæ muscles.

Longus Capitis.—The longus capitis **arises** from the anterior tubercles of the transverse processes of the third, fourth, fifth, and sixth cervical vertebræ. It is a flat, triangular muscle which is directed upwards, behind the carotid sheath, and overlapping the upper oblique part of the longus cervicis muscle, to be **inserted** into an impression on the inferior surface of the basilar part of the occipital bone, anterior and lateral to the pharyngeal tubercle (Fig. 356).

Rectus Capitis Anterior.—The rectus capitis anterior **arises**, under cover of the longus capitis, from the lateral mass of the atlas. It is **inserted** into the basilar part of occipital bone between the longus capitis and the occipital condyle (Fig. 356).

Longus Cervicis.—The longus cervicis is a flattened muscular band which extends from the third thoracic vertebra to the atlas. It is divisible into three portions—a vertical, an inferior oblique, and a superior oblique portion. The **vertical portion** of the muscle **arises** from the bodies of the first three thoracic and the last three cervical vertebræ. Passing vertically upwards, it is **inserted** into the bodies of the second, third, and fourth cervical vertebræ (Fig. 360). The **inferior oblique portion arises** from the bodies of the first three thoracic vertebræ and is **inserted** into the anterior tubercles of the transverse processes of

the fifth and sixth cervical vertebræ. The **superior oblique portion arises** from the anterior tubercles of the transverse processes of the third, fourth, and fifth cervical vertebræ and is directed upwards to be **inserted** into the anterior tubercle of the atlas.

Rectus Capitis Lateralis.—The rectus capitis lateralis, in series with the posterior intertransverse muscles in the neck, **arises** from the transverse process of the atlas, and is **inserted** into the inferior surface of the jugular process of the occipital bone. It is placed alongside the rectus capitis anterior, separated from it by the anterior primary ramus of the first cervical nerve, and is covered anteriorly by the internal jugular vein.

Nerve-Supply.—All the muscles of this group are supplied by branches from the **anterior primary rami** of the **cervical nerves**—the recti from the loop between the first two, the longus capitis from the first four, the longus cervicis from second to eighth, and the scaleni from the lower five or six.

Actions.—The muscles of this group act together with, and as antagonists to, the cervical postvertebral muscles in movements of the neck and head. Against gravity and resistance they are flexors of the cervical vertebral column and of the head upon the column (including lateral flexion), according to their attachments. They also take part in movements of rotation; the lower oblique part of the longus cervicis, for example, may help to produce rotation to the opposite side. The *scalene* muscles, in addition to their action as lateral flexors of the vertebral column, are important accessory muscles of respiration as elevators of the first and second ribs.

MUSCLES OF THE HEAD

The muscles of the head are divisible into three separate groups: superficial (cutaneous) muscles, muscles of the orbit, and muscles of mastication.

Superficial Muscles

The superficial muscles are those of the scalp and face, and the platysma (which lies chiefly in the neck).

Muscles of the Scalp

The muscles of the scalp are the occipito-frontalis muscle and the extrinsic muscles of the auricle.

Occipito-Frontalis—The occipito-frontalis is a muscle with two pairs of bellies —frontal and occipital—united by a tendinous sheet, called the epicranial aponeurosis, which stretches uninterruptedly across the median line of the cranium. Each **occipital belly arises** as a broad flat band from the lateral two-thirds of the superior nuchal line of the occipital bone. The **frontal bellies** have no bony attachments. Each **arises** from the epicranial aponeurosis about the level of the coronal suture and passes downwards to the supra-orbital arch, where it interlaces with the orbicularis oculi muscle and is **inserted** into the skin. The two frontal bellies extend across the full width of the forehead and blend with each other in the median plane.

The **epicranial aponeurosis,** extending between the frontal and the occipital fleshy bellies, caps the dome of the skull, and has been termed the galea aponeurotica (from *galea*, a leather helmet). Posteriorly, it is attached to the superior nuchal line—its medial part directly, and its lateral part indirectly through the occipital bellies. Anteriorly, it joins the frontal bellies, sending a short slip between them; and a fascial layer beneath that is fixed to the supra-orbital margin. Laterally, it gives origin to the superior and anterior auricular muscles, and is continued downwards as a thin sheet that blends with the temporal fascia a short distance above the zygomatic arch. The superficial surface is bound to the skin of the scalp by dense fibrous strands with enmeshed fatty granules, but the deep surface is connected with the pericranium only by loose areolar tissue.

The attachments of the aponeurosis limit effusions beneath it which may extend forwards to the supra-orbital margin and downwards almost to the zygomatic arch. The mobility of

the scalp as a whole accounts for the readiness with which it may be torn away from the pericranium and for the scalp-hunter's dexterity in removing his victim's scalp by cutting through the aponeurosis.

The **extrinsic muscles of the auricle** are three in number: posterior, superior, and anterior. They are rudimentary and usually functionless, though variable in development and capable of training.

The **auricularis posterior** is a narrow fleshy slip which **arises** from the surface of the mastoid part of the temporal bone and is **inserted** into the cranial surface of the auricle. It bridges across the groove between the mastoid part of the temporal bone and the auricle, and conceals the posterior auricular vessels and nerve.

The **auricularis superior** is a fan-shaped muscle and is the largest of the three.

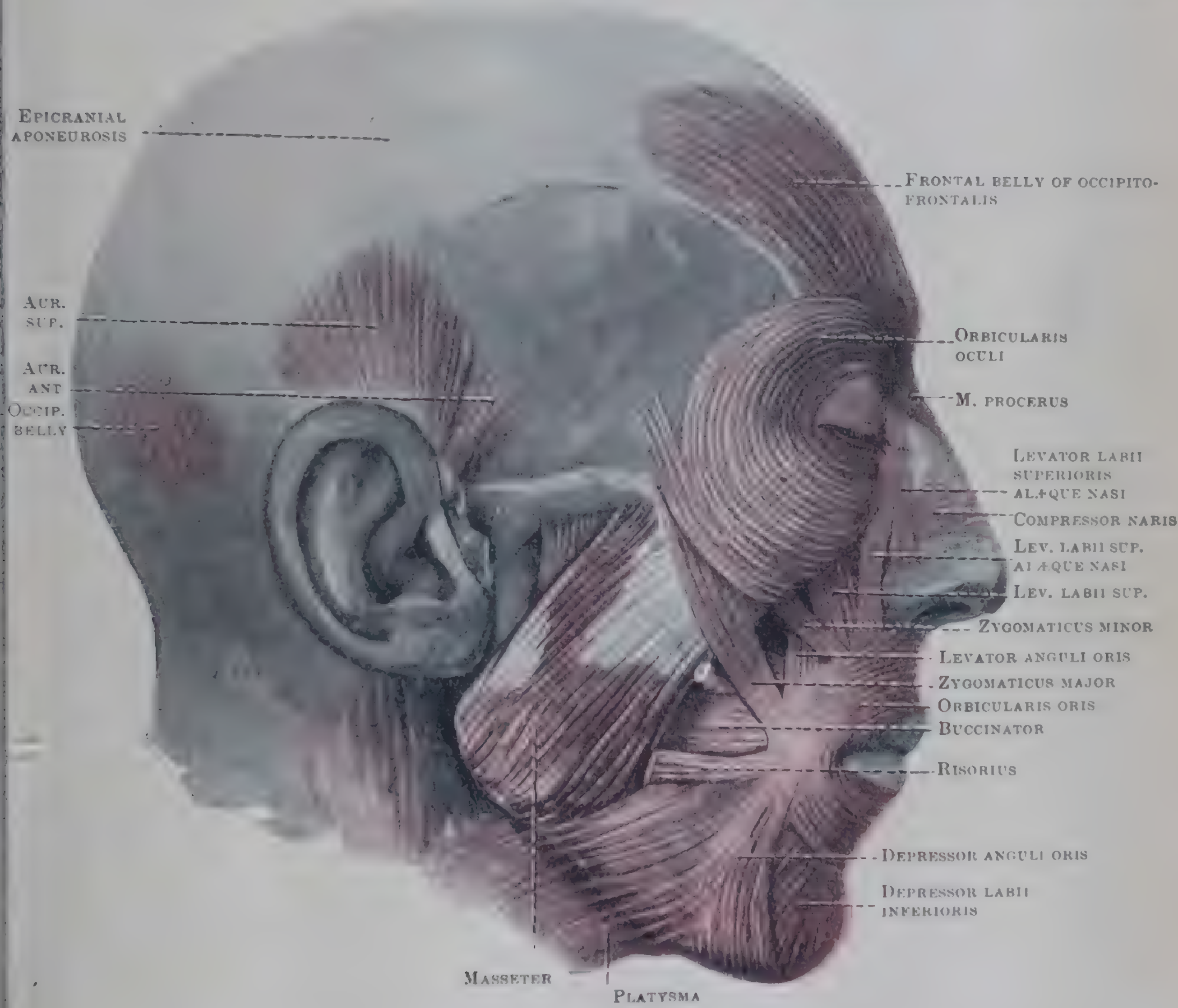


FIG. 361.—MUSCLES OF FACE AND SCALP (Muscles of Expression).

It **arises** from the epicranial aponeurosis and the temporal fascia, and descends to be **inserted** into the medial surface of the auricle opposite the fossa of the antihelix.

The **auricularis anterior** is a small muscle placed in front of the auricularis superior; it stretches obliquely from the temporal fascia to the anterior part of the medial surface of the helix.

The intrinsic muscles of the auricle and the small muscles of the tympanic cavity (tensor tympani and stapedius) are described with the Ear as an Organ of Sense.

Muscles of the Face

The facial muscles are divided into groups associated with the eyelid, the external nose, and the mouth.

1. The **muscles of the eyelids** are the orbicularis oculi, and the levator palpebræ superioris—which is described with the orbital muscles (p. 428).

Orbicularis Oculi.—The orbicularis oculi is a transversely oval sphincter muscle that surrounds and occupies the eyelids (Fig. 361). It is divisible into two parts which differ in action. The peripheral, **orbital part** has red, thick fibres, spreads on to the forehead, temple, and cheek, and closes the eyes forcibly; the central, **palpebral part** has pale, thin fibres, is situated beneath the skin of the eyelids, and closes the eyes gently.

The **orbital part** is attached to the medial orbital margin between the supra-orbital notch and the infra-orbital foramen—the medial palpebral ligament, also a source of origin, interrupting this bony attachment. Fibres arch from the site above the ligament round the upper lid and then return round the lower lid to the site below the ligament, without interruption laterally. (Some authors describe interlacing of the fibres of both lids laterally.) A deep bundle (*corrugator supercilii*), inseparable from the orbital fibres and arising from the medial part of the supra-orbital margin, runs, intermingling laterally with the superficial fibres, to be inserted into the skin of the medial half of the eyebrow.

The **palpebral part** has two origins—a superficial origin from the medial palpebral ligament and adjacent bone, and a deep origin from the crest of the lacrimal bone. The superficial fibres (preseptal) arch round the peripheral (septal) portions of the eyelids, while the deep fibres (pretarsal) pass across the tarsal plates; both sets interlace at the lateral angle to form the *lateral palpebral raphe*. The deep fibres, termed the *lacrimal part*, enclose the lacrimal canaliculi and run posterior to the lacrimal sac. A slip of delicate fibres, called the *ciliary bundle*, runs from the palpebral part along the free margin of each lid behind the eyelashes.

2. The **muscles of the nose**, small and feeble, are the procerus, compressor naris, dilator naris, and depressor septi.

Procerus.—The muscles of the two sides are united. **Arising** from the fascia covering the lower parts of the nasal bones, they broaden to be **inserted** into the skin between and above the eyebrows, interlace with the frontal bellies of the occipito-frontalis, and draw down the skin at the root of the nose and produce transverse wrinkling of the skin in this area.

Compressor Naris.—This muscle **arises** from the upper end of the canine eminence and is **inserted** with its fellow into an aponeurosis on the cartilaginous part of the nose. It compresses the nostril in the production of certain sounds, and its action is well seen in the crying infant.

Dilator Naris.—The dilator naris **arises** from the maxilla above the lateral incisor tooth and is **inserted** into the lateral part of the lower margin of the ala of the nose. It dilates the nostril.

The **depressor septi** is a flat quadrangular muscle that **arises** with the medial fibres of the dilator and is **inserted** into the mobile part of the nasal septum. It draws the septum downwards and narrows the nostril.

3. The **muscles of the mouth** are bilaterally placed, except for orbicularis oris. They are:—(1) orbicularis oris; (2) levator labii superioris alæque nasi; (3) levator labii superioris; (4) zygomaticus minor; (5) levator anguli oris; (6) zygomaticus major; (7) risorius; (8) depressor anguli oris; (9) depressor labii inferioris; (10) mentalis; (11) buccinator. With them may be considered the platysma, as it is a prolongation downwards into the neck of the same superficial sheet.

Orbicularis Oris.—The orbicularis oris is a sphincter formed by contributions from muscles converging on the mouth; it arches around the two lips, its constituent fibres partly interlacing at the angles of the mouth, thereby forming a nodule that may be felt in the living subject. Lying between the skin and mucous membrane of the lips, it is limited superiorly by the nose, and inferiorly by the junction of the lower lip and chin. The deeper fibres in the upper lip are derived from the buccinator muscle, reinforced by the *superior incisive* bundles. This pair of little bands arises from the nasal septum and from the maxilla above the lateral incisor teeth, and each passes laterally towards the angle of the mouth. The more superficial fibres are continued upwards from the depressor anguli oris and are inserted into the skin of the central part of the lip. A similar arrangement is found in the orbicularis oris in the lower lip. The deeper fibres are derived from the buccinator, but they are reinforced on each side by an *inferior*

incisive bundle, which runs laterally from the mandible below the canine tooth. The more superficial fibres are continued downwards from the levator anguli oris to be inserted into the skin of the median part of the lip.

Levator Labii Superioris Alæque Nasi.—With the dual action implied in its name, this is a narrow band that **arises** from the root of the frontal process of the maxilla, and descends along the side of the nose to be **inserted** partly into the ala of the nose and partly into the skin of the naso-labial groove, blending with the orbicularis oris.

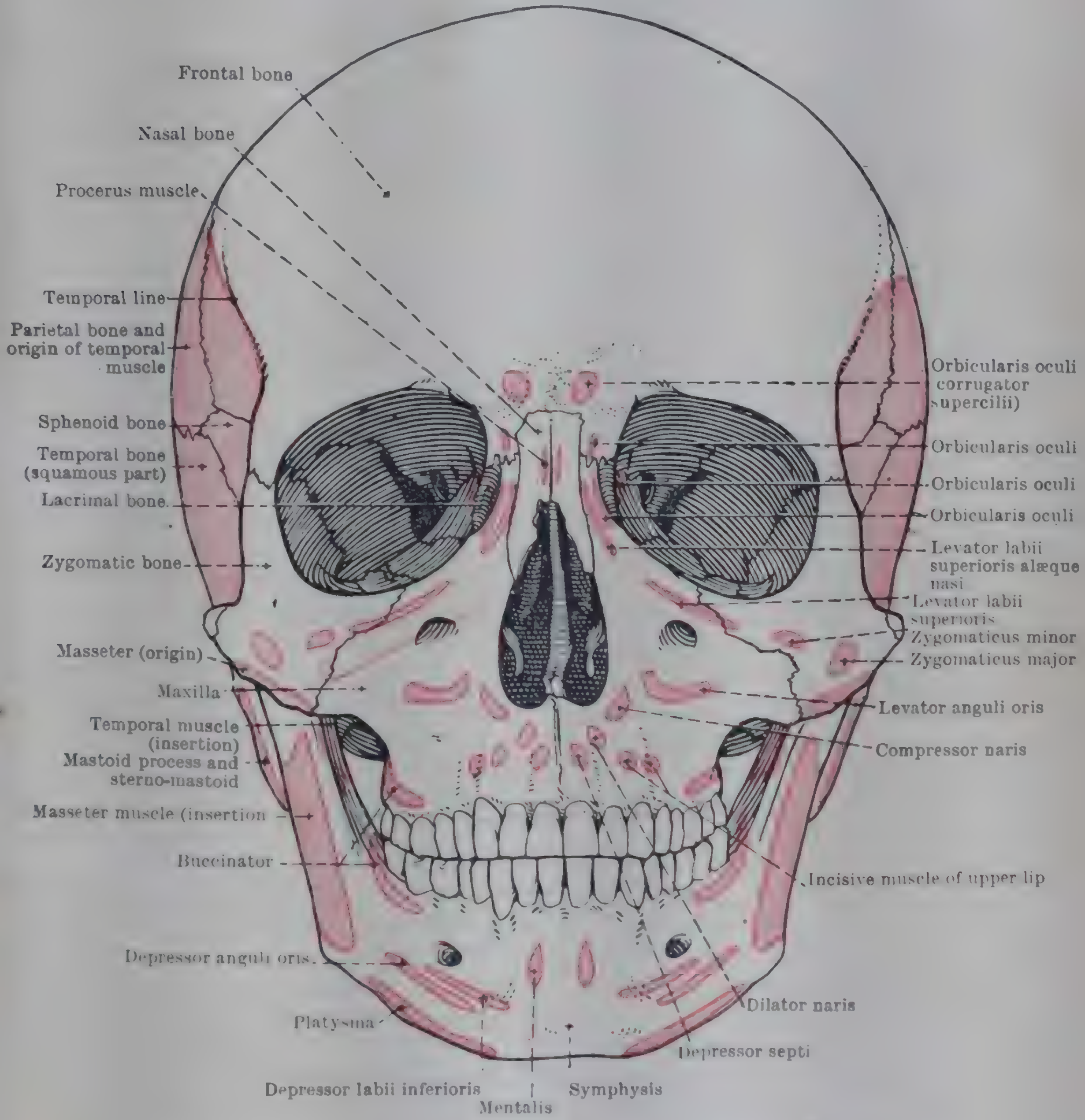


FIG. 362.—ANTERIOR VIEW OF SKULL, SHOWING THE MUSCULAR ATTACHMENTS.

Levator Labii Superioris.—The levator labii superioris **arises** from the maxilla immediately above the infra-orbital foramen, and it is **inserted** into the skin of the naso-labial groove; it conceals the infra-orbital vessels and nerve.

Zygomaticus Minor.—This slender slip **arises** from the zygomatic bone and is often continuous near its origin with the orbicularis oculi; it is **inserted** into the skin of the naso-labial groove and upper lip.

Levator Anguli Oris.—The levator anguli oris **arises** from the maxilla below the infra-orbital foramen and under cover of the zygomaticus minor. It is directed laterally and downwards, to be **inserted** into the orbicularis oris and the skin at the angle of the mouth, some fibres arching into the lower lip.

Zygomaticus Major—This narrow muscular band **arises** from the zygomatic portion of the zygomatic arch and passes to the angle of the mouth to be **inserted**

partly into the skin, partly into the orbicularis oris. When this muscle is involved in tetanus its spasm produces the facial appearance known as 'risus sardonicus'.

Risorius.—The risorius is a thin flat muscle which is in part a continuation of the platysma on the face, and in part a separate muscle, with an **origin** from the parotid fascia. It passes transversely forwards to be **inserted** into the skin at the angle of the mouth.

Depressor Anguli Oris—This muscle **arises** from the oblique line of the mandible and is continuous with the platysma (Fig. 361). It is triangular in form, its fibres converging on the angle of the mouth, where they are **inserted** into the orbicularis oris and the skin. Some of the fibres reach the upper lip through the orbicularis muscle.

Depressor Labii Inferioris—The depressor of the lower lip **arises** from the lateral surface of the mandible deep and medial to the depressor anguli oris (Fig. 362). It is quadrilateral in form and is directed upwards to be **inserted** into the orbicularis oris and the skin of the lower lip. Its lateral fibres are overlapped by the depressor anguli oris, and its medial fibres join with those of the opposite muscle.

Mentalis.—This small muscle **arises** from the mandible below the incisor teeth and passes downwards to be **inserted** into the skin of the chin.

Buccinator.—The buccinator muscle lies in the side-wall of the mouth, and is in series posteriorly with the constrictor muscles of the pharynx. **It arises** from the outer surfaces of the maxilla and mandible opposite the sockets of the molar teeth (Fig. 362), and from the pterygo-mandibular ligament. Its fibres are directed forwards to the angle of the mouth, where they blend with the corresponding (upper and lower) portions of the orbicularis oris muscle. The *middle fibres* of the muscle decussate at the angle of the mouth—the lower set passing to the upper lip, the upper set to the lower lip (cf. orbicularis oris, p. 424). Where the decussation occurs a firm node may easily be felt by gripping the angle between the finger and thumb. The buccinator is covered on its deep surface with the mucous membrane of the mouth. Towards its insertion it is concealed by the muscles which converge on the angle of the mouth; and it is covered behind by the masseter, from which it is separated by the buccal pad of fat. It is pierced by the duct of the parotid gland, and by branches of the buccal nerve. A small gap between the fibres arising from the maxilla and those arising from the pterygo-mandibular ligament transmits the tendon of the tensor palati as it bends round the pterygoid hamulus to gain the soft palate.

Platysma.—The platysma is a thin, quadrilateral sheet that **arises** in the upper pectoral and deltoid regions by scattered bundles from the superficial fascia and the skin, and extends from the chest over the side of the neck between the superficial and deep fasciæ to the face (Fig 361 and Pl. XXXVII, p. 456, Fig. 1).

It is directed upwards and forwards, and is partly **inserted** (by its intermediate fibres) into the lower border of the mandible, becoming connected with the depressor labii inferioris and depressor anguli oris muscles (Figs. 361, 362). The more anterior fibres pass across the median plane and decussate with those of the opposite side for a variable distance below the chin. The posterior fibres sweep over the angle of the jaw and become continuous with the risorius muscle.

Nerve-Supply.—The facial and scalp muscles are all innervated by the **facial nerve**. The *posterior auricular branch* supplies the posterior auricular muscle and the occipital belly of occipito-frontalis; the branches into which the facial nerve breaks up in the parotid gland supply the frontal belly, the superior and anterior auricular muscles, the several muscles associated with the apertures of the orbit, nose, and mouth (including the buccinator), and the platysma (cervical branch). The facial nerve conveys motor fibres to these muscles, and sensory fibres from them which gain the nucleus of the fifth nerve (Wakeley & Edgeworth, 1933); there is a similar arrangement in the innervation of the ocular muscles (p. 430) and probably also for the muscles of mastication and the muscles of the tongue.

Actions.—The almost infinite variety of facial expression is produced partly by the action of these muscles, partly by their inactivity, or by the action of antagonising muscles (antithesis). Joy is betrayed by the action of one set of muscles, while grief is accompanied by the contraction of an opposing set. Determination or eagerness is accom-

panied by a fixed expression due to a combination of muscles acting togeth ; and despair is expressed by a relaxation of muscular action.

The frontal belly of **occipito-frontalis** raises the eyebrows as in surprise, contraction of the occipital and frontal bellies moves the scalp backwards and fo ternate The **auricular** muscles may be capable of moving the auricle upwards and backwards. rds.

The **procerus,** assisting the upper deep part of the orbital portion of orbicularis ocu in wrinkling the skin at the root of the nose and adjacent part of the forehead, is s li habitually in use in some people as to be almost involuntary in its action. The **orbicularis oculi** contracts in protecting the eye from intense light and injury. The **orbital part** closes the lids firmly; the **palpebral part** closes the lids gently and keeps them applied to the eyeball, but it acts also reflexly—contracting periodically to moisten and clean the eye. This it does by drawing the eyelids medially and thereby wiping the tears across the eyeball to the lacus lacrimalis where they drain into the puncta. The *lacrimal part* is important because its destruction, *e.g.*, in operations on the lacrimal sac, results in the lower lid falling away from the eyeball (ectropion—seen also in facial paralysis). This portion also probably dilates the lacrimal sac and canaliculi. The levator palpebræ superioris and occipito-frontalis are antagonists of the orbicularis oculi. The **muscles of the nose** take part in contraction and dilatation of the nostrils. Their tonic action supports the alæ nasi, which do not move during ordinary respiration; but in deep and laboured respiration a visible movement of elevation and expansion takes place with each inspiration. In enfeebled states, on the other hand, owing to the diminution of the tonic action, the alæ nasi are drawn in with each inspiration giving a characteristic 'sharp' appearance to the nose. Of the muscles of the mouth, the **orbicularis oris** has a complex action, depending on the degree of contraction of its component parts, producing compression, contraction, and protrusion. The **zygomaticus major** and **risorius** are associated with mirth, the **depressor anguli oris** with grief, while the **mentalis** raises the skin of the chin and protrudes the lower lip.

The muscles of the lips are concerned in the production of speech, and they have an important function in retaining food during mastication. The delicate co-ordination between the **buccinator** and the tongue muscles in keeping food poised between the grinding teeth may be appreciated by the infrequency of the accident of biting either the inside of the cheek or the tongue. Apart from retracting the angles of the mouth as antagonists of the orbicularis oris, the buccinators control the expulsion of air from the distended cheeks (*buccinator*—a trumpeter). With the orbicularis protruding the lips the buccinators cave in the cheeks, producing a suctorial action. The **platysma** (Pl. XXXVII, p. 456, Fig. 1) retracts and depresses the angle of the mouth. Its contraction when the head is extended produces longitudinal ridging of the skin, well seen in violent stages of athletic effort, and the view has been advanced that its contraction prevents the retraction of the soft tissue at the root of the neck which would press on the veins and impede the return of blood to the heart in violent inspiratory effort. Its action is evident in sudden fear. It depresses the mandible, but only against resistance.

When the muscles of one side of the face are paralysed because of injury to the facial nerve (peripheral paralysis) the face is twisted to the opposite side by the unopposed pull of the sound muscles of that side; and, on the opposite side, the lines of the features are smoothed out, the eye cannot be closed and tears run down the cheek because the lacrimal puncta are not kept close to the eyeball through the lower lid falling away (see above). The lips are open upon the active side and slightly closed towards the affected side. Food and saliva cannot be retained by the affected cheek, and escape from between the lips on that side.

For further information, see Lightoller (1925); Huber (1931); Bell (1847); Duchenne (1867); and Darwin (1872).

Fasciæ and Muscles of Orbit

The eyeball, with its muscles, vessels, and nerves, is lodged in a mass of soft and yielding fat within the cavity of the orbit. The eyeball is surrounded by a fascial cup called the **fascial sheath of the eyeball**, which is loosely connected with the sclera by easily cleft *episcleral tissue.* The fascial cup accompanies the eyeball in its wider excursions, but there is a slight play of the eyeball within the cup. Anteriorly the sheath is adherent to the overlying conjunctiva, and to the sclera close to the corneal margin while more posteriorly it is pierced by the muscles, vessels, and nerves of the eyeball and is continuous with the sheath of the

...scial cup is thickened at the points where the muscles pierce it, ...ckwards over them as tightly-adherent sleeves, so that the fascial ...t anchor by the fascial expansions or **check ligaments** that extend ...the muscle-sheaths to the orbital walls; the strongest of these ligaments ...ing from the sheaths of the medial and lateral rectus and are called the medial

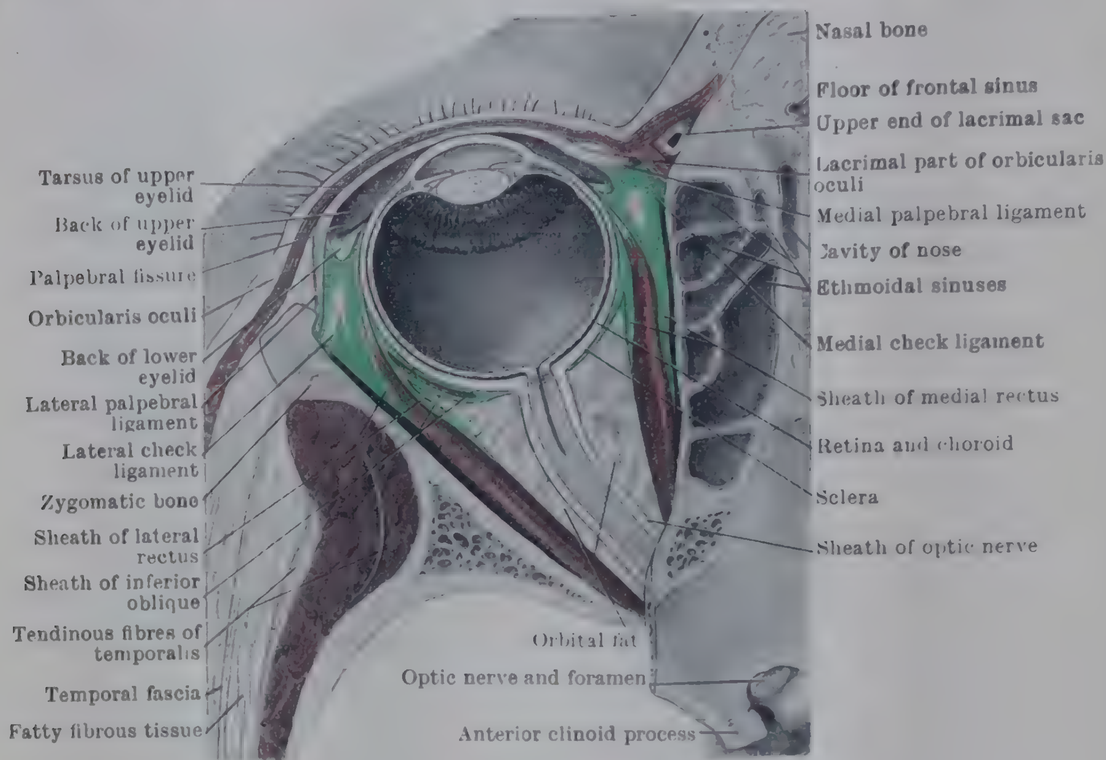


Fig. 363.—Horizontal Section through Left Orbit to show Arrangement of Fascial Sheath of Eyeball and Check Ligaments.

and lateral check ligaments. The *medial check ligament* is attached (1) just behind the crest of the lacrimal bone, (2) to the palpebral fascia behind the pars lacrimalis muscle, (3) to the caruncle and medial conjunctival fornix. The *lateral check ligament* is attached to (1) the orbital tubercle of the zygomatic bone at the mid-point of the orbital margin, (2) the lateral palpebral ligament and the lateral conjunctival fornix (Fig. 363). In the case of the inferior rectus, these expansions, sweeping towards the medial and lateral check ligaments, form a hammock—*suspensory ligament of the eyeball*—that holds the eyeball up in position and must therefore be preserved in surgical removal of the floor of the orbit. The fascial sheath helps to form a socket for an artificial eye when the eyeball is removed, and after this operation the muscles cannot retract far because of their tight adherence to the fascial sleeves.

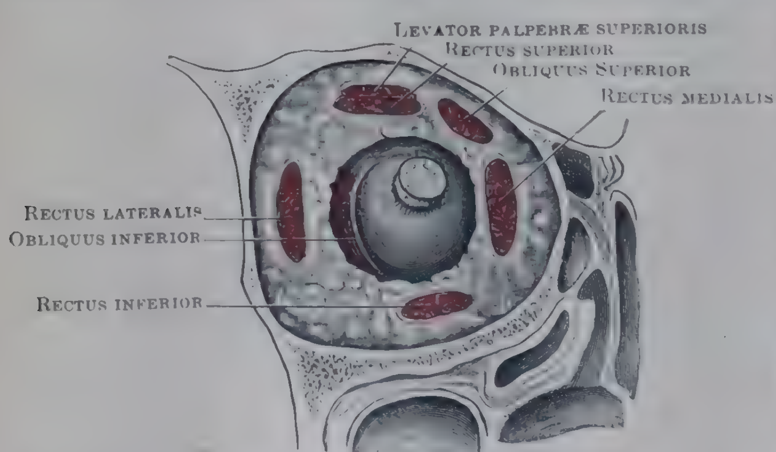


Fig. 364.—Coronal Section through Left Orbit behind the Eyeball to show Arrangement of Muscles.

The muscles of the orbit (Figs. 364-367) are seven in number: one, the levator palpebræ superioris, belongs to the upper eyelid; the other six are extrinsic muscles of the eyeball.

Levator Palpebræ Superioris.—The levator palpebræ superioris lies immediately beneath the roof of the orbit and covers the superior rectus muscle. It has a narrow **origin** from the roof of the orbit in front of the optic foramen. It

expands as it passes forwards to be **inserted**, in relation to the upper lid, into a membranous expansion. This aponeurosis has the following attachments: (1) arching from side to side over the eyeball, its ends, or horns, are fixed to the mid-points of the medial and lateral orbital margins; (2) a superficial layer of fibres from the anterior edge of the aponeurosis runs downwards into the eyelid to become attached to the front of the tarsus, and into the skin of the eyelid with the orbicularis; (3) a layer of plain (involuntary) muscle-fibres **arises** from the deep surface of the aponeurosis and is **inserted** into the upper border of the tarsus of the upper eyelid. The muscle has an additional attachment through its fascial sheath; anteriorly, the sheath is thickened by fusion with the sheath of the rectus superior, and is then attached to the superior fornix of the conjunctiva, so that the fornix also is pulled up when the lid is elevated.

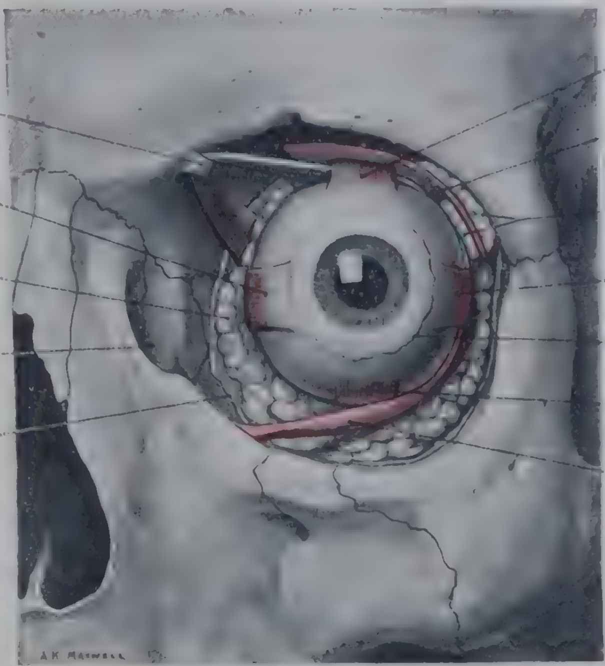


FIG. 365.—DISSECTION OF LEFT ORBIT FROM THE FRONT.

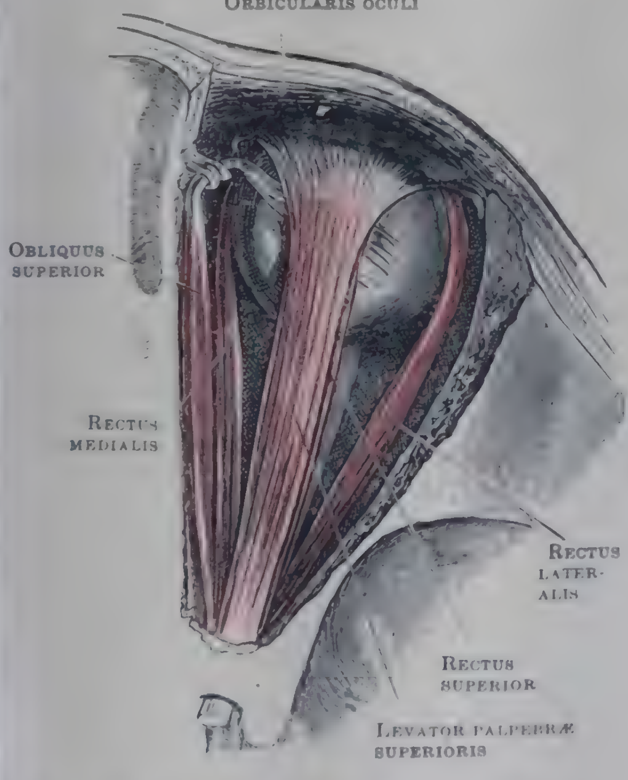


FIG. 366.—MUSCLES OF RIGHT ORBIT (from above).

Non-striated muscle is present in the eyelids of land mammals, but in the seal striated slips run from the recti to the eyelids, a condition partly represented in Man by the striated part of the elevator of the upper lid.

Mm. Recti.—The recti muscles are four in number—**superior, inferior, medial, and lateral**—and they all **arise** from a *common tendinous ring* (Fig. 896, p. 1024). Medially and superiorly the ring is attached around the optic foramen; laterally it bridges across the superior orbital fissure to be fixed to a tubercle on its lower margin. The part of the ring that gives origin to the rectus lateralis transmits the two divisions of the oculomotor nerve, the naso-ciliary nerve, and the abducent nerve between the two heads of origin. Forming flattened bands which lie in the fat around the optic nerve and eyeball, the four muscles end in tendons which pierce the fascial sheath and are **inserted** into the sclera about eight millimetres behind the margin of the cornea.

The **superior** and **inferior recti** are inserted in the vertical plane slightly medial to the vertical axis of the eyeball; the **lateral** and **medial recti** in the transverse plane of the eyeball; and all are attached in front of the equator of the eyeball.

Superior Oblique.—The superior oblique **arises** near the margin of the optic foramen supero-medial to the origin of the rectus medialis. It passes forwards, as a narrow muscular band, medial to the rectus superior, and at the anterior part of the orbit it forms a narrow tendon which passes (invested by a synovial sheath) through a special fibro-cartilaginous pulley (trochlea) attached to the roof of the orbit (the pulley is sometimes palpable in the living subject). Its direction is then altered, and, passing laterally and backwards between the tendon of the superior rectus and the eyeball, it is **inserted** into the sclera between the superior and lateral recti, midway between the margin of the cornea and the entrance of the optic nerve.

Inferior Oblique.—The inferior oblique **arises** from the floor of the orbit immediately lateral to the naso-lacrimal canal. It is a slender, rounded slip which passes laterally and backwards below the inferior rectus tendon and curves upwards between the lateral rectus and the eyeball to be **inserted** into the sclera between the superior and lateral recti, and farther back than the superior oblique muscle.

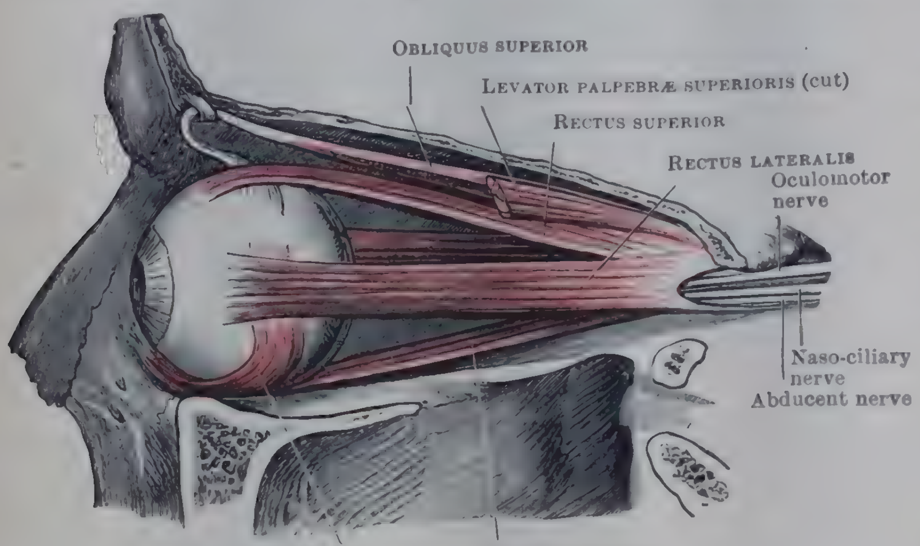


Fig. 367.—Muscles of Left Orbit (from lateral aspect).

The superior oblique muscle occasionally arises from the site of the pulley. This is normal in lower vertebrates, where the muscle is the counterpart of the inferior oblique; in mammals, a posterior belly develops; the two bellies join, and the pulley and tendon are the remains of the original anterior belly.

M. orbitalis is a rudimentary bundle of plain muscular fibres that bridges across the inferior orbital fissure and infra-orbital groove. It is supplied by sympathetic fibres, and it has been suggested that contraction of the muscle compresses the veins, producing congestion that causes the protrusion of the eyeball seen in hyperactivity of the sympathetic nervous system.

Nerve-Supply.—The muscles of the orbit are supplied by the third, fourth, and sixth cranial nerves. The **trochlear (fourth) nerve** supplies the obliquus superior; the **abducent (sixth) nerve** supplies the rectus lateralis; the **oculomotor (third) nerve** supplies the others—the levator palpebræ superioris and rectus superior by its superior division; the rectus medialis and inferior, and the obliquus inferior by its inferior division. The afferent fibres from the ocular muscles run in the third, fourth, and sixth nerves to the nucleus of the fifth nerve (Woollard, 1931; Tarkhan, 1934) (cf. p. 426). The plain muscle-fibres of the eyelids are supplied by the sympathetic system, and the upper lid is retracted or dropped in conditions that stimulate or paralyse this system (Fig. 890, p. 1017).

Actions.—The lateral and medial recti, by virtue of their insertions in front of the equator, rotate the eyeball so as to make the pupil look laterally or medially, respectively. As their insertions extend equally on to the upper and lower quadrants of the sclera, they produce no rotation around the transverse axis of the eyeball.

The superior and inferior recti rotate the eyeball so as to make the pupil look upwards and downwards, respectively; but, as the line of pull of each muscle passes by the medial side of the vertical axis of the eyeball, a slight degree of medial rotation accompanies the primary movement.

The superior and inferior oblique muscles, by virtue of their insertion behind the equator of the eyeball and because their pull is exerted from the forepart of the orbit, rotate the eyeball so as to make the pupil look downwards and upwards, respectively. As in the case of the superior and inferior recti, the lines of pull pass by the medial side of the vertical axis of the eyeball, but, as the pull is exerted from in front instead of from behind, the opposite effect—viz., lateral rotation—is added to the primary movement.

When the eyeball is rotated so as to make the pupil look directly downwards, the

superior oblique and the inferior rectus act together and the lateral rotation caused by the obliquus is counteracted by the medial rotation caused by the rectus. In a similar way the inferior oblique and the superior rectus act together to produce a purely upward direction of the pupil.

Combinations of rotation around the vertical and transverse axes of the eyeball are brought about by the combined actions of the superior oblique with the inferior and medial recti, or with the inferior and lateral recti, or by the combined actions of the inferior oblique with the superior and medial recti, or superior and lateral recti.

The levator palpebræ superioris elevates the upper eyelid and antagonizes the action of the palpebral part of the orbicularis oculi muscle. The plain muscle of the upper lid attached to the aponeurosis of the levator palpebræ superioris and the upper border of the tarsus raises the lid involuntarily.

Muscles of Mastication

The muscles of mastication are the masseter, the temporal, and the two pterygoid muscles—lateral and medial.

Masseter.—The masseter (Fig. 361), flat, quadrangular and the most superficial of these muscles, has an origin which is partly tendinous and partly fleshy. It arises in two parts: (1) superficially from the lower border of the zygomatic arch in its anterior two-thirds, and (2) more deeply from the deep surface of the zygomatic arch in its whole length. The superficial fibres, directed downwards and backwards towards the angle of the mandible, and the deeper fibres, directed vertically downwards, blend anteriorly but are separated behind by a slight cleft. The muscle is **inserted** by fleshy and tendinous fibres into the lateral surfaces of the coronoid process, ramus and angle of the mandible. The deepest fibres blend with the subjacent fibres of the temporal muscle. A "sub-masseteric space" that extends obliquely forwards across the ramus from above downwards has been

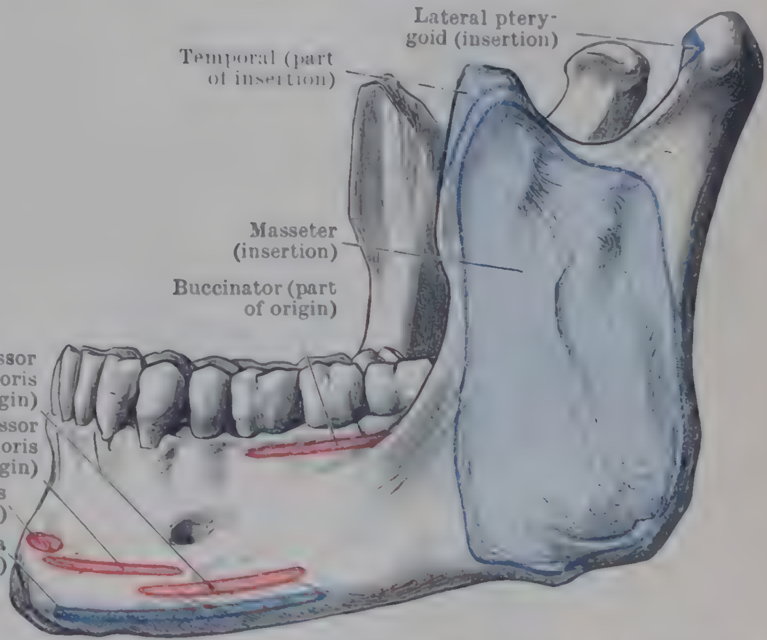


Fig. 368.—Muscle-Attachments to Superficial Surface of Mandible.

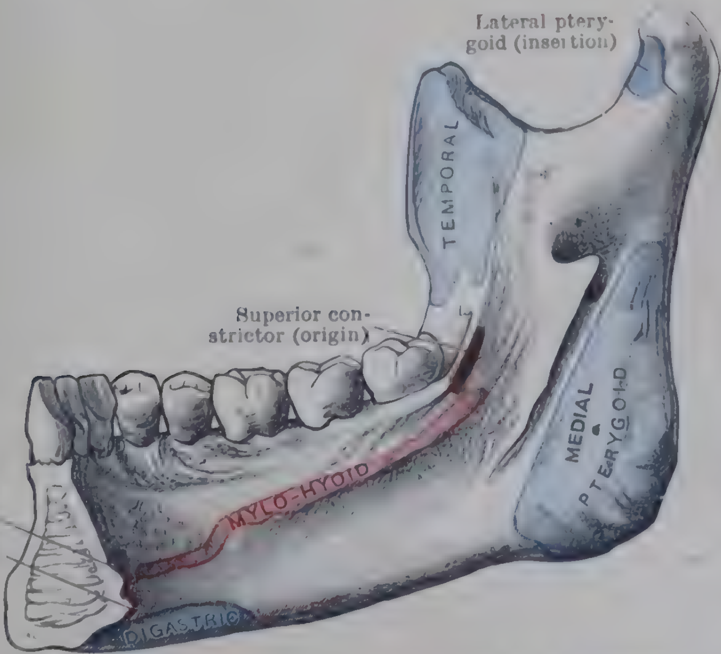


Fig. 369.—Muscle-Attachments to Deep Surface of Mandible.

described as separating the insertions of the deep fibres above and the superficial fibres below (Bransby-Zachary, 1948).

The muscle is partially concealed by the parotid gland, the accessory parotid gland, and the parotid duct; by the anterior facial vein; by the branches of the facial nerve; and by the zygomaticus major and platysma muscles. It conceals the ramus of the mandible, and, anteriorly, is separated from the buccinator muscle by the buccal pad of fat. The masseteric nerve and vessels reach its deep surface through the mandibular notch. When the teeth are clenched the parotid

FIG. 370.—RIGHT TEMPORAL MUSCLE. (The zygomatic arch and the masseter muscle have been removed.)

duct may be rolled under the finger against the contracted muscle as the duct turns round the anterior border of the masseter to pierce the buccinator.

Temporal Muscle.—This is a fan-shaped muscle that **arises** from the whole of the floor of the temporal fossa and also from the temporal fascia, which covers it. Although thin at its origin, its converging fibres form a thick tendon as they pass medial to the zygomatic arch—the anterior fibres vertically, the posterior horizontally and then curved—to be **inserted** into the apex and deep surface of the coronoid process, and into the anterior border of the ramus of the mandible, almost as far as the last molar tooth, its lower fibres becoming continuous with the buccinator.

As the muscle passes to its insertion it is concealed by the zygomatic arch, the masseter muscle, and the coronoid process of the mandible. The maxillary artery usually passes between it and the lateral pterygoid muscle. The masseteric nerve and vessels appear at its posterior border; the buccal nerve and vessels at its anterior border.

Lateral Pterygoid Muscle.—The lateral pterygoid muscle is deeply placed in the infratemporal fossa. It **arises** by two heads—upper and lower. The *upper head* is attached to the infratemporal surface of the greater wing of the sphenoid;

the *lower head* takes origin from the lateral surface of the lateral pterygoid plate. The muscle is directed laterally and backwards to be **inserted** into the front of the neck of the mandible (Figs. 368 and 369), and the capsule of the mandibular joint.

This muscle is covered by the lower part of the temporal muscle and the coronoid process of the mandible, and its lower head is usually crossed by the maxillary artery. It conceals the mandibular branch of the trigeminal nerve, the pterygoid origin of the medial pterygoid muscle, and the spheno-mandibular ligament.

Medial Pterygoid Muscle.—The medial pterygoid muscle has a double **origin**—(1) from the medial surface of the lateral pterygoid plate and the posterior surface of the tubercle of the palatine bone, and (2) by a small slip from the tuberosity of the maxilla. Its two heads of origin embrace the inferior fibres of the lateral pterygoid muscle. It is quadrilateral in form, and is directed downwards, laterally, and backwards to be **inserted** into a triangular impression on the medial surface of the mandible between the mylo-hyoid groove and the angle (Fig. 369).

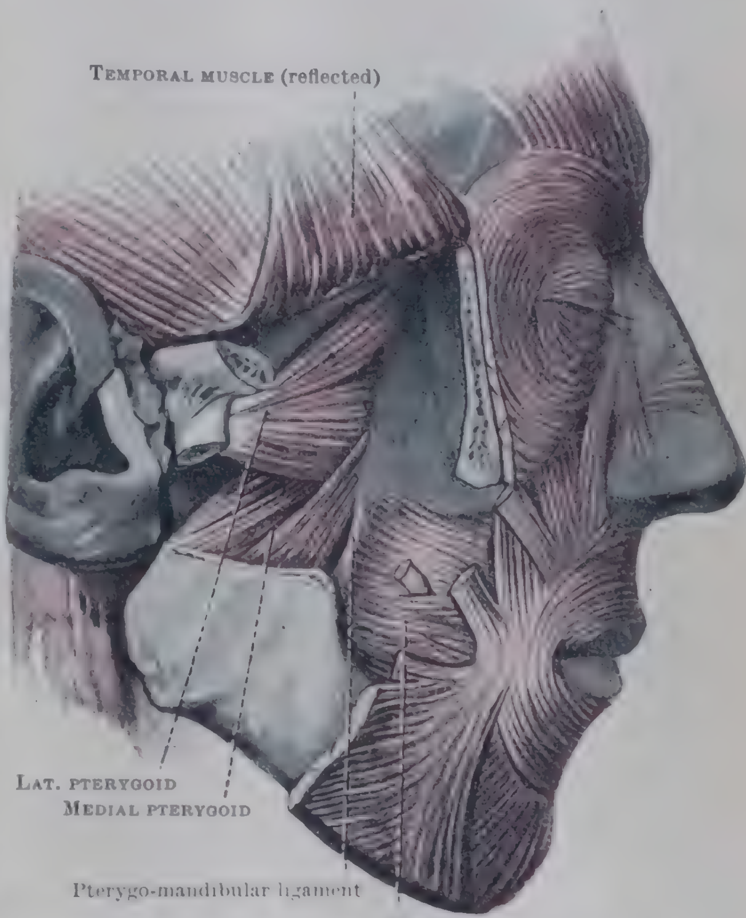


FIG. 371.—PTERYGOID MUSCLES OF THE RIGHT SIDE.

Lateral to the muscle there are the ramus of the mandible, the temporal and lateral pterygoid muscles, the maxillary vessels with their inferior dental branches, the inferior dental and lingual nerves, part of the parotid gland, and the spheno-mandibular ligament; the deep surface, at its origin, is separated from the pharyngo-tympanic tube and levator palati by the tensor palati, and, lower down, from the superior constrictor of the pharynx by the stylo-glossus and stylo-pharyngeus.

Nerve-Supply.—The mandibular division of the trigeminal (fifth cranial) nerve supplies all the muscles of mastication. The medial pterygoid muscle is supplied by the nerve before it divides; the other muscles are innervated by the anterior division.

Actions.—The temporal, masseter, and medial pterygoid muscles raise the jaw and have great power in keeping the teeth clenched. (But it is important to note that in the dislocated jaw their contraction increases the opening of the mouth.) The muscles that raise the mandible are also good examples of antigravity or postural muscles (see p. 409). The mouth opens by the relaxation of these muscles and the weight of the mandible, and, against resistance, by the contraction of the suprahyoid and infrahyoid groups and the platysma, and the lateral pterygoids. When the teeth are tightly clenched, the hyoid bone will be found firmly fixed. (See action of hyoid muscles, p. 438.)

The lateral pterygoids protrude the jaw and pull the articular discs forward; the temporal muscles retract the jaw.

The co-ordinated alternate action of the right lateral pterygoid with the elevators of the left side, and of the left one with the elevators of the right side, produces chewing movements.

MUSCLES OF THE NECK

In addition to the muscles included among those of the vertebral column (p. 411), the following muscles lie wholly or chiefly in the neck: (1) sterno-(cleido-)mastoid; (2) the muscles of the hyoid bone (suprahyoid and infrahyoid); (3) the muscles of the tongue (extrinsic and intrinsic); (4) the muscles of the pharynx and soft palate; and (5) the intrinsic muscles of the larynx. The last group is described with the larynx itself (p. 695).

Sterno-Mastoid.—The sterno-mastoid muscle lies obliquely in the side of the neck between the anterior and posterior triangles, and stands out prominently when thrown into action (Pl. XXXVII, p 456, Figs. 3, 4; Pl. XL, p. 457, Fig. 3). It **arises** by two heads—(1) a narrow, tendinous, *sternal* head from the anterior surface of the manubrium sterni (Fig. 407, p. 479), and (2) a broader, *clavicular* head, partly tendinous, partly fleshy, from the upper surface of the clavicle in its medial third. The clavicular head ascends to blend with the deep surface of the sternal head forming a thick belly which is **inserted** by a short, strong tendon into the anterior border and tip of the mastoid process, and the lateral surface of the mastoid portion of the temporal bone, and by a thin tendinous expansion into the lateral half of the superior nuchal line of the occipital bone (Fig. 356, p. 416).

Relations

The careful dissection of the relations of this muscle provides a good guide to the disposition of most of the structures in the neck. It is seen and felt superficially throughout its extent, but its upper part is overlapped anteriorly by the parotid gland; the external jugular vein descends over its surface; and, curving round its posterior border, there are the lesser occipital nerve, the great auricular nerve, the anterior cutaneous nerve of the neck, and the medial and intermediate supraclavicular nerves—all, except the first two, covered by the platysma. Its deep surface is related to a large number of structures. Its lower third is in relation with the scalenus anterior, the phrenic nerve, the transverse cervical and suprascapular arteries, and, at its posterior border, with the brachial plexus; farther forward, the infrahyoid muscles (along with the anterior jugular vein, which crosses them superficially above the clavicle) separate the muscle from the common carotid artery, the subclavian artery and the internal jugular vein, the lower part of the vein being opposite the depression between the two heads of the muscle. The middle third is in relation with the internal jugular, the common facial and lingual veins, the external and internal carotid arteries (with the vagus posteriorly), the descending branch of the hypoglossal nerve, the nervus descendens cervicalis, and deep cervical lymph-glands. The upper third is related to the cervical plexus, the scalenus medius, the levator scapulæ, the posterior belly of the digastric, and, near its insertion to the splenius capitis and longissimus capitis. The occipital artery runs upwards and backwards along the lower border of the digastric; and the accessory nerve, escaping from under cover of that muscle, descends to sink into the sterno-mastoid. A group of lymph-glands forms a chain along its posterior border.

Nerve-Supply.—The muscle is innervated by the **accessory (eleventh cranial) nerve** and also by branches from the **second cervical nerve** which are said to be afferent.

Actions.—Figs. 1 and 2, Pl. XLI, p. 512, show the left sterno-mastoid in action as it turns the head to the opposite side. The two muscles acting together can flex the head, but do so only against resistance or against gravity when the subject is supine. They function also as muscles of forced inspiratory effort—raising the thorax when the head is fixed.

Muscles of Hyoid Bone

There are two groups of these muscles: (1) infrahyoid muscles, which connect the hyoid bone to the scapula, the wall of the thorax, and the thyroid cartilage; (2) suprahyoid muscles, which connect it to the mandible, cranium, and tongue. The middle constrictor muscle of the pharynx also is attached to the hyoid bone.

The **infrahyoid muscles** are the omo-hyoid, sterno-hyoid, sterno-thyroid, and thyro-hyoid.

Omo-Hyoid.—The omo-hyoid is a muscle with two bellies—superior and inferior. The *inferior belly* **arises** from the upper margin of the scapula and the suprascapular ligament (Fig. 211, p. 243). It is a narrow muscular band which passes obliquely forwards and upwards across the scalene muscles to end in an

intermediate tendon under cover of the sterno-mastoid muscle. From this tendon the *superior belly* proceeds upwards across the carotid sheath to be **inserted** into the lower border of the body of the hyoid bone, lateral to the sterno-hyoid. A sling of the deep cervical fascia binds down the tendon and the inferior belly to the clavicle and the first rib.

Sterno-Hyoid.—The sterno-hyoid muscle **arises** from the posterior surface of the manubrium sterni, from the posterior sterno-clavicular ligament, and from the medial end of the clavicle. Converging slightly towards its fellow, it ascends along the medial border of the omo-hyoid and superficial to the sterno-thyroid muscle to be **inserted** into the medial part of the lower border of the body of the hyoid bone. Near its origin it is covered by the sternum, clavicle, and sternal head of the sterno-mastoid, but the greater part of the muscle is superficial.

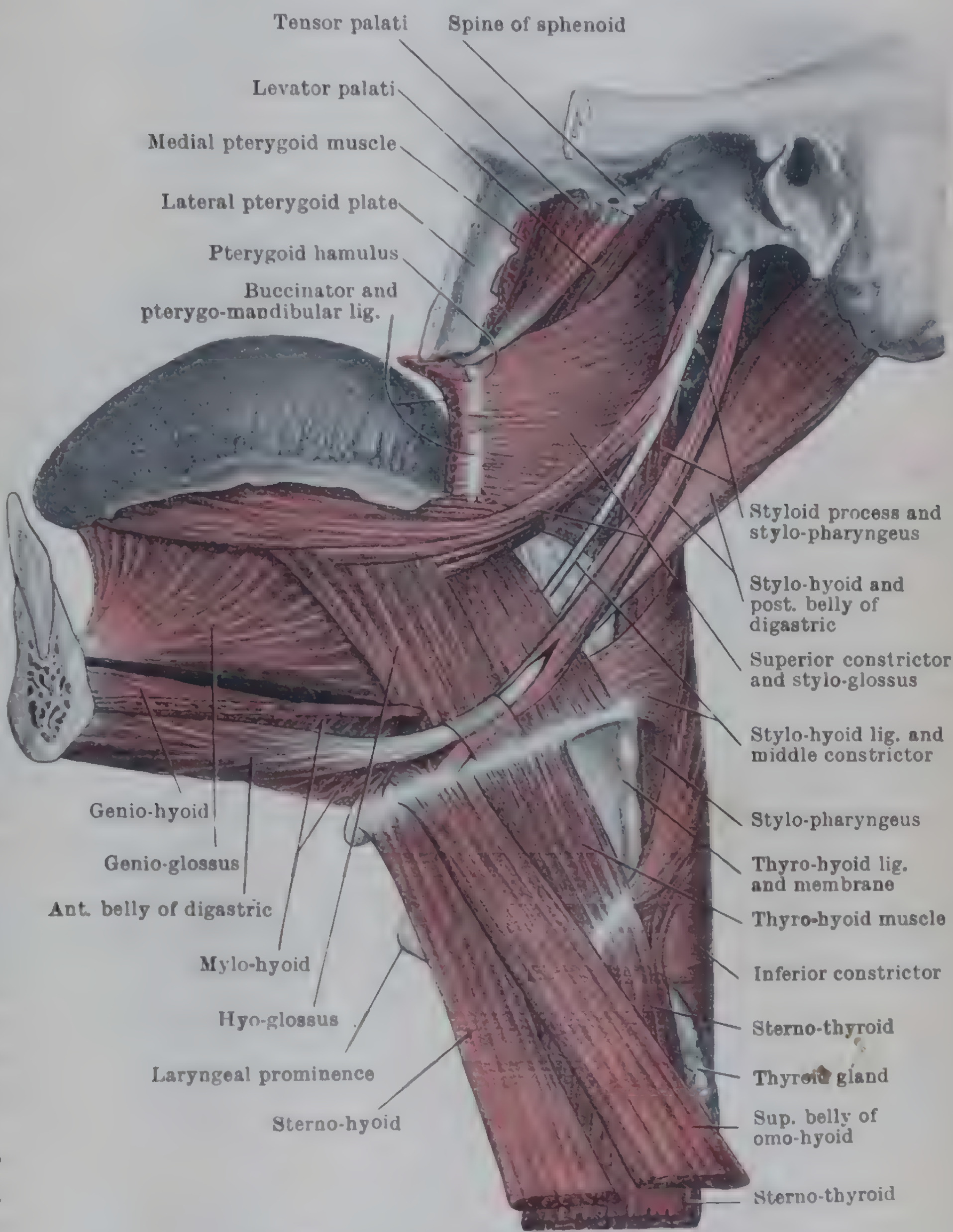


FIG. 372.—MUSCLES OF THE TONGUE, HYOID BONE, AND PHARYNX.

Sterno-Thyroid.—The sterno-thyroid muscle **arises** from the back of the manubrium and first costal cartilage. Broader than the preceding muscle, and diverging from its fellow, it passes upwards in front of the trachea and thyroid gland, and deep to the sterno-mastoid, omo-hyoid, and sterno-hyoid muscles. It is **inserted** into the oblique line of the thyroid cartilage. The muscle may show an oblique tendinous intersection in the middle of its length.

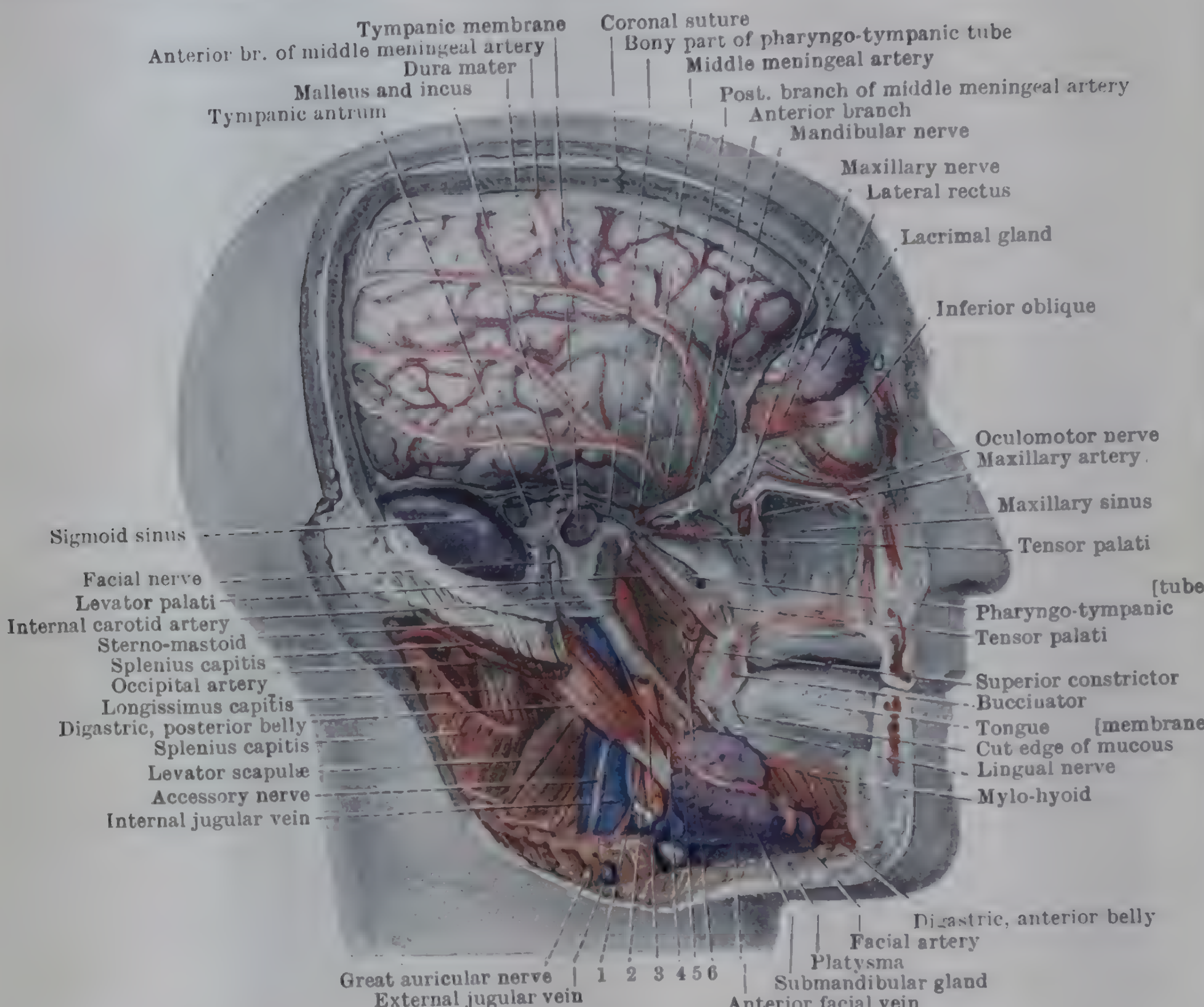
Thyro-Hyoid.—The thyro-hyoid muscle continues the line of the preceding muscle to the hyoid bone. Short and quadrilateral, it **arises** from the oblique line of the thyroid cartilage. Passing over the thyro-hyoid membrane, deep to the omo-hyoid and sterno-hyoid, it is **inserted** into the lower border of the body and adjacent part of the greater horn of the hyoid bone.

The **levator glandulæ thyreoideæ** is an occasional unpaired slip that stretches between the hyoid bone and the isthmus or the pyramidal lobe of the thyroid gland.

The **suprahyoid muscles** are the digastric, stylo-hyoid, mylo-hyoid, and

genio-hyoid; and also two muscles—the genio-glossus and hyo-glossus—which will be described along with the extrinsic muscles of the tongue.

Digastric Muscle.—The digastric muscle, as its name implies, has two bellies—anterior and posterior. The *posterior belly* **arises** from the mastoid notch of the temporal bone. It is directed forwards and downwards, in company with the stylo-hyoid muscle, to end in an intermediate tendon which passes through the stirrup-like insertion of the stylo-hyoid, and is connected by a sling of fascia to the body of the hyoid bone. The *anterior belly* is directed forwards and slightly upwards from the tendon and often from the body of the hyoid bone, and is **inserted** into the lower border of the mandible close to the symphysis (Fig. 369).



1. Sterno-mastoid artery.
2. Hypoglossal nerve.
3. External carotid artery.
4. Stylo-hyoid.
5. Stylo-glossus.
6. Ascending palatine artery.

FIG. 373.—DISSECTION OF HEAD SHOWING THE RELATIONS OF MUSCLES AT ITS JUNCTION WITH THE NECK. For enlargement of part of this illustration, see Fig. 378, p. 443.

The muscle forms the inferior boundary of the space occupied by the submandibular gland. The posterior belly, in company with the stylo-hyoid, crosses lateral to the transverse process of the atlas, the accessory nerve, the internal jugular vein and carotid arteries. The occipital artery runs backwards along its lower margin, and the parotid gland covers its upper border. The hypoglossal nerve emerges from under cover of the muscle just above the tendon. The anterior belly lies on the lower surface of the mylo-hyoid muscle.

Stylo-Hyoid.—The stylo-hyoid muscle **arises** from the posterior border of the styloid process of the temporal bone near its root. Extending downwards and forwards, along with the posterior belly of the digastric muscle, it is **inserted** into the upper surface of the greater horn near the body of the hyoid bone by two slips which enclose the tendon of the digastric muscle.

Mylo-Hyoid.—The mylo-hyoid muscle forms with its fellow a diaphragm in the floor of the mouth. It **arises** from the mylo-hyoid ridge of the mandible

(Fig. 369). It is directed downwards and medially to be **inserted** into the body of the hyoid bone, and, more anteriorly (along with the opposite muscle), into a median raphe that extends from the hyoid bone nearly to the chin.

The muscle is in contact, on its superficial surface, with the digastric muscle, the submandibular gland, the mandible, and the mylo-hyoid vessels and nerve. Its deep surface is partially covered by the mucous membrane of the floor of the mouth, and is separated from the muscles of the tongue by the submandibular duct and the deep part of the gland, the sublingual gland, the lingual and hypoglossal nerves and the vena comitans of the hypoglossal nerve.

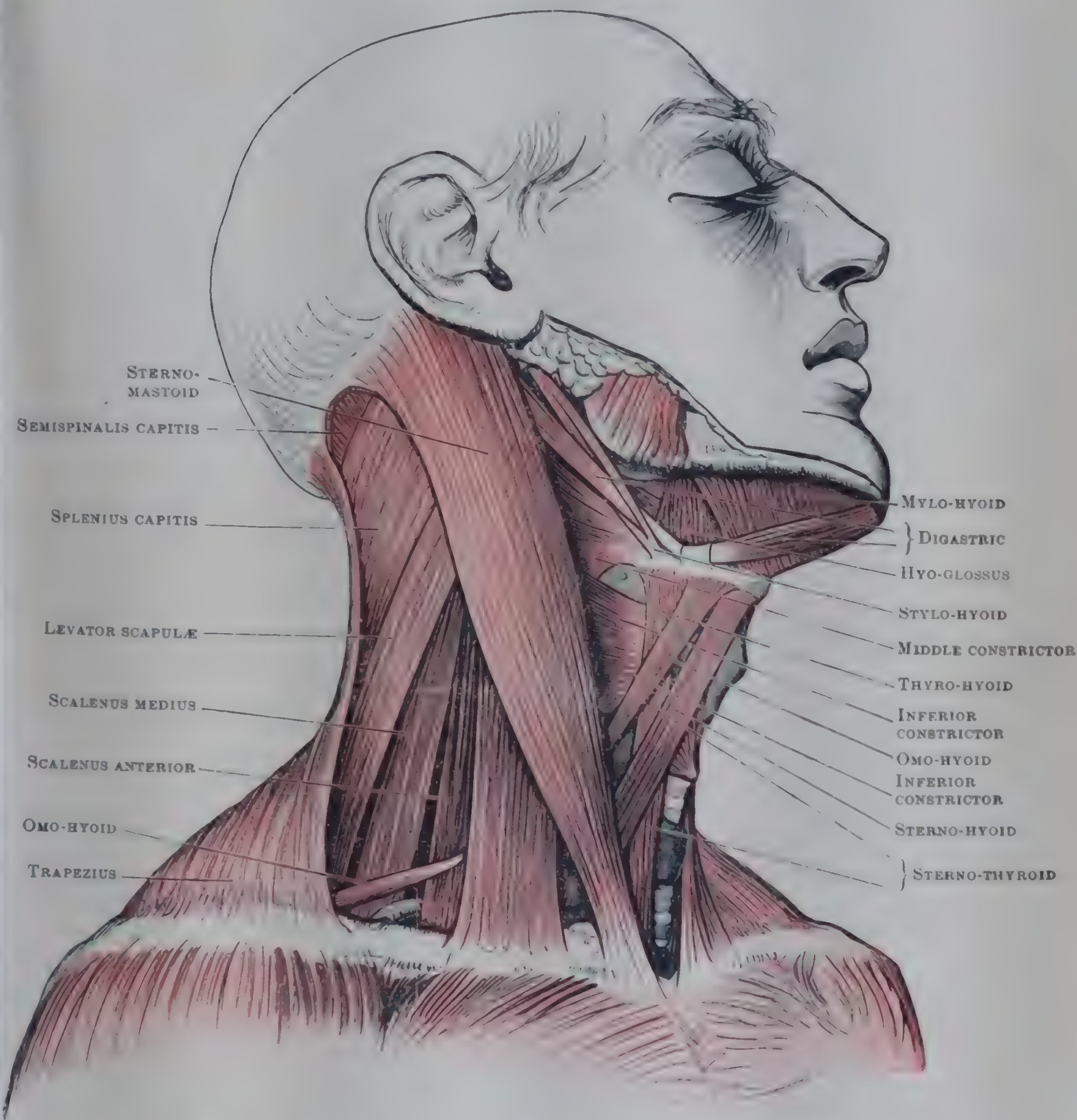


FIG. 374.—MUSCLES OF SIDE OF NECK (anterior and posterior triangles).

Genio-Hyoid.—The genio-hyoid muscle **arises** from the inferior genial tubercle of the mandible (Fig. 369). It is directed backwards and slightly downwards, between the mylo-hyoid and the genio-glossus (Fig. 372), to be **inserted** into the body of the hyoid bone. The muscles of opposite sides are often fused together.

Nerve-Supply.—The sterno-hyoid, sterno-thyroid, and omo-hyoid are supplied by the *ansa hypoglossi*, through which the muscles are innervated by fibres ultimately derived from the **first three cervical nerves.** The ramus descendens hypoglossi is derived from the loop between the **first two cervical nerves,** and the ramus descendens cervicalis springs from the second and third. These two trunks combine to form the ansa. The thyro-hyoid muscle is innervated (through the hypoglossal) from the loop between the **first and second cervical nerves** (Fig. 909, p. 1044).

Three cranial nerves are concerned in the supply of the suprahyoid muscles — an indication of their diverse developmental origins. The posterior belly of the digastric and the stylo-hyoid are supplied by branches from the trunk of the **facial nerve**; the anterior belly of the digastric and the mylo-hyoid by the **trigeminal** through the mylo-hyoid branch of the inferior dental nerve; and the genio-hyoid is supplied by the **hypoglossal nerve**. From the point of view of nerve-supply, the genio-hyoid is a link between the infrahyoid muscles and the muscles of the tongue, since its nerve can be traced back to the communication between the first two cervical nerves and the hypoglossal.

Actions.—The hyoid bone is steadied by the suprahyoid and infrahyoid muscles, as a ship rides when anchored fore and aft. The hyoid bone, through its muscles, provides a fulcrum for the action of the tongue, and plays a part in mastication, deglutition, and phonation—with the associated muscle-groups. The suprahyoid and infrahyoid groups act in concert, and, whether the bone is being raised by one group or lowered by the other, the opposing group steadies the bone like a guy-rope. Descent of the hyoid is not usually an active movement. Both hyoid groups relax slightly as the jaws are closed against resistance. In the first stage of swallowing, the mylo-hyoid and genio-hyoid raise the hyoid bone and the floor of the mouth (the digastric and stylo-hyoid assisting, while the infrahyoid group steadies the bone); the tongue is pressed against the palate and the food is forced backwards; the hyoid bone then regains its resting position. Though not attached to the hyoid bone, the sterno-thyroid, in concert with the thyro-hyoid, depresses the bone. When the upper end of the thyro-hyoid is fixed, the muscle pulls the larynx upwards in the production of high notes; the sterno-thyroid pulls down the larynx markedly when low notes are produced. During high and low notes, the hyoid bone is relatively fixed by the action of the appropriate muscles. During deglutition, the thyro-hyoid pulls the larynx upwards and slightly backwards, probably assisting the synchronous sphincteric action of the laryngeal muscles as they approximate the arytenoid cartilages and the tubercle of the epiglottis.

Muscles of Tongue

The substance of the tongue consists mainly of muscular fibres arranged symmetrically on each side of a median fibrous septum, and interlacing with one another in three main directions—longitudinal, transverse, and vertical. They belong to two sets of muscles—(1) the **intrinsic** muscles, proper to the tongue itself; and (2) the **extrinsic** muscles, arising outside the tongue (from the mandible, the hyoid bone, and the styloid process) and inserted into it.

Intrinsic Muscles of the Tongue.—There are four pairs of intrinsic muscles—the superior and inferior longitudinal, the transverse and vertical muscles.

The **superior longitudinal muscle** extends from the back of the tongue to its tip, and is united to its fellow of the opposite side without the intervention of the median septum at this level. It is placed immediately under the mucous membrane, into which many of its fibres are inserted. The **inferior longitudinal muscle** is a cylindrical band of muscular fibres that lies in the lower part of the tongue, in the interval between the genio-glossus and the hyo-glossus. Posteriorly, some of its fibres extend to the hyoid bone. The **transversus linguæ** arises from the median septum and radiates to the dorsum and sides of the tongue, intermingling with the extrinsic muscles and the fibres of the vertical muscle. The **verticalis linguæ** arises from the mucous membrane of the dorsum of the tongue, and sweeps downwards and laterally to its sides, intermingled with the fibres of the transversus and the extrinsic muscles. The transverse and vertical muscles form a very considerable part of the muscular substance of the organ.

Extrinsic Muscles of the Tongue.—There are three pairs of these muscles: genio-glossus, hyo-glossus, and stylo-glossus. The palato-glossus, also attached to the tongue, is described with the muscles of the soft palate (p. 443).

The **genio-glossus muscle** (Fig. 372) is an extrinsic muscle of the tongue as well as a suprahyoid muscle. It is a fan-shaped muscle that **arises** by its apex from the upper genial tubercle of the mandible (Fig. 369, p. 431) and radiates into the tongue. The lowest fibres are directed downwards and backwards, to be **inserted** into the body of the hyoid bone; the highest fibres curve forwards, to be attached to the tip of the tongue; the intermediate fibres end in the

substance of the tongue in its whole length. The muscles of opposite sides are separated only by the median septum of the tongue. Laterally, each is related to the inferior longitudinal muscle, the stylo-glossus, the hyo-glossus, the lingual artery, and the sublingual gland.

The **hyo-glossus muscle** also is an extrinsic muscle of the tongue as well as a suprahyoid muscle. It is a quadrilateral sheet that **arises** from the body and greater horn of the hyoid bone and is directed upwards and forwards to be **inserted** into the side of the tongue, its fibres interlacing with the fibres of the longitudinalis inferior medially, and the stylo-glossus laterally (Fig. 372).

With the exception of its posterior portion, the muscle is hidden by the mylo-hyoid and the structures that lie on its surface partly between the two muscles. A little above the greater horn of the hyoid bone the tendon of the digastric, the hypoglossal nerve and its accompanying vein lie on the muscle; at a higher level there are the submandibular duct, the deep part of the submandibular gland, the submandibular ganglion, and the lingual nerve. The uppermost part of the hyo-glossus is separated from the mylo-hyoid by the mucous membrane of the floor of the mouth. The deep surface of the hyo-glossus is in contact with the genio-glossus in front, and with the glosso-pharyngeal nerve and the middle

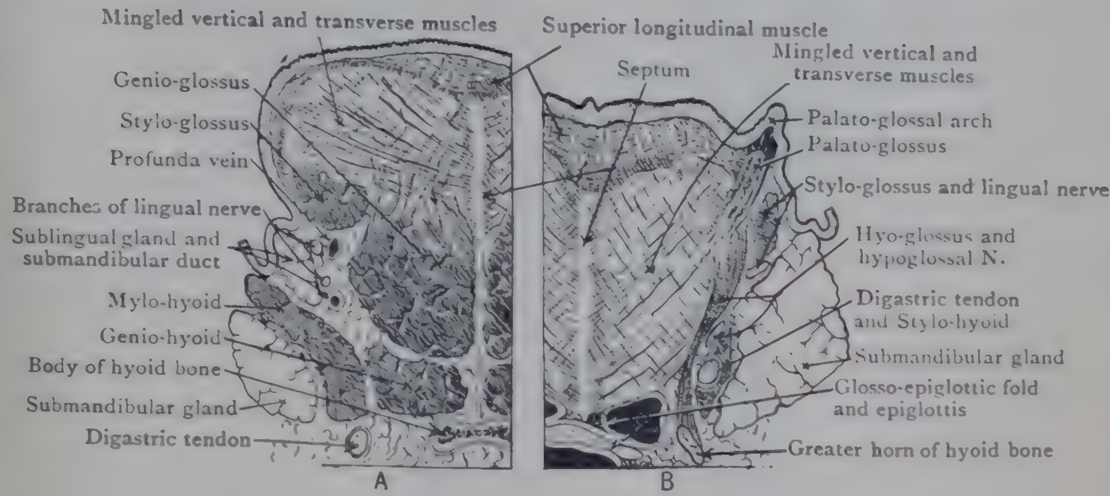


FIG. 375.—A. SECTION THROUGH TONGUE AND BODY OF HYOID BONE.
B. SECTION THROUGH TONGUE AND GREATER HORN OF HYOID BONE.

constrictor of the pharynx arising from the stylo-hyoid ligament behind, but the lingual vessels intervene between it and these muscles.

The **chondro-glossus** is a small separated slip of the hyo-glossus, not always present. It arises from the lesser horn of the hyoid bone.

The **stylo-glossus muscle arises** from the anterior border of the styloid process near its tip and from the stylo-hyoid ligament. It sweeps forwards and medially, at first on the stylo-pharyngeus, and then on the lower and anterior part of the superior constrictor muscle of the pharynx, by which it is separated from the tonsil; finally it runs inferior to the mandibular attachment of the superior constrictor muscle. It is **inserted** into the side of the tongue, its fibres spreading out to mingle with those of the palato-glossus and hyo-glossus beneath the mucous membrane of the tongue.

Nerve-Supply.—All the muscles of the tongue, except the palato-glossus, are supplied by the **hypoglossal nerve.**

Actions.—The intrinsic muscles alter the shape of the tongue. The extrinsic muscles alter the shape and also produce changes in its position. The tongue is protruded by the action of the posterior fibres of the genio-glossus, retracted by the anterior fibres aided by the stylo-glossus and hyo-glossus. The stylo-glossus and palato-glossus are elevators of the tongue, while the genio-glossus and hyo-glossus are depressors. The tongue is active during speech, and in the mastication and swallowing of food.

Muscles of Pharynx

The muscular wall of the pharynx is composed of two strata. The *external* or *circular layer* consists of the three constrictor muscles; the *internal* or *longitudinal layer* consists of the fibres of the stylo-pharyngeus and palato-pharyngeus muscles. (The palato-pharyngeus is described with the muscles of the soft palate.) The outer surface of the muscular wall is covered with a thin layer of fascia, called

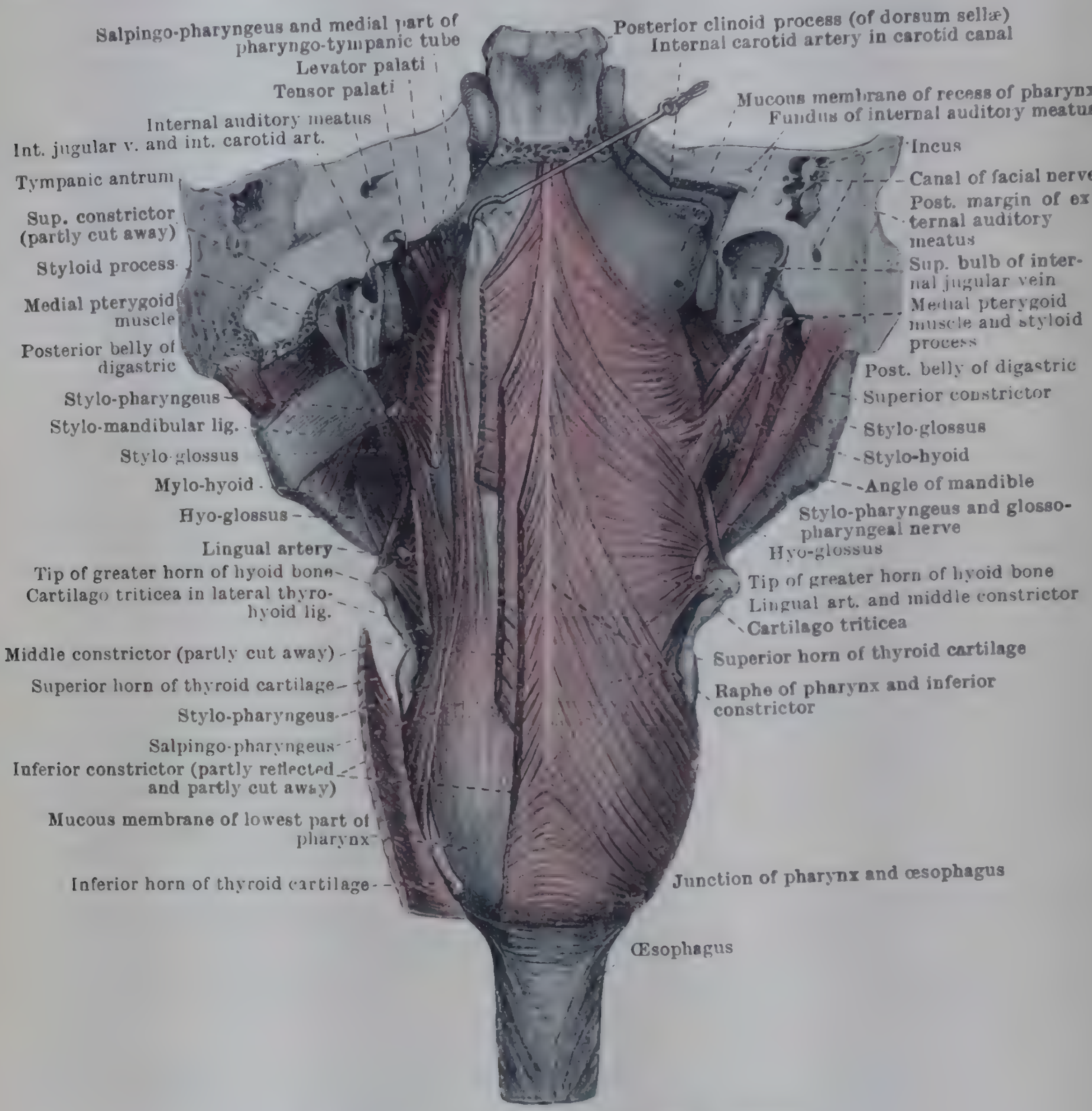


Fig. 376.—Muscles of Pharynx from Behind.
The constrictors of the left side have been cut to show the deeper muscles.

the *bucco-pharyngeal fascia*, which extends forwards to cover the buccinator also. The inner surface is lined with the *pharyngo-basilar fascia*, which is very thin inferiorly but thickens as it approaches the skull.

Superior Constrictor.—The superior constrictor muscle **arises** successively from the lower half of the posterior border of the medial pterygoid plate, from the pterygo-mandibular ligament, from the mylo-hyoid line of the mandible, and from the musculature of the side of the tongue and adjacent mucous membrane of the mouth.

The muscular fibres radiate backwards and medially, and are **inserted**, for the most part, into a median raphe in the posterior wall of the pharynx; the highest fibres are attached to the pharyngeal tubercle of the occipital bone (Fig. 356). A band of fibres from the anterior and lateral part of the palatine aponeurosis sweeps backwards lateral to the levator palati to blend with the pharyngeal

surface of the superior constrictor near its upper border. It forms a "palato-pharyngeal sphincter" (Whillis, 1930) and produces the ridge of pharyngeal mucous membrane known as Passavant's ridge (see pp. 445 and 593). This band is highly developed in cases of complete cleft palate. Between the upper border of the muscle and the base of the skull there is a crescentic interval which is occupied by the pharyngo-basilar fascia and transmits the levator palati muscle and the pharyngo-tympanic tube.

Posteriorly and laterally it is overlapped from below by the middle constrictor. Anteriorly it is continuous with the buccinator through the pterygo-mandibular ligament. A triangular gap filled with fibrous tissue is seen between its lower border, the posterior border of the hyo-glossus and the upper border of the middle constrictor. Here, the stylo-pharyngeus insinuates itself between the superior and middle constrictors; and the glosso-pharyngeal nerve and the stylo-hyoid ligament cross the gap (Figs. 372, 379).

Middle Constrictor.—The middle constrictor muscle **arises** from the lower part of the stylo-hyoid ligament and from both horns of the hyoid bone, and it spreads fanwise backwards and medially to be **inserted** into the median raphe. The upper fibres overlap the superior constrictor; the lower fibres are concealed posteriorly by the inferior constrictor muscle. Between its lower border and the upper border of the inferior constrictor there is a triangular gap. This gap is bounded in front by the thyro-hyoid muscle, and is occupied by the posterior part of the thyro-hyoid membrane and the lower part of the stylo-pharyngeus. The internal laryngeal nerve and the superior laryngeal vessels pierce the thyro-hyoid membrane in this region.

Inferior Constrictor.—The inferior constrictor muscle **arises** from the oblique line of the thyroid cartilage, from the area behind that line, from the side of the cricoid cartilage, and from the fascia on the posterior part of the crico-thyroid muscle.

Its fibres curve backwards and medially to be **inserted** into the median raphe of the pharynx. The upper fibres incline markedly upwards and overlap the middle constrictor; the lowest fibres are horizontal, and blend with the circular muscular fibres of the œsophagus. Under cover of the lower border of the muscle, the inferior laryngeal artery and recurrent laryngeal nerve pass up behind the crico-thyroid joint to enter the larynx.

Stylo-Pharyngeus.—The stylo-pharyngeus **arises** from the root of the styloid process on its medial side, and passes downwards between the external and internal carotid arteries. It enters the wall of the pharynx in the interval between the superior and middle constrictor muscles, accompanied by the glosso-pharyngeal nerve which has curved round the lateral aspect of the muscle. Spreading out internal to the middle constrictor muscle, the greater horn of the hyoid bone, and the thyro-hyoid membrane, it is **inserted** into the superior and posterior borders of the thyroid cartilage and into the wall of the pharynx itself, becoming continuous posteriorly with the palato-pharyngeus.

Muscles of Soft Palate

The soft palate and uvula consist of a fold of mucous membrane enclosing a fibrous aponeurosis and several muscles. The fold hangs down from the hard palate between the pharynx and the mouth.

The muscular substance is composed of five pairs of muscles—the palato-pharyngeus, musculus uvulæ, levator palati, tensor palati, and palato-glossus (Fig. 377). In its anterior part the fold contains the **palatine aponeurosis**, which is attached in front to the posterior border of the bony palate and on each side to the pharyngo-basilar fascia and fades away posteriorly. The palatine aponeurosis is derived mainly from the tendons of the two tensor muscles; the other muscles, with the exception of the palato-glossus, are inserted into it.

Palato-Pharyngeus.—The palato-pharyngeus extends from the soft palate to

the pharyngeal wall and is covered by the mucous membrane of the palato-pharyngeal arch. In the soft palate it is arranged in two layers which enclose the levator palati and the musculus uvulæ. The postero-superior layer is thin; it lies under the mucous membrane of the back of the soft palate, and blends with its companion of the opposite side. A thicker, antero-inferior layer lies between the levator and tensor palati muscles, joins with its fellow in the median plane and **arises** from the palatine aponeurosis and the posterior border of the bony palate. At the postero-lateral part of the soft palate the two layers blend and are joined posteriorly by the **salpingo-pharyngeus** muscle, which is a slender slip that descends

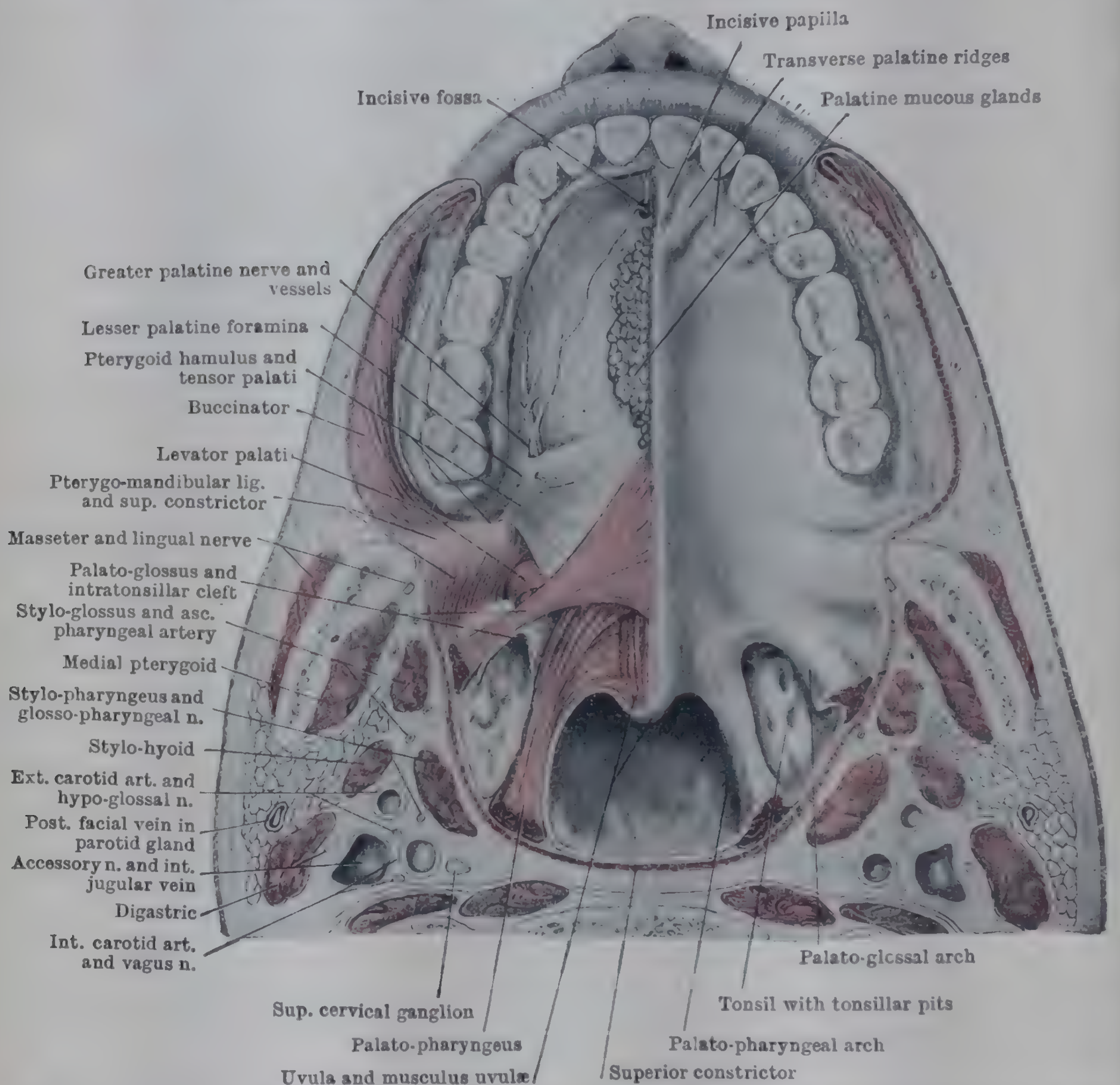


FIG. 377.—HORIZONTAL SECTION AT LEVEL OF ORAL FISSURE SEEN FROM BELOW WITH RIGHT SIDE DISSECTED TO SHOW MUSCLES OF SOFT PALATE.

from the pharyngeal end of the pharyngo-tympanic tube in close relation to the salpingo-pharyngeal fold. The united muscles run downwards along the postero-medial margin of the stylo-pharyngeus, and their fibres spread out in a thin sheet to be **inserted** into the posterior border of the thyroid cartilage, and, behind that, into the pharyngo-basilar fascia. The muscle is covered by the middle and inferior constrictors and decussates with its fellow in the lower part of the pharyngeal wall.

Musculus Uvulæ.—This slender bundle lies alongside its fellow, between the layers of the palato-pharyngeus and above the levator palati. Both bundles **arise** from the posterior nasal spine and the palatine aponeurosis, and they unite as they proceed backwards to end in the mucous membrane of the uvula.

Levator Palati.—The levator palati is a rounded muscle with a double **origin**: (1) from the quadrate area of the lower surface of the petrous portion of the

temporal bone, and (2) from the medial side of the cartilaginous portion of the pharyngo-tympanic tube. Passing obliquely downwards and medially, across the medial side of the upper border of the superior constrictor muscle, it descends in front of the salpingo-pharyngeus and enters the soft palate between the two layers of the palato-pharyngeus muscle to be **inserted** by its anterior fibres into the palatine aponeurosis, but mainly by its posterior fibres becoming continuous with those of the opposite muscle.

It is separated from the tensor palati muscle (1) by the pharyngo-tympanic tube, (2) by the upper fibres of the superior constrictor, and (3) by the deeper layer of the palato-pharyngeus muscle.

Tensor Palati.—The tensor palati is a flat, triangular muscle which **arises**

FIG. 378.—REGION OF PHARYNGO-TYMPANIC TUBE AND TYMPANIC ANTRUM SHOWING THE LEVATOR AND TENSOR PALATI MUSCLES. Enlargement of part of Fig. 373, p. 436.

(1) from the scaphoid fossa and the spine of the sphenoid bone, and (2) from the lateral side of the cartilaginous part of the pharyngo-tympanic tube.

Tapering by the vertical descent of its anterior border, and the oblique descent of its posterior border, the muscle ends in a tendon which hooks round the pterygoid hamulus, a bursa intervening, and passes through a gap in the origin of the buccinator muscle (p. 426) to enter the soft palate. The tendon spreads out below the lower layer of the palato-pharyngeus to be inserted into the posterior border of the hard palate and into the palatine aponeurosis. It is related *medially* to the medial pterygoid plate, the pharyngo-basilar fascia, the pharyngo-tympanic tube, and the upper origin of the superior constrictor. Its lateral surface is related to the otic ganglion, the mandibular and chorda tympani nerves, the middle meningeal vessels, and the medial pterygoid muscle.

Palato-Glossus.—The palato-glossus **arises** as a thin sheet of muscle, in continuity with its fellow, above the mucous membrane of the antero-inferior surface of the soft palate (Fig. 377). The fibres become roped together and pass downwards, forwards, and laterally in front of the tonsil, forming the substance of the palato-glossal arch to be **inserted** into the dorsum and side of the tongue by scattered fibres that blend with the stylo-glossus and the transversus linguæ.

Nerve-Supply.—All the muscles of the pharynx and soft palate, except the tensor palati and the stylo-pharyngeus, are innervated by the **vagus (tenth cranial) nerve**, through the pharyngeal plexus, but the principal motor fibres of the pharynx are derived mainly from the cranial root of the **accessory nerve**. The tensor palati receives its supply from the mandibular division of the **trigeminal** by a branch from the nerve to the medial pterygoid muscle through the otic ganglion. The stylo-pharyngeus is supplied by the **glosso-pharyngeal** nerve. The inferior constrictor receives additional supply from the external and recurrent laryngeal nerves.

Actions of the Muscles of the Pharynx and Soft Palate.—The muscles of the pharynx and soft palate are concerned in **the act of swallowing**. This act is divided into a *voluntary stage*, in which the bolus lies in front of the oro-pharyngeal isthmus,[1] and an *involuntary stage*, during which the food passes from the mouth through the pharynx. The movements that occur during the passage of food through the mouth are as follows: the cheeks are compressed by the action of the buccinator muscles; the tongue, hyoid bone, and thyroid cartilage are successively raised by the action of the muscles which close the mouth and elevate the hyoid bone. By these means the food is pushed backwards between the palatine arches.

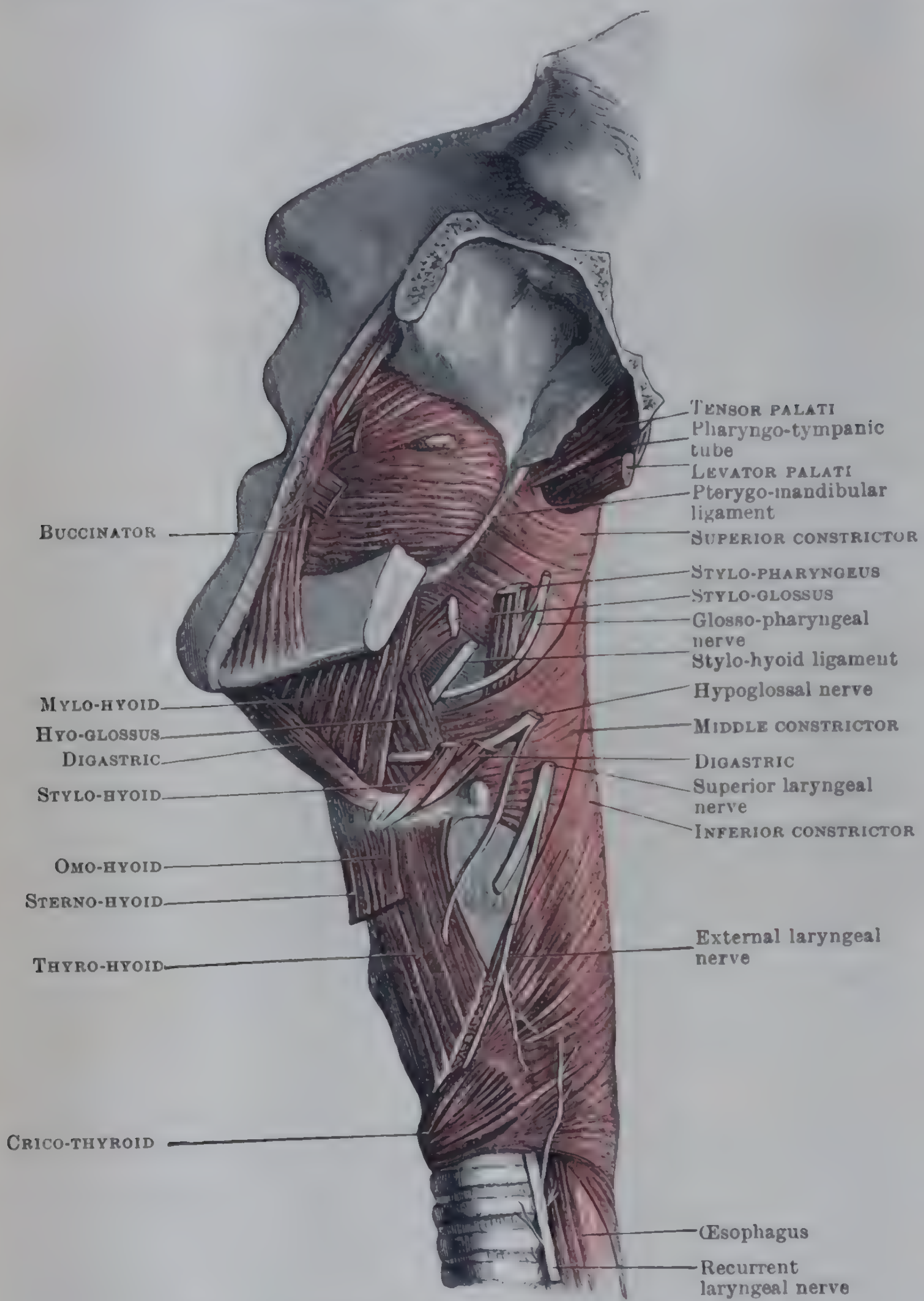


Fig. 379.—Lateral View of Wall of Pharynx.

At this time, by the contraction of the palato-glossus and palato-pharyngeus, the oro-pharyngeal isthmus is narrowed, while the levators raise the soft palate, and by bringing it into contact with the posterior wall of the pharynx, shut off the nasal portion of the cavity, thereby preventing regurgitation of food into the naso-pharynx—seen in paralysis of the palate. It should be noted that the levators, in raising the palate against the flange formed by Passavant's ridge (p. 445) to shut off the naso-pharynx, are assisted in this occlusion by their antagonists—the tensors—which keep the soft palate tense. The elevation of the tongue, hyoid bone (p. 438), and larynx causes the elevation of the epiglottis and the inlet of the larynx, which is closed by the approximation of the arytenoid cartilages to the tubercle of the epiglottis by the combined sphincteric action of the laryngeal muscles (arytenoid, thyro-arytenoid, and

[1] The term *oro-pharyngeal isthmus* (p. 566) is applied to the opening between the cavity of the mouth and the oral part of the pharynx, while the term *pharyngeal isthmus* (p. 587) is applied to the communication between the nasal and oral parts of the pharynx.

thyro-epiglottic). The food thus slips over the posterior surface of the epiglottis and the closed inlet of the larynx into the pharynx (see also Respiratory System, p. 700).

When the bolus of food enters the pharynx, it is clasped by the constrictor muscles, which, by their contractions, force it down into the œsophagus—their constriction at one level being accompanied by their relaxation at the level immediately below. The contraction of the constrictor muscles results in a flattening of the pharynx and elevation of its anterior attachments; and, as the larynx ascends, the pharynx also is pulled up by the palato-pharyngeus and stylo-pharyngeus.

During the act of swallowing, it is generally thought that the pharyngo-tympanic tube is opened by the contraction of the tensor palati muscle, which arises from it. On the other hand, it has been held that the tube is closed during swallowing by contraction of the levator palati compressing its wall.

Throughout the **production of speech** (Wardill, 1928; cf. Browne, 1935) the upper part of the superior constrictor (chiefly by means of its palatine bundle, p. 441) forms a ridge (Passavant, 1869) to or from which the soft palate moves in occluding or opening the pharyngeal isthmus. Occlusion is complete for most consonants, but not complete for vowels. (Occlusion, as by a "cold in the head", is therefore not such a serious defect for speech as is the patency in cleft palate.) The muscles which pull the palate away from the ridge are the palato-pharyngeus, the palato-glossus, and the tensor palati, while the levators close the isthmus—as may be seen by the dimples that appear at their insertion in the soft palate when they contract during the saying of "Ah".

FASCIÆ OF HEAD AND NECK

The **superficial fascia** of the head and neck possesses certain features of special interest. In the scalp, it is closely adherent to the skin and the epicranial aponeurosis, and it contains the superficial vessels and nerves. In the eyelids it is loose and thin and contains no fat. In the face and in the side of the neck, it is separated from the deep fascia by the facial muscles and the platysma. Between the buccinator and the masseter, it is continuous with the *buccal pad of fat*, which lies in the interval between those muscles.

The **deep fascia** of the head and neck presents remarkable characters in certain areas, but in studying the various planes described, it is well to remember in general that the fascia is a packing material that ensheaths more highly differentiated structures and fills the spaces between them (cf. p. 410).

In the scalp, it is replaced by the **epicranial aponeurosis.** *In the temple*, the **temporal fascia** is a stout layer that extends from the superior temporal line to the zygomatic arch and covers the temporal muscle. Near the zygomatic arch, it separates into two layers to enclose a quantity of fat and some small vessels. *On the face*, the deep fascia is practically non-existent anteriorly in relation to the facial muscles. Posteriorly it forms the **parotid fascia**; this fascia is thin where it covers the masseter, but it thickens to cover and ensheath the parotid gland.

In the neck, the deep fascia invests the muscles, and forms fascial coverings for the pharynx, trachea, œsophagus, glands, and large vessels, making, in brief, a superficial collar or tube connected with various intermuscular septa; but most of the deep septa are condensations of areolar tissue rather than definite membranes (Fig. 380). The **investing** layer is usually less dense where it is covered by the platysma; it encloses the sterno-mastoid muscle, and forms the roof of the posterior triangle as it extends backwards to enclose the trapezius; in this region a fascial sling keeps the posterior belly of the omo-hyoid approximately parallel to the clavicle. The fascia can be traced forwards over the anterior triangle to the median plane, where it is continuous with the fascia of the other side.

In the upper part of the neck, this layer is bound down to the body and greater horn of the hyoid bone, and then extends upwards over the digastric muscle and splits to enclose the submandibular gland, the superficial layer passing to the lower border of the mandible and the deep layer to the mylo-hyoid line. At the angle of the mandible it blends with the fascial sheath of the parotid gland. Through this intermediary the investing layer gains attachment to the zygoma, the posterior boundary of the squamo-tympanic fissure, the styloid process, and the lower border of the tympanic plate. Behind the parotid gland, the line of attachment of this layer follows the line of attachment to the skull of the sterno-mastoid and trapezius

muscles—so reaching the external occipital protuberance. A specially thickened portion of the parotid sheath extends between the styloid process and the posterior border of the mandible, separating the lower part of the parotid gland from the submandibular gland. This is termed the **stylo-mandibular ligament.**

Below the cricoid cartilage, the investing layer separates into anterior and posterior lamellæ which are continuous on each side with the layers that invest the sterno-mastoid muscle. At the suprasternal notch, the lamellæ are attached to the anterior and posterior surfaces of the manubrium sterni; the posterior lamella, which covers the infra-hyoid muscles, is attached also to the interclavicular ligament. The **suprasternal space** is enclosed between these two lamellæ, and contains the *jugular arch*, which connects the right and left anterior jugular veins.

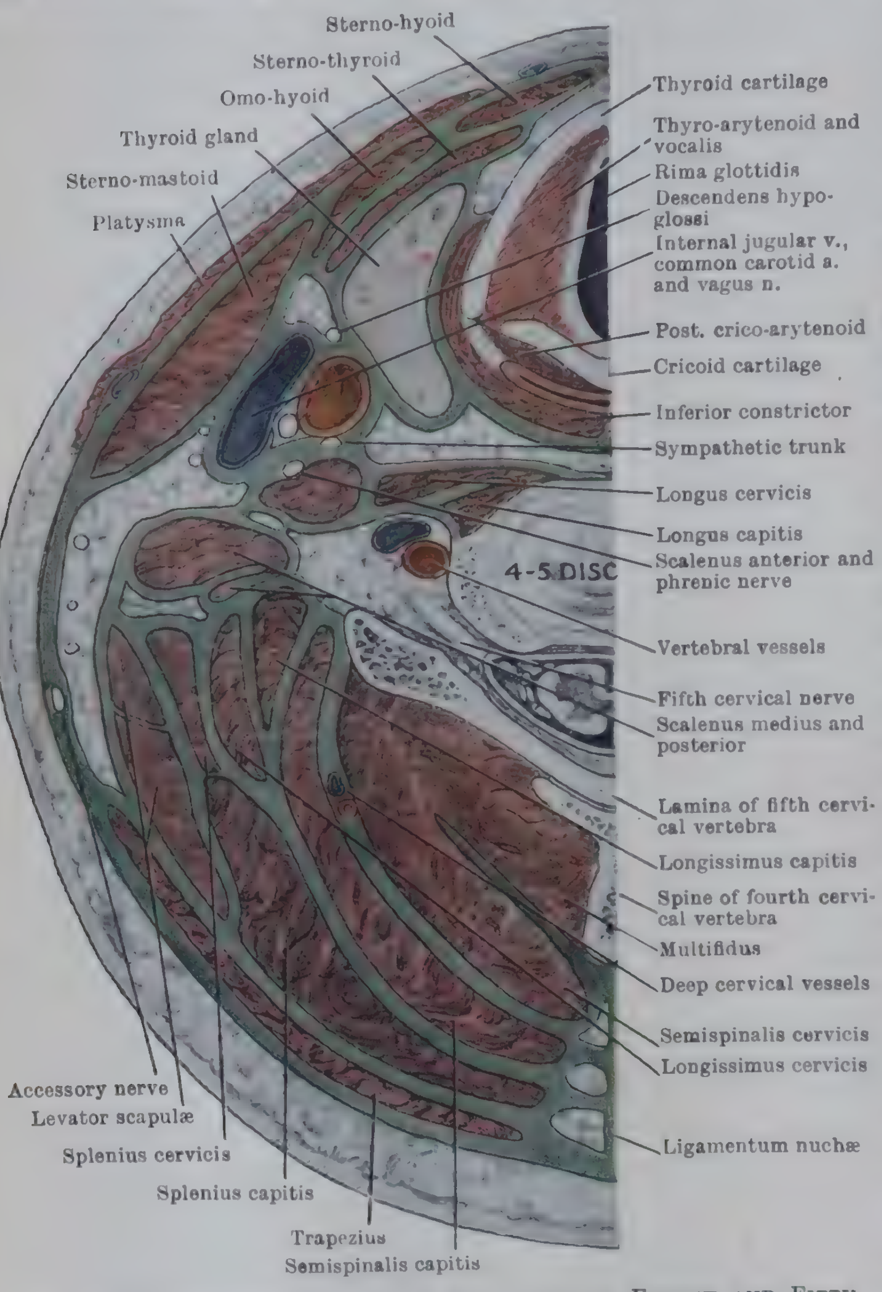


Fig. 380.—Transverse Section of Neck between Fourth and Fifth Cervical Vertebræ.

The **prevertebral fascia** extends from the basilar part of the occipital bone into the thorax, where it blends with the anterior longitudinal ligament. It covers the prevertebral muscles, and from their lateral borders extends over the scalene muscles on to the levator scapulæ and the splenius—covering the cervical plexus and constituting a fascial floor for the posterior triangle of the neck. The subclavian artery and the trunks of the brachial plexus, as they emerge from behind the scalenus anterior, carry a prolongation of this fascia downwards behind the clavicle into the axilla, where it forms the *axillary sheath.*

In the median plane, above, the prevertebral fascia is connected to the bucco-pharyngeal fascia by some loose areolar tissue which occupies the *retropharyngeal space*, and in which the retropharyngeal lymph-glands are imbedded.

As the phrenic nerve descends on the front of the scalenus anterior, it is situated between the muscle and the fascia. The nerves to the rhomboids and serratus anterior also, as they lie in the floor of the posterior triangle of the neck, are retro-fascial.

The **carotid sheath** is formed by a condensation of fibro-areolar tissue around and between the common carotid artery, the internal jugular vein and the vagus nerve, and is usually regarded as a derivative of the deep fascia of the neck. Around the artery the sheath is thick and the ansa hypoglossi and its constituent

nerves are embedded in it; but over the anterior, lateral, and posterior aspects of the vein it is reduced to a very thin layer. Antero-medially the carotid sheath blends with the sheath of the thyroid gland (pretracheal fascia), and, antero-laterally, it is intimately connected to the fascia on the deep surface of the sterno-mastoid and the infra-hyoid muscles. Posteriorly, it is connected to the prevertebral fascia by some loose areolar tissue in which the sympathetic trunk is embedded.

The **pretracheal fascia** is a very ill-defined layer; its most definite part forms a sheath for the thyroid gland. Placed deep to the sterno-thyroid muscle, it is attached to the oblique line of the thyroid cartilage, where it blends with the fascial covering of the inferior constrictor muscle. It is also bound down to the cricoid cartilage anteriorly; and, on the postero-lateral aspect of the lobe of the thyroid gland, it blends with the carotid sheath. From the isthmus of the thyroid gland it is carried downwards in front of the trachea, and blends with the fascial sheaths of the great vessels in the thorax.

MUSCLES OF THE THORAX

MUSCLES OF RESPIRATION

The muscles which complete the boundaries of the thorax are: (1) The external and internal intercostal muscles (Figs. 381-383); (2) the transversus thoracis;

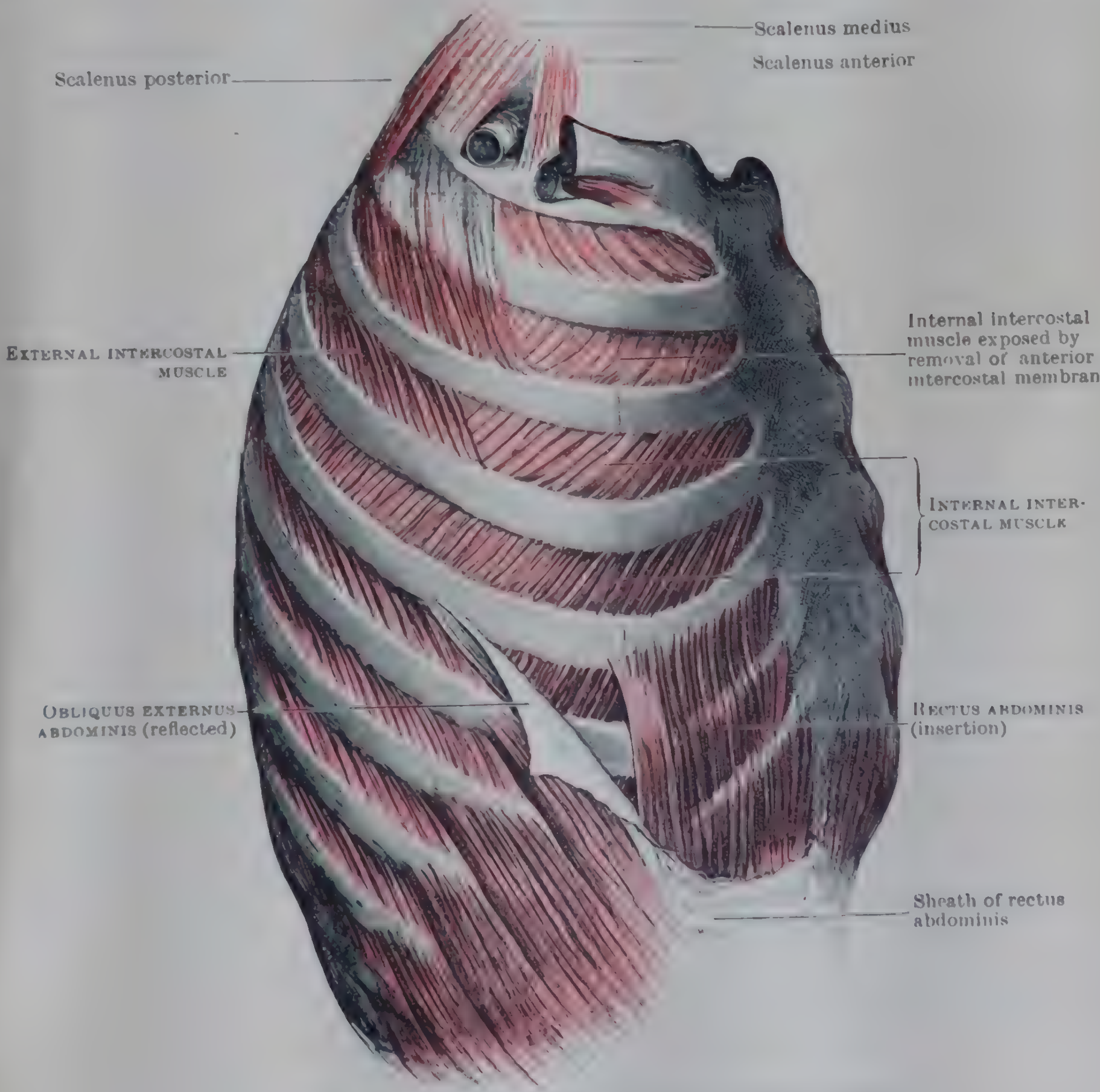


FIG. 381.—MUSCLES OF THE RIGHT SIDE OF THORACIC WALL.

(3) the levatores costarum; (4) the serrati posteriores: and (5) the diaphragm.

Intercostal Muscles.—In each intercostal space there are two intercostal

muscles—an external and an internal. Deep to the middle part of the internal intercostal there is a thin and variable layer called the innermost intercostal muscle (intercostalis intimus), which is part of the transversus thoracis.

Each **external intercostal muscle arises** from the lower border of a rib, and its fibres are directed downwards and forwards to be **inserted** into the upper border

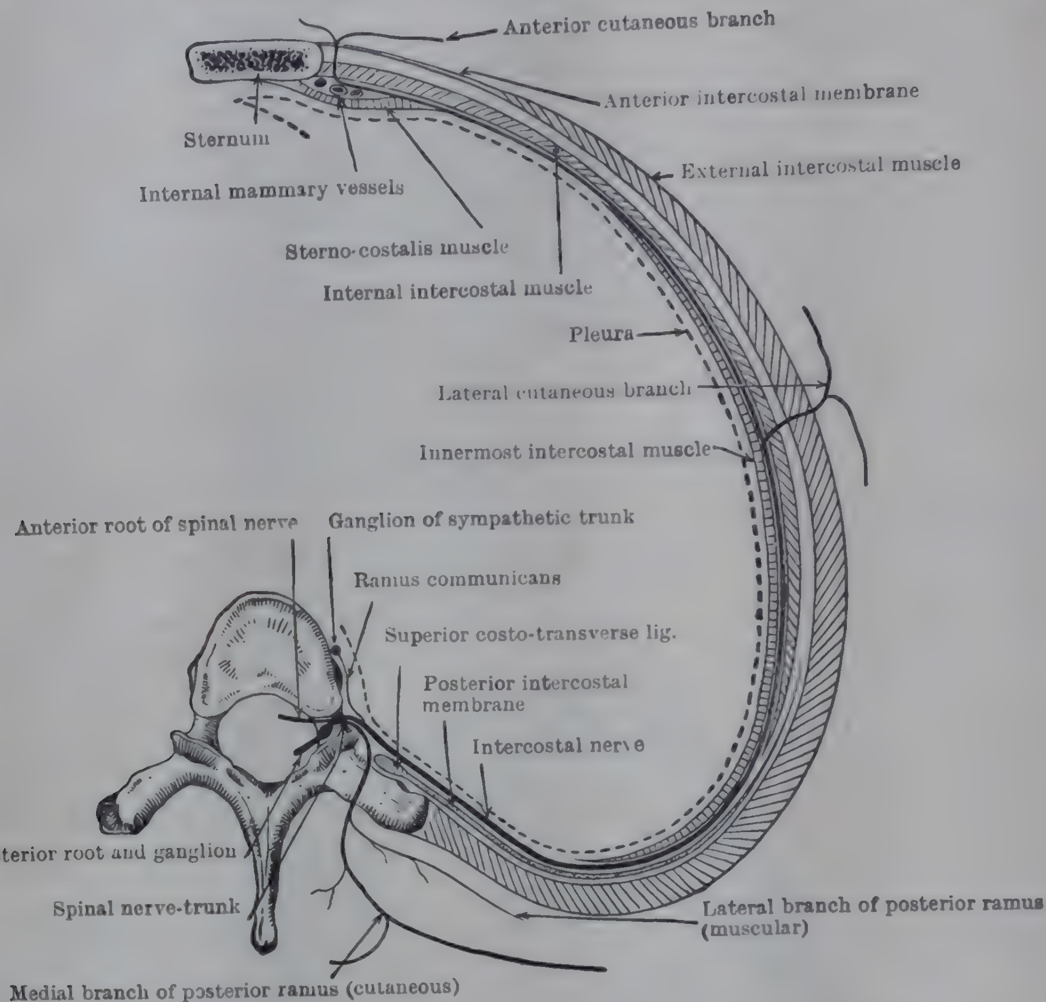


Fig. 382.—Diagram of Intercostal Space to show relations of Intercostal Muscles, Membranes, and Nerve.

of the rib below. It extends from the tubercle of the rib almost to the costal cartilages, gradually thinning to become continuous with the *anterior intercostal membrane*. This membrane extends onwards to the ventral end of the interspace and is attached above and below to the costal cartilages. In the lower spaces, the muscular fibres may merge into the external oblique muscle, which is the abdominal representative of this sheet.

Each **internal intercostal arises** from the upper border of the costal cartilage and rib and is directed upwards and forwards to be **inserted** into the costal cartilage and the upper edge of the costal groove of the rib above. It is thicker anteriorly than posteriorly and extends from the side of the sternum to the angle of the rib, where it is replaced by the *posterior intercostal membrane*, which extends to the tubercle of the rib and there becomes continuous with the superior costo-transverse ligament. The internal intercostal lies external to the intercostal vessels and nerves, and in the lower two spaces is continuous with the internal oblique muscle of the abdominal wall.

Transversus Thoracis.—This muscular sheet is divided into three parts, named the sterno-costalis, the innermost intercostals and the subcostals.

The **sterno-costalis** is the most constant part of the muscle, and lies on the back of the anterior wall of the thorax. It **arises** from the back of the xiphoid process and the body of the sternum as high as the level of the third costal cartilage, and is **inserted** into the costal cartilages from the sixth to the second. The lowest fibres are horizontal, and are continuous with the uppermost part of the transversus

abdominis; the other fibres pass obliquely upwards and laterally to their insertion. The internal mammary artery descends in front of the muscle; the pleura is behind it.

The **innermost intercostal** muscles are incomplete and variable layers that pass from rib to rib, deep to the internal intercostal. The fibres have the same direction as those of the internal muscle, and often cannot be distinguished from it except where they are separated by the intercostal nerve and vessels. Occasionally some of the bundles pass over a rib to the next below. They are connected by their fascia with the sternocostalis. Posteriorly they may be continuous with the subcostal muscles, or may be connected only by fascia with them also. (T. Walmsley, 1916; Davies, Gladstone & Stibbe, 1932.)

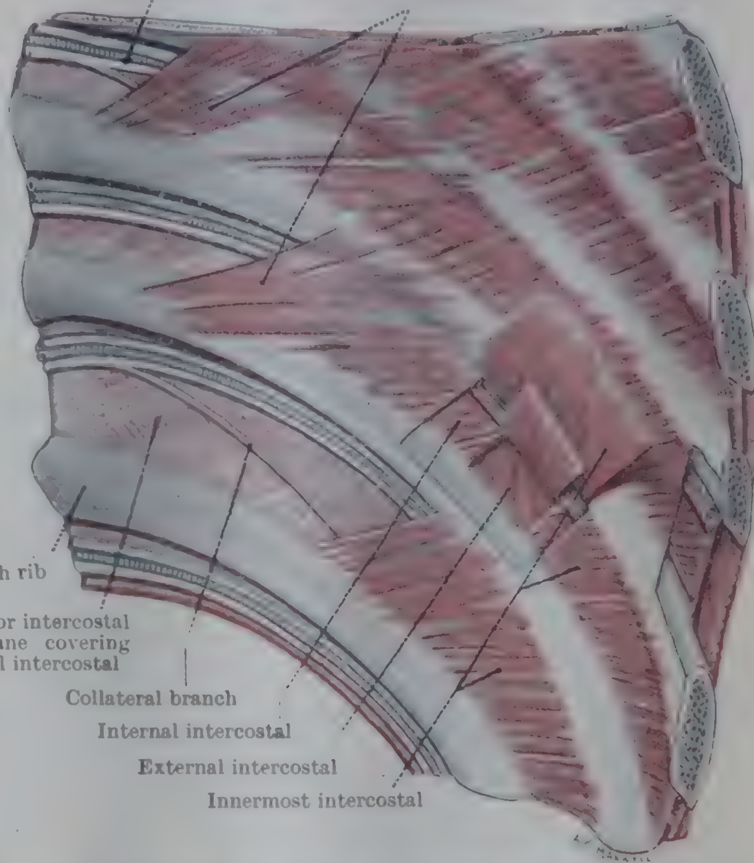


FIG. 383.—DISSECTION OF INNER SURFACE OF CHEST-WALL to show intercostal muscles, vessels, and nerves.

The **subcostal muscles** are slips that vary greatly in number, width, and length. They lie on the internal surface of the lower ribs near their angles. They are in the same plane as the innermost intercostals, and pass over one or two spaces.

Levatores Costarum.—These muscles are twelve small slips that **arise** from the transverse processes of the seventh cervical and upper eleven thoracic vertebræ. Each spreads out in a fan-like manner as it descends to the external surface of the rib immediately below, into which it is **inserted** medial to the angle.

Serrati Posteriores.—These are two thin and fairly wide muscles that lie on the outer aspect of the ribs between the superficial and deep muscles of the back. The **serratus posterior superior** has a membranous **origin** from the lower part of the ligamentum nuchæ and the spines of the last cervical and upper three or four thoracic vertebræ. It is directed obliquely downwards and laterally to be **inserted** by separate slips into the second, third, fourth, and fifth ribs. The muscle is concealed by the vertebro-scapular muscles, and crosses obliquely over the splenius, sacro-spinalis, and semispinalis capitis. Its aponeurosis is blended with the deep fascia that extends upwards from the lumbar fascia.

The **serratus posterior inferior** has a membranous **origin**, through the medium of the lumbar fascia, from the last two thoracic and first two lumbar spines. It forms four muscular bands which pass almost horizontally to an **insertion** into the last four ribs. The muscular slips overlap one another from below upwards. The muscle is concealed by the latissimus dorsi.

Diaphragm

The **diaphragm** is the great muscular and membranous partition that separates the cavities of the thorax and abdomen. A peripheral muscular portion completely surrounds a central aponeurotic membrane, and together

they form a thin but strong lamella which arches over the abdominal cavity, and is clothed on that surface, for the most part, with peritoneum. It is related, on its inferior, concave surface to the liver, stomach, and spleen, the kidneys and suprarenal glands, and the inferior vena cava. Its superior, convex surface bulges into the thoracic cavity, rising higher on the right side than on the left, and is related to the pericardium and pleuræ, and, along its margin, to the chest-wall. The œsophagus and thoracic aorta are in contact with this surface posteriorly.

The diaphragm as a whole has an extensive peripheral attachment to the inner surface of the lower margin of the thorax and to the lumbar vertebræ. Its muscular fibres, springing from sternum, ribs, and vertebræ, arch upwards and inwards, with varying degrees of curvature, to end in tendinous fibres which by their interlacement constitute the central tendon.

The **central tendon** is a dense felted aponeurosis, resembling a trefoil, since it

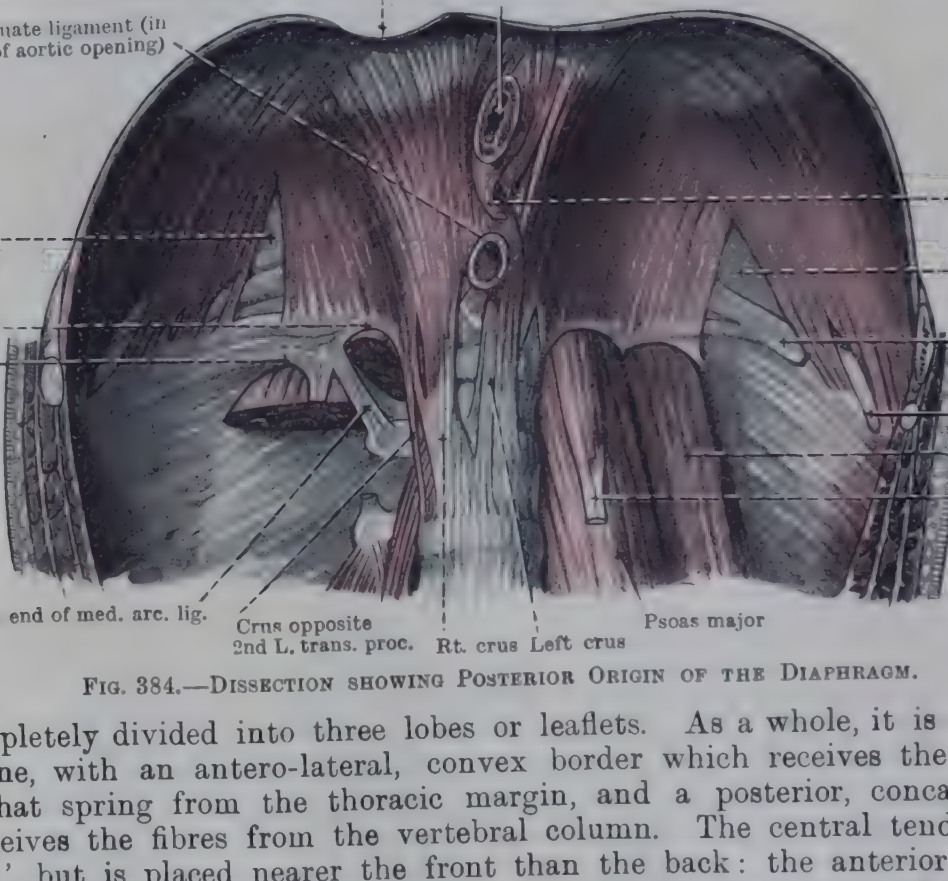


Fig. 384.—Dissection showing Posterior Origin of the Diaphragm.

is incompletely divided into three lobes or leaflets. As a whole, it is crescentic in outline, with an antero-lateral, convex border which receives the muscular fibres that spring from the thoracic margin, and a posterior, concave border that receives the fibres from the vertebral column. The central tendon is not 'central', but is placed nearer the front than the back: the anterior muscular fibres (from the xiphoid process) are consequently the shortest; and the crural fibres (from the vertebral column) are the longest. The middle or anterior lobe of the central tendon is rounded, and projects forwards from the convex border towards the sternum; by contrast, the lateral or posterior lobes appear to be narrowed from side to side. Nor is the central tendon symmetrical; the right lobe is the largest, the middle is intermediate in size, and the left is a little narrower.

The central tendon is made up of interlacing tendinous bundles which are continuous at each end with portions of the muscular sheet. The main bundles are related to the margins of the large opening for the inferior vena cava at the posterior part of the junction between the middle and right lobes; and the most obvious interlacement is found, in the densest part of the central tendon, in the median plane to the left of that opening. In that situation the interlacing tendinous bundles are arranged more or less regularly in the form of a St. Andrew's cross; in the right concavity of this X-shaped figure the vena caval opening is situated, and it has been shown that there is frequently a small venous foramen in the corresponding situation on the left side, so that the whole arrangement is in reality symmetrical (Blair, 1923).

The fleshy portion of the diaphragm is naturally divided into two portions—

a sterno-costal and a vertebral (distinguished in the classical descriptions as the *greater* and the *lesser* muscles of the diaphragm)—which are not only distinct developmentally but are separated on one or both sides of most bodies by a hiatus in the muscular sheet termed the *vertebro-costal trigone*. The sterno-costal portion

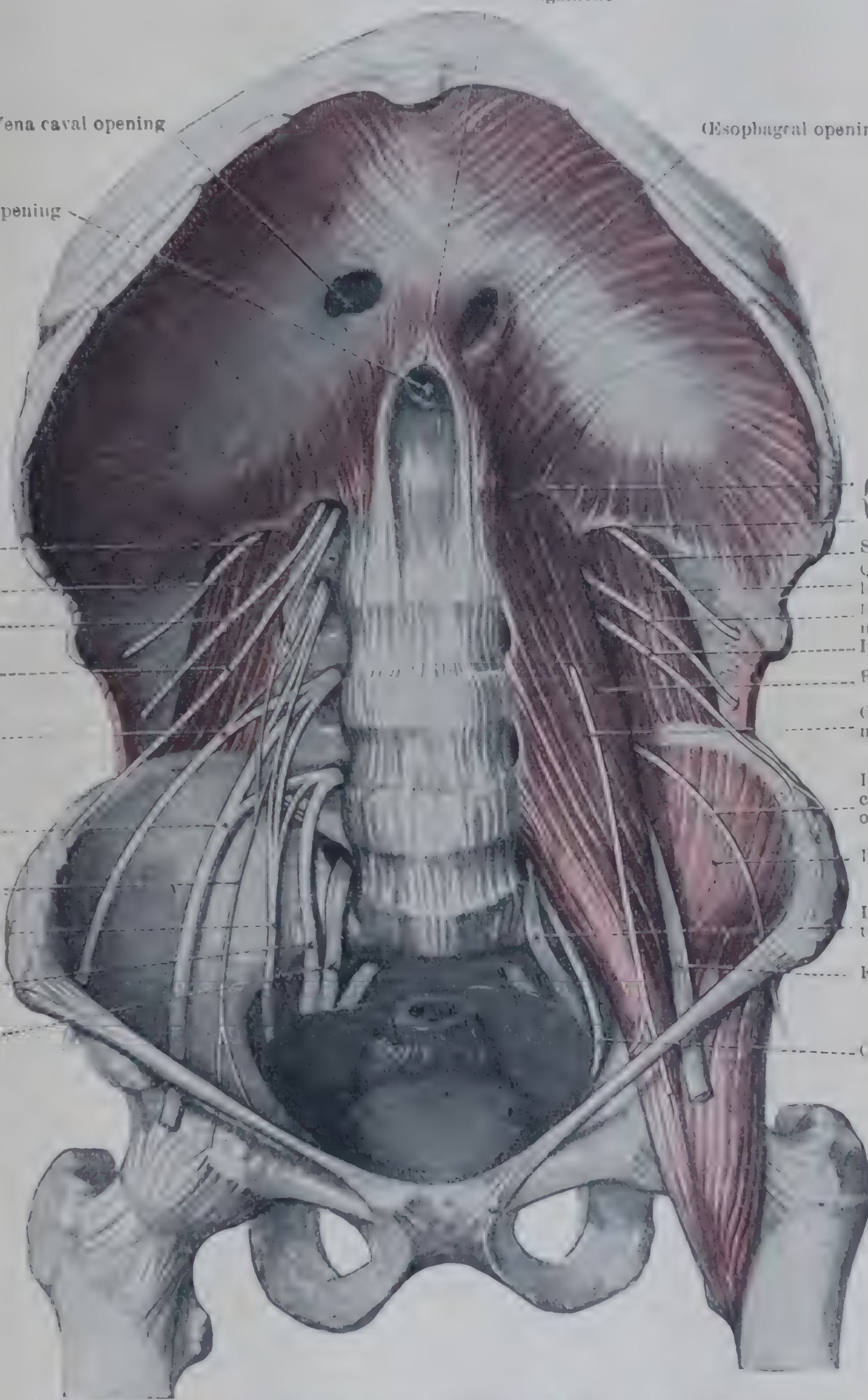


FIG. 385.—DIAPHRAGM AND POSTERIOR WALL OF ABDOMEN.

is subdivided, according to the attachment of its fibres, into sternal and costal parts.

The **sternal part** consists of a pair of short narrow slips that **arise** from the back of the xiphoid process and pass backwards and slightly upwards to be **inserted** into the central tendon.

The **costal part arises** from the deep surfaces of the lower six costal cartilages on each side by fleshy bands which interdigitate with those of the transversus abdominis. It is **inserted** into the whole length of the antero-lateral border of the central tendon.

The **vertebral part arises** from the lumbar vertebræ—directly from the bodies of the first three by the crura, and indirectly from the transverse processes of the first or second (or both) by means of the medial and lateral arcuate ligaments. It is **inserted** into the posterior border of the central tendon.

The **crura** are a pair of elongated musculo-tendinous bundles which arise, at the sides of the aorta, from the anterior surfaces of the bodies of the lumbar vertebræ—the right crus from the first three, the left crus from the first two. They are partly separated from the vertebral bodies by the upper lumbar arteries, but are firmly attached, with the anterior longitudinal ligament, to their margins and to the intervertebral discs.

The **right crus** is, as a rule, much the larger. It spreads out to form a thick triangular sheet which is directed upwards to its insertion into the middle part of the concave border of the central tendon on both sides of the median plane. Its left margin is directed obliquely upwards and to the left in front of the aorta, and splits as it approaches the central tendon to form an elliptical opening for the passage of the œsophagus (Figs. 384 and 385 show slight variations); the muscular fibres usually meet again and decussate to form the anterior margin of that opening, which is thus separated from the central tendon and surrounded by a sphincter-like arrangement of the muscle. From the right crus, below the œsophageal opening (from both sides of which it may spring), a narrow, detached band of muscle passes forwards and downwards to the left of the cœliac artery; this is the upper portion of the **suspensory muscle of the duodenum** (Low, 1907). (See also Digestive System, p. 633.)

The **left crus** is very variable in its size and attachments, but usually it is much smaller and arises higher up and farther from the median plane than the right crus. The main part of its muscular fibres is directed upwards to the left of the œsophageal opening, from which it is separated by the left margin of the right crus. Frequently a separate bundle passes to the right, between the aortic and œsophageal openings behind the fibres of the right crus (Fig. 384), to be inserted into the central tendon in the neighbourhood of the vena caval opening; but as a general rule this bundle takes no part in the formation of the œsophageal opening.

The medial part of each crus forms at its origin a tendinous funnel; the mouth of each funnel is limited above by a spiral edge that runs downwards and laterally from the aortic opening, and from it the muscular bundle emerges. Each crus is connected with its fellow of the opposite side by a tendinous band, called the **median arcuate ligament**, which arches between them, in front of the aorta, and gives origin to fibres which join the right crus as it splits to encircle the gullet. The most lateral part of the crus is continuous with the medial end of the medial arcuate ligament. Each crus is frequently divided into two or three distinct portions in relation to the passage of the splanchnic nerves and the sympathetic trunk. The splanchnic nerves pierce the crus between the medial and intermediate parts. The sympathetic trunk sometimes pierces the crus between the intermediate and lateral parts.

Between the crus and the medial edge of the costal portion of the diaphragm the origin of the lateral part of its vertebral portion is associated with the tendinous structures known as the medial and lateral arcuate ligaments; by means of these the origin of the diaphragm is carried across the upper parts of the psoas major and quadratus lumborum muscles. Both of these arches have frequently been described as mere thickenings of the fascial covering of those two muscles, but one of them is in reality an independent structure with which the fascia is fused. The medial arch is an essential tendinous origin of the diaphragm itself, while the lateral is a thickened portion of the anterior lamella of the lumbar fascia from which muscular fibres of the diaphragm may secondarily arise. It may be compared with the *arcuate line* formed by the aponeurosis of the internal oblique muscle in the lower part of the posterior wall of the sheath of the rectus abdominis.

The **medial arcuate ligament** springs from the side of the body of the second (or first) lumbar vertebra, where it is continuous with the lateral part of the crus, and arches obliquely over the upper part of the psoas muscle, behind the lateral border of which it passes downwards and medially to be attached to the transverse process of the first (or second) lumbar vertebra near the tip. The lateral end of the ligament furnishes a direct tendinous origin of the diaphragm from the transverse process to which it is attached, and the part of the arch which lies in front of the psoas gives rise to a thin sheet of muscle which fills the interval between that origin and the crus.

The **lateral arcuate ligament** stretches from the transverse process of the first (or second) lumbar vertebra across the upper part of the quadratus lumborum to be attached laterally to the twelfth (or eleventh) rib. Between the lateral margin of the quadratus and the costal attachment the ligament is continuous below with the posterior aponeurosis of the transversus abdominis, and it corresponds to similar, smaller arches which exist between the ends of the twelfth and eleventh, and of the eleventh and tenth ribs. A broad band of muscular fibres sweeps upwards from this ligament to be inserted into the medial and posterior border of the lateral portion of the central tendon. This band is overlapped towards its insertion by the edge of the costal portion of the diaphragm, and it may or may not completely fill the interval between the edge of the psoas and the last rib.

The **vertebro-costal trigone** may be defined as the interval between the posterior margin of the costal part and the lateral margin of the vertebral portion of the diaphragm. A

muscular hiatus is present in this situation on one or both sides in at least 80 per cent. of bodies, disclosing to a considerable extent the lower limit of the pleura, with which the kidney may thus be intimately related; it is more frequent, and (when bilateral) usually larger, on the left side. It varies in size from a slight separation of the muscular fibres just medial to the twelfth rib (or the eleventh when the twelfth is short and does not give origin to the diaphragm) to a large, triangular gap with a base extending from the lateral border of the psoas to the twelfth (or eleventh) rib, and an apex reaching the central tendon. Its size depends upon the degree of lateral migration of the vertebral part of the diaphragm. The gap is occasionally filled by a sheet of muscle whose fibres arch *transversely* between the margins of the two portions of the diaphragm; this sheet is sometimes in continuity with the subcostal sheet of muscle, of which it appears to be a portion displaced in *front* of the lower limit of the pleura. The vertebro-costal hiatus in the muscular continuity of the diaphragm is situated in the position of the pleuro-peritoneal opening of the embryo, and is the site of congenital diaphragmatic hernia (more common on the left side), in which the pleural and peritoneal cavities are continuous.

The diaphragm is pierced by numerous structures. The superior epigastric artery enters the sheath of the rectus abdominis between its sternal and costal origins; the musculo-phrenic artery passes between its attachments to the seventh and eighth costal cartilages. The splanchnic nerves pierce the crus, and the sympathetic trunk descends behind the medial end of the medial arcuate ligament. The subcostal nerve and vessels pass behind the lateral arcuate ligament; and the aorta and thoracic duct pass between the crura, behind the median arcuate ligament (*aortic opening*). The azygos vein is usually described as passing through the aortic opening, but it is placed postero-lateral to the thoracic duct and completely under cover of the right crus. The special openings are two in number. The *vena caval opening* in the right half of the central tendon transmits the inferior vena cava and small branches of the right phrenic nerve. The *œsophageal opening* is in the muscular substance of the diaphragm, behind the central tendon, and is surrounded by a sphincter-like arrangement of the fibres of the right crus (Low, 1907; Whillis, 1931). Besides the œsophagus, this opening transmits the two gastric nerves, each containing fibres from both the right and the left vagus, and œsophageal branches of the left gastric artery.

The comparative morphology of the diaphragm and its derivation from the fourth cervical myotome are summarized on p. 555.

Nerve-Supply.—The intercostal muscles, the transversus thoracis, the levatores costarum, and the serrati posteriores (superior, Th. 1-4; inferior, Th. 9-11) are all supplied by the **anterior primary rami** of the **thoracic nerves**.

The diaphragm receives its motor supply from the **phrenic nerve** (C. 3. 4. 5.), mainly on its inferior surface after the nerves have pierced it. The phrenic nerves contain afferent fibres also, and the branches to the diaphragm from the lower intercostal nerves (9th, 10th, and 11th), which have been described, may be of this nature, or they may supply motor fibres to a portion of the subcostal sheet if that is incorporated in the diaphragm, between its lumbar and sterno-costal portions, in the closure of the vertebro-costal trigone. The sympathetic nerve-supply to the diaphragm is conveyed to it from the cœliac ganglion through the phrenic plexus, with which the phrenic nerve communicates.

Actions.—The opposite respiratory movements of expiration and inspiration, essentially associated with the rise and fall of the diaphragm, are effected by antagonistic forces and are supported by an array of accessory and fixation muscles; and the greater the respiratory excursions, the more reserves are enlisted. The delicate, yet intensive, control exercised by the diaphragm in regulating the outflow of air through the larynx is remarkably evident in singing, when it opposes its abdominal antagonists, while the quadratus lumborum acts as a fixation muscle.

Before considering the details of these movements, points of clinical value regarding the position of the diaphragm as affected by posture in the living subject during expiration and inspiration may be considered with reference to the radiographs on Plates XXXVIII and XXXIX, pp. 456-457. With the subject standing (Fig. **1**) the diaphragm occupies a lower level than in the supine position (Fig. **3**), in which the abdominal weight presses against the diaphragm instead of pulling it downwards. Breathless patients breathe more easily, therefore, when propped up in bed. When the subject lies prone the diaphragm rises markedly on the right side. The diaphragm occupies the same level in sitting as in standing (Pls. XXXVIII and XXXIX, Figs. **1** and **2**).

When the subject lies on one side (Figs. **4** and **5**), apart from the fact that the corresponding side of the diaphragm, owing to the pressure of the abdominal viscera, reaches a higher level than in other positions, the costo-diaphragmatic recess (p. 711)

are separate to the mid line. It gains attachments, below to the pubic tubercle and the front of the symphysis (Fig. 391), above to the xiphoid process, and by its intermediate decussating fibres to the **linea alba.**

The muscle is superficial in almost its whole extent. It is overlapped posteriorly by the latissimus dorsi, but is often separated from it immediately above the iliac

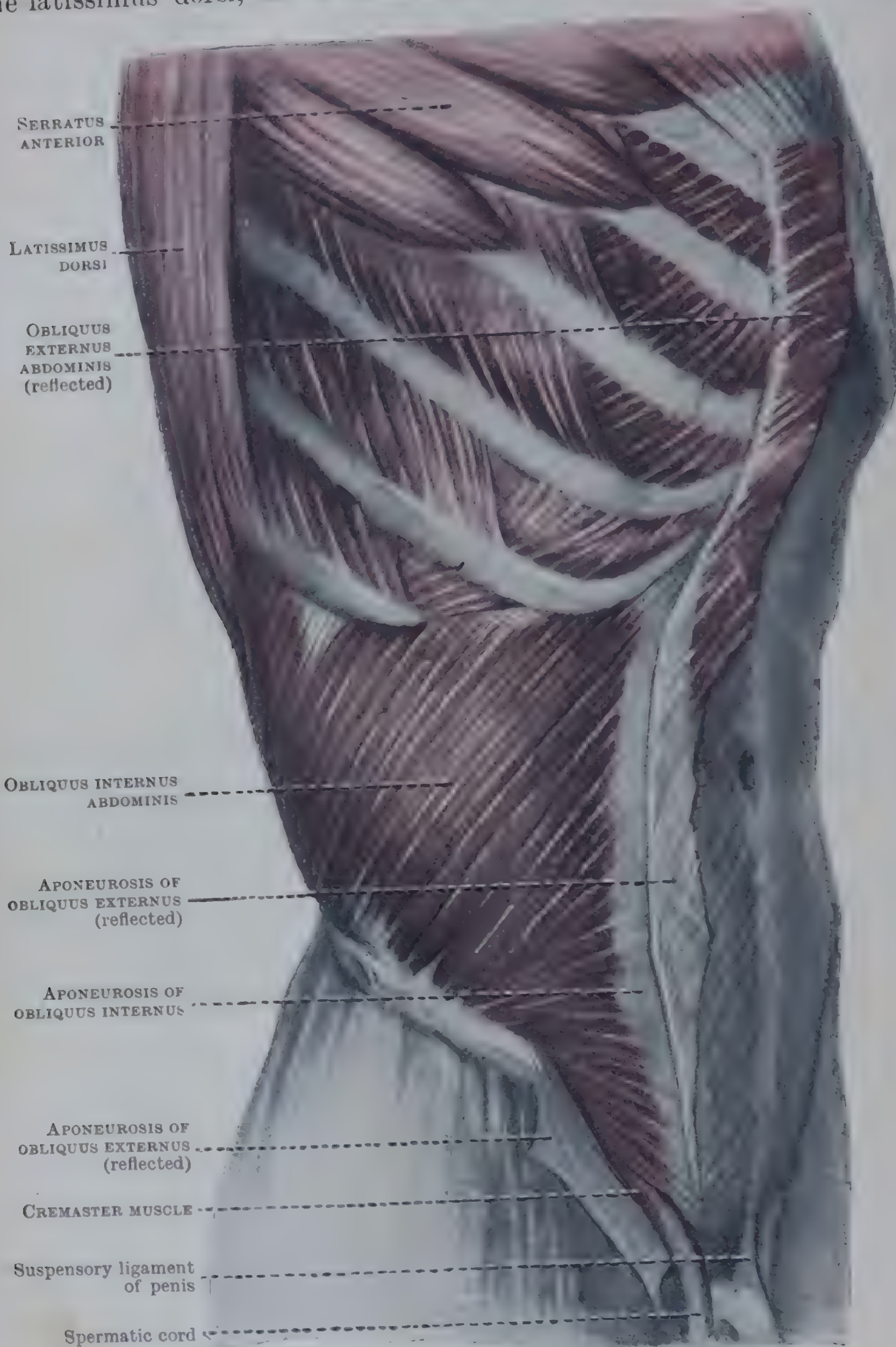


FIG. 387.—RIGHT OBLIQUUS INTERNUS ABDOMINIS.

crest by an angular interval called the **lumbar triangle.** The uppermost part of the aponeurosis covers the insertion of the rectus abdominis on the chest-wall, and gives origin to fibres of the pectoralis major; its lower border is folded slightly backwards upon itself, between the anterior superior iliac spine and the pubic tubercle, to form the inguinal ligament; and immediately above the pubic tubercle there is a cleft in the aponeurosis, called the superficial inguinal ring, which transmits the spermatic cord or the round ligament of the uterus.

The **linea alba** is a band of interlacing fibres, narrow below the umbilicus but increasing to about half an inch in width in its upper part. It occupies the median

FIG. 1.—THE PLATYSMA IN ACTION.

FIG. 2.—ACTION OF TRAPEZIUS AND DELTOID MUSCLES IN ELEVATION OF THE UPPER LIMB.

FIG. 3.—THE RECTUS ABDOMINIS IN ACTION.

FIG. 4. SUBJECT ATTEMPTING INSPIRATION WITH CLOSED GLOTTIS

Note the effect of atmospheric pressure on the abdomen, the intercostal spaces, the suprasternal and the supraclavicular and infraclavicular fossæ.

PLATE XXXVII.—PHOTOGRAPHIC ILLUSTRATIONS OF MUSCLES IN ACTION.

[Facing p. 456

PLATE XXXVIII

Fig. 1.—Standing.

Fig. 2.—Sitting.

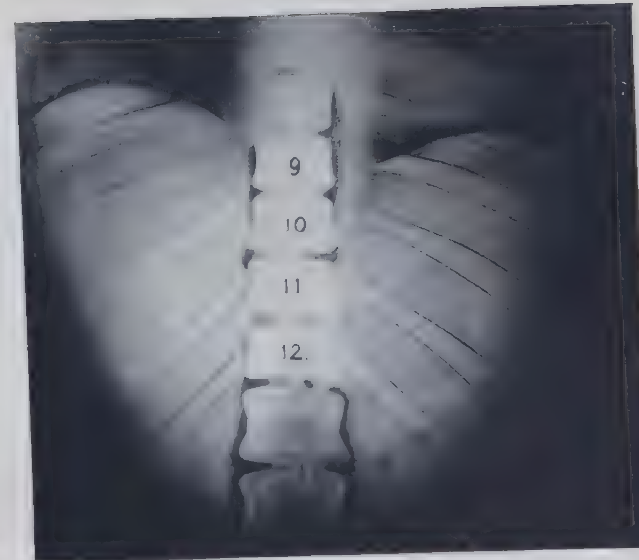


Fig. 3.—Lying on Back.

Fig. 4.—Lying on Right Side.

Fig. 5.—Lying on Left Side.

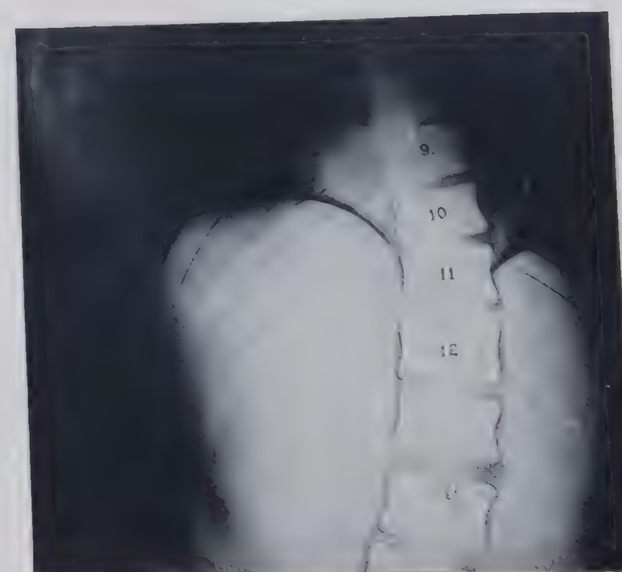


Fig. 6.—Standing with Bend to Right.

Plate XXXVIII. Series of Radiographs showing the Position of the Diaphragm at the end of Full Expiration in the same Subject in Six Different Postures.

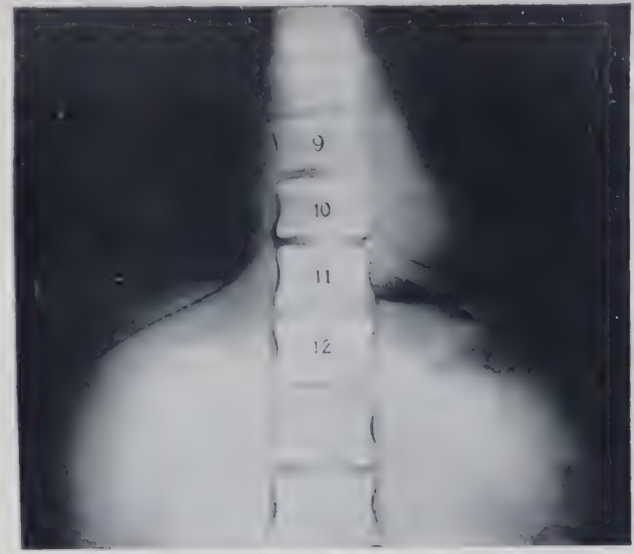


Fig. 1.—Standing.

Fig. 2.—Sitting.

Fig. 3.—Lying on Back.

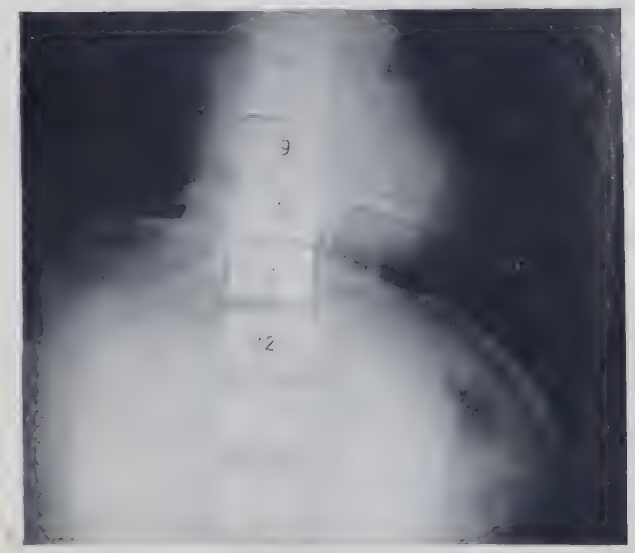


Fig. 4.—Lying on Right Side.

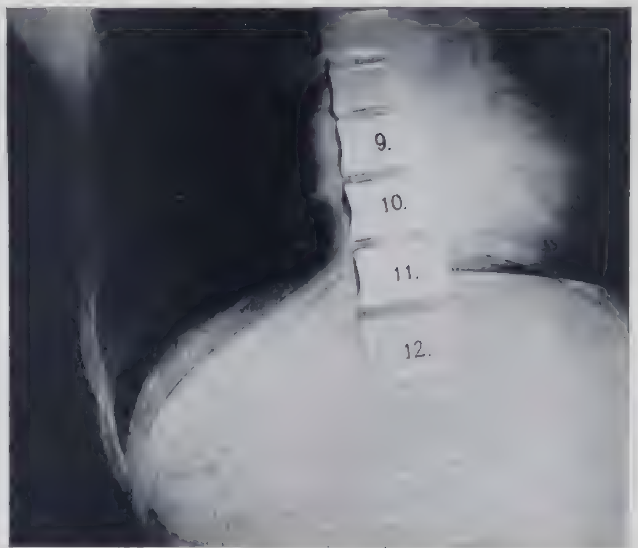


Fig. 5.—Lying on Left Side.

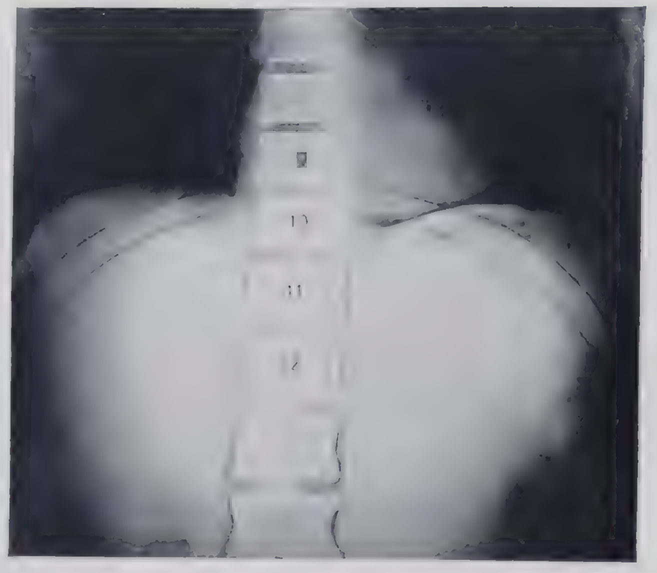


Fig. 6.—Standing with Contraction of Transversus Abdominis.

Plate XXXIX. Series of Radiographs showing the Position of the Diaphragm at the end of Full Inspiration in the same Subject in Six Different Postures.

Compare with the Expiration series in Plate XXXVIII.

FIG. 1.—ACTION OF LATISSIMUS DORSI AS DEPRESSOR AND ADDUCTOR OF UPPER LIMB. SUBJECT PULLING ON A ROPE

FIG. 2.—ACTION OF SERRATUS ANTERIOR IN ELEVATION OF UPPER LIMB.

FIG. 3.—FOLDS OF THE AXILLA AND THE MEDIAL ASPECT OF THE UPPER ARM, SHOWING THE POSITION OF THE LONG AND MEDIAL HEADS OF THE TRICEPS.

Note the contraction of the right Sterno-Mastoid and compare with Plate XXXVII, Figs. 3 and 4, p. 456.

PLATE XL.—PHOTOGRAPHIC ILLUSTRATIONS OF MUSCLES IN ACTION.

[Facing

plane of the anterior abdominal wall in its whole extent, is pierced by the umbilicus and forms the greater part of the ultimate insertion of all the lateral abdominal muscles.

The **umbilicus** or navel is a little below the middle of the linea alba, usually opposite the disc between the third and fourth lumbar vertebrae. It is a puckered scar in the skin and the linea alba, and it results from the closure of the *umbilical orifice* of the fœtus. The orifice transmits the umbilical vein and arteries and the connexion between the allantois and the urachus. After birth the derivatives of those structures remain attached to the umbilicus—the round ligament of the liver derived from the vein, the lateral umbilical ligaments from the arteries, and the

Fig. 388.—Left Inguinal Canal. Structures seen on reflexion of Obliquus Externus.

median umbilical ligament from the urachus. The deep surface of the umbilicus is related also to the extraperitoneal tissue; and a fibrous band may connect it with the diverticulum ilei when the diverticulum is present.

The **inguinal ligament** is a tendinous band curving with a downward convexity from the anterior superior iliac spine to the pubic tubercle across the iliacus, psoas major and pectineus. The convexity gives attachment to the fascia lata. The ligament is the lower margin of the external oblique aponeurosis folded back on itself, and its upper surface is therefore grooved. In its lateral part, this surface gives partial origin to the internal oblique and the transversus, and receives the attachments of the fascia transversalis and fascia iliaca; in its medial part it forms the gutter-like floor of the inguinal canal. This portion includes the **pectineal part** of the ligament, which is a triangular expansion that spreads *backwards* from the most medial part of the ligament to the pectineal line (Fig. 391). Some of these

fibres are reflected from the pectineal line obliquely through the linea alba to mingle with the aponeurosis of the other side; this **reflected part** of the inguinal ligament, sometimes described as an additional insertion of the opposite external oblique aponeurosis, is seldom well marked. A lateral extension along the pectineal line from the pectineal part of the inguinal ligament is termed the *pectineal ligament* (Astley Cooper). The inguinal ligament is related posteriorly to the femoral nerve and to the femoral vessels enclosed in the femoral sheath: the nerve is between the iliacus and the psoas major; the artery is on the psoas; the vein is partly on the psoas and partly on the pectineus. The lateral margin of the pectineal part of the ligament is the medial boundary of the *femoral ring* (p. 532 and Fig. 393).

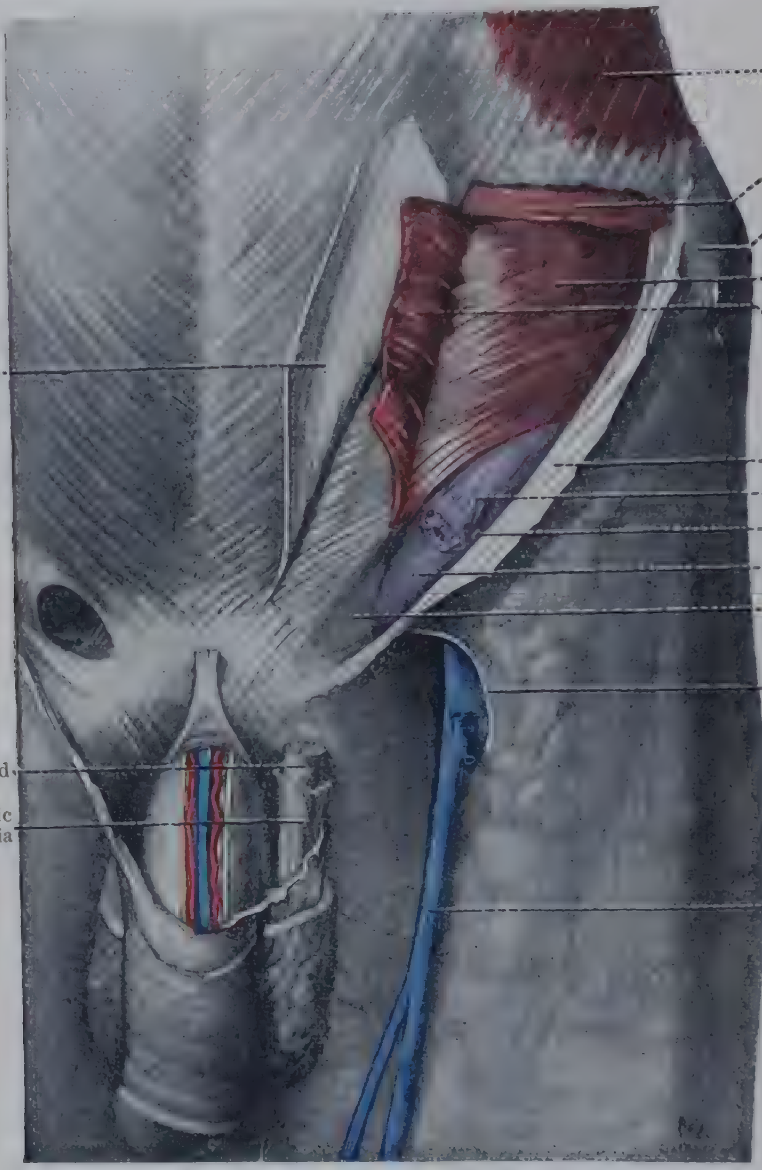


FIG. 389.—DISSECTION OF INGUINAL CANAL.

The **superficial inguinal ring**, important as the place of exit of an inguinal hernia, is a triangular cleft in the external oblique aponeurosis with its base at the pubic crest and its apex directed upwards and laterally.

The margins of the cleft are called its crura. The **inferior crus** is narrow, and is formed from that part of the aponeurosis which is fixed to the pubic tubercle, and constitutes the medial end of the inguinal ligament. The **superior crus**, flat and broad, is the part of the aponeurosis which is attached to the pubic crest and symphysis. In the male it transmits the spermatic cord, enclosed in the internal spermatic fascia and the cremaster muscle and fascia; in the female the cleft is much smaller and transmits the round ligament of the uterus. The opening is variable in width and is triangular in outline; its edges are drawn together by a thin fascia, strengthened superficially by a number of arched and horizontal fibres, called the **intercrural fibres** (Fig. 394), which arise from the inguinal ligament and

sweep medially across the cleft in the aponeurosis; but the margins of the opening are readily felt in the living subject if the finger is passed upwards over the spermatic cord, invaginating the overlying skin, till it is opposite the ring, and is then pressed backwards.

The intercrural fibres and the crura of the ring are continuous with a thin tubular

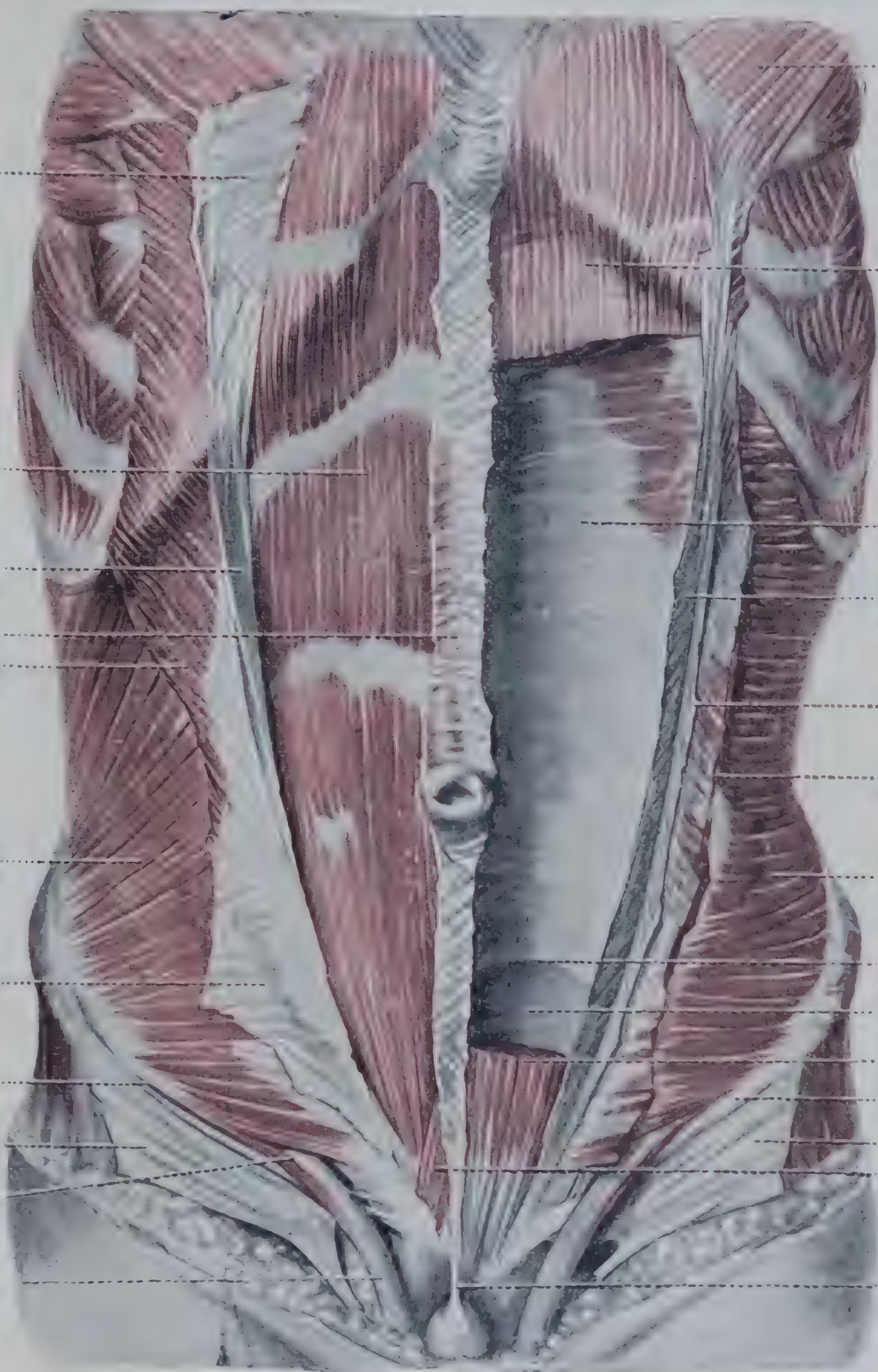


FIG. 390.—DEEP DISSECTION OF ABDOMINAL WALL. RECTUS MUSCLE AND ITS SHEATH.

sheath, called the **external spermatic fascia**, which forms an envelope for the spermatic cord (or for the round ligament) after it has passed beyond the abdominal wall; and it must be noted that the ring is not apparent until the external spermatic fascia has been removed from its edges.

Obliquus Internus Abdominis.—The internal oblique muscle is a broad, thin sheet situated between the external oblique and the transversus. It arises from (1) the lumbar fascia, (2) the anterior half or two-thirds of the intermediate area of the iliac crest, and (3) the lateral two-thirds of the inguinal ligament.

It runs, for the most part, upwards and forwards, and its highest and most posterior fibres are inserted directly into the cartilages of the last three ribs in line with the internal intercostals. The rest of the muscular fibres spread like a fan and become an aponeurosis, the change taking place along a line that extends downwards and medially from the tenth costal cartilage to the pubic bone. The principal insertion of the aponeurosis is the whole length of the linea alba, but it does not reach its insertion as an undivided sheet. The lower fourth passes in front of the rectus abdominis, and, spreading downwards and medially, reaches the pubic bone as well as the linea alba. The upper three-fourths splits at once into

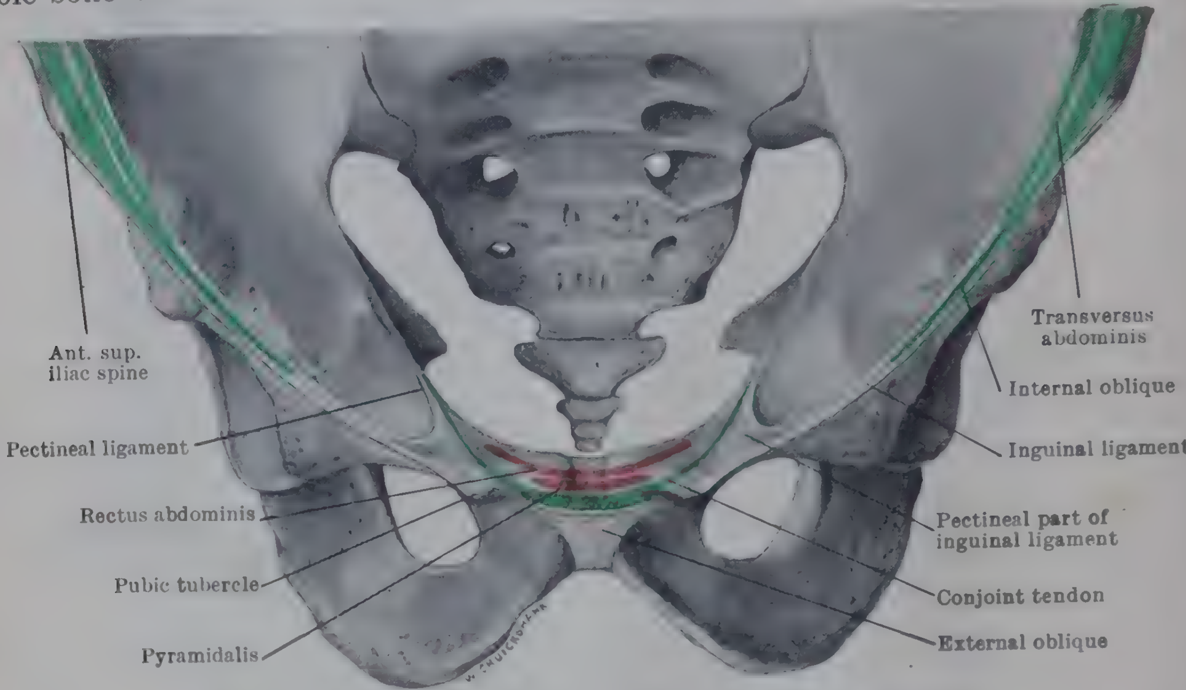


Fig. 391.—Muscle-Attachments to Inguinal Ligament and Pubis.

two layers which enclose the rectus as they pass to their insertion into the linea alba and the xiphoid process; the posterior layer is attached also to the margins of the ninth, eighth, and seventh costal cartilages, and above that level the rectus abdominis muscle is therefore in direct contact with the chest-wall. The part which passes undivided in front of the rectus is derived from the fleshy fibres that arise from the inguinal ligament. It fuses with the part of the transversus aponeurosis that has a like origin to form a sheet called the conjoint tendon. The **conjoint tendon** meets its fellow at the linea alba, and also extends downwards to be attached to the pubic crest and the pectineal line (Fig. 391).

The internal oblique is limited above by the inferior margin of the thorax. Its lower fibres, arching over the spermatic cord, assist in forming, laterally, the anterior wall of the inguinal canal; medially, by means of the conjoint tendon, they help to form the posterior wall.

Its lowest fibres are continued into the **cremaster muscle**, which is prolonged along the spermatic cord through the inguinal canal.

Cremaster—The cremaster muscle, a series of delicate muscle-fibre festoons connected by fascia—the *cremasteric fascia*—**arises** from the inferior edge of the internal oblique and the adjacent part of the inguinal ligament, and loops over the spermatic cord and testis, the highest fibres getting an **insertion** into the pubic tubercle. In the female it is more largely represented by fascia than by muscle-fibres. The name 'cremaster' refers to the suspensory function of the muscle [κρεμαστός=suspended].

Transversus Abdominis.—The transversus abdominis muscle **arises** (1) from the deep surfaces of the costal cartilages of the lower six ribs, interdigitating with the origins of the diaphragm; (2) from the transverse processes of the lumbar vertebræ through the middle layer of the lumbar fascia; (3) from the anterior half or two-thirds of the inner lip of the iliac crest; and (4) from the lateral third of the inguinal ligament.

The muscular fibres run, for the most part, horizontally forwards, and they end

in an aponeurosis which has a twofold **insertion.** (1) After taking part in the formation of the sheath of the rectus, the aponeurosis is attached to the xiphoid process, the whole length of the linea alba, and the pubic symphysis. (2) The fibres that arise from the inguinal ligament form the larger part of the conjoint tendon, to which the lower part of the internal oblique also contributes.

The aponeurosis of the transversus abdominis is widest opposite the interval between the last rib and the iliac crest, and gradually becomes narrower above and below. Near the xiphoid process it is barely 3 cm. wide, and in this situation fleshy fibres of the muscle are separated from the rectus abdominis only by the posterior lamella of the aponeurosis of the internal oblique (Fig. 390).

The lower intercostal nerves lie between the internal oblique muscle and the transversus muscle, which is lined on its deep surface by the fascia transversalis. Its inferior border forms a concave edge, separated from the inguinal ligament by a semilunar interval in which the fascia transversalis appears, and through which the spermatic cord emerges at the deep inguinal ring, under cover of the internal oblique muscle and the aponeurosis of the external oblique.

Pyramidalis.—The pyramidalis is a small triangular muscle that lies on the front of the lower part of the rectus abdominis. It **arises** from the pubic crest lower down than the origin of the rectus (Fig. 391). It is directed obliquely upwards, for a variable distance, to be **inserted** into the linea alba (Fig. 390). The muscle is often absent.

Rectus Abdominis.—The rectus abdominis muscle is long and strap-like; and it **arises** by a medial head from the ligaments in front of the pubic symphysis, many of the fibres coming from the opposite side, and by a lateral head from the pubic crest (Figs. 390, 391).

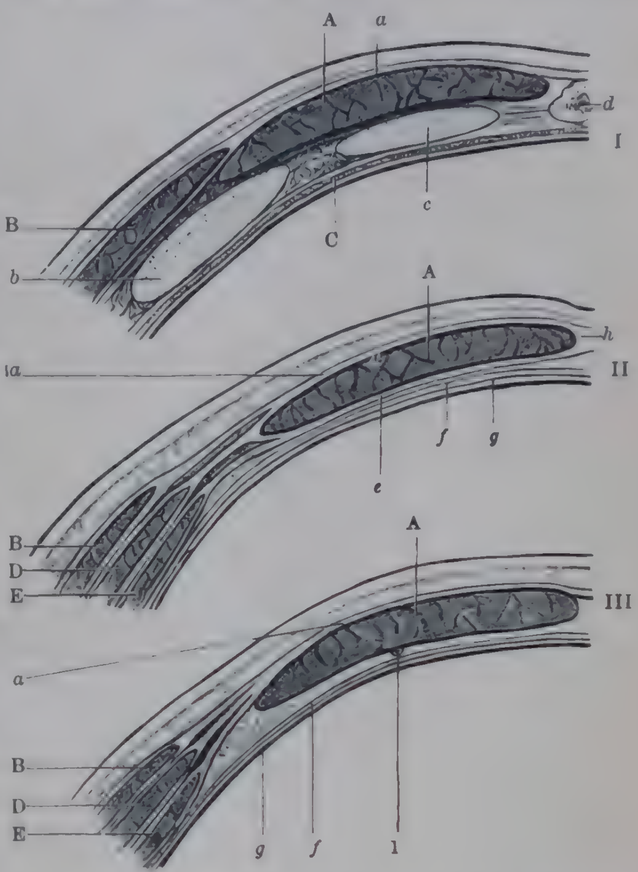


Fig. 392.—Sheath of Rectus Abdominis Muscle.

I. In the thoracic wall; II. In the upper three-quarters of the abdominal wall, cf. Fig. 390; III. In the lower fourth of the abdominal wall. (Below the umbilicus, the fusion of the aponeuroses of external and internal oblique muscles in front of the rectus is incomplete, p. 455).

A, Rectus muscle; B, Obliquus externus; C, Diaphragm; D, Obliquus internus; E, Transversus abdominis. *a*, Anterior wall of rectus sheath; *b*, Fifth costal cartilage; *c*, Sixth costal cartilage; *d*, Xiphoid process; *e*, Posterior wall of rectus sheath; *f*, Fascia transversalis; *g*, Peritoneum; *h*, Linea alba. 1, Inferior epigastric artery.

The muscle widens as it passes upwards, and is **inserted** into the anterior surface of the xiphoid process, and into the superficial surfaces of the seventh, sixth, and fifth costal cartilages. On its anterior surface, but not extending through the entire substance of the muscle, are three or more transverse **tendinous intersections**, firmly adherent to the anterior wall of the sheath of the muscle; the lowest is at the side of the umbilicus, and the highest is near the xiphoid process. These may be evident in the well-developed living subject (Pl. XXXVII, p. 456, Fig. 3). The medial border of the muscle lies alongside the linea alba; its lateral border is convex, and corresponds to a shallow groove on the skin called the **linea semilunaris.** The muscle is pierced by the terminal branches of the lower thoracic nerves after they have passed between the muscle and the posterior wall of its sheath.

The **sheath of the rectus abdominis** is derived from the aponeuroses of the lateral muscles of the abdominal wall, which, after enclosing the rectus, give rise, in the median plane, to the linea alba. At the linea semilunaris, the aponeurosis of the internal oblique splits into anterior and posterior layers. The anterior layer, joined by the aponeurosis of the external oblique, passes in front of the rectus and

constitutes the anterior wall of the sheath. The posterior layer, joined by the aponeurosis of the transversus muscle, passes behind the rectus and constitutes the posterior wall of its sheath. (In the uppermost part of the posterior wall there are muscular fibres of the transversus as well as aponeurotic fibres.) This arrangement obtains in the upper three-fourths of the abdominal wall. Below the level of the anterior superior iliac spine the sheath of the muscle is deficient posteriorly, and a crescentic border, called the **arcuate line,** marks the lower limit of the posterior wall. In consequence, the rectus in the lower fourth of the abdominal wall rests directly on the fascia transversalis. Close examination, however, usually reveals a thin layer behind the muscle in continuity with the arcuate line, and merging below with the fascia transversalis. In this region (see p. 455) the rectus is covered anteriorly by the aponeuroses of the external oblique, internal oblique, and transversus (Fig. 392). The upper part of the rectus, lying directly on the chest-wall, (because the posterior wall of the sheath ascends no higher than the costal margin) is covered anteriorly by only a single layer of aponeurosis derived from the external oblique, which in that situation is giving origin to the pectoralis major muscle. In addition to the rectus the sheath contains the pyramidalis, the superior and inferior epigastric vessels, the terminal portions of the lower five intercostal vessels and nerves and the subcostal vessels and nerve.

Inguinal Canal.—The spermatic cord in the male (or the round ligament in the female) traverses the **inguinal canal**, which is an oblique passage through the muscular layers of the lowest part of the abdominal wall. The canal, about $1\frac{1}{2}$ inches long, begins at the *deep inguinal ring*, which is an area of evagination in the fascia transversalis, half an inch or less above the inguinal ligament, and midway between the anterior superior iliac spine and the pubic symphysis. It ends at the *superficial inguinal ring*, which is an area of evagination in the external oblique aponeurosis immediately above the pubic tubercle and the medial end of the inguinal ligament. The *anterior wall* of the canal is formed by the aponeurosis of the external oblique, and in its lateral part by the muscular fibres of the internal oblique; the *posterior wall* of the canal is formed by the fascia transversalis, and in its medial part by the conjoint tendon and by the reflected part of the inguinal ligament when that structure is well developed. Thus, the anterior wall is strongest opposite the deep inguinal ring, and the posterior wall opposite the superficial ring. The *floor* of the canal is formed by the inguinal ligament, and, medially, by its pectineal part; the *roof* is formed by the arching fibres of the internal oblique and transversus. The spermatic cord, evaginating the transversalis fascia, enters the inguinal canal at the deep inguinal ring, and is there invested by its *first coat*—the **internal spermatic fascia**—a sheath of fascia derived from the margins of the ring and continuous with the fascia transversalis. The cord then passes obliquely medially, downwards, and forwards, and escapes below the lower border of the internal oblique muscle, from which it carries off a *second coat*, partly fascial, partly muscular—the **cremaster muscle** and **fascia**. Continuing its course, in front of the conjoint tendon, it emerges through the superficial inguinal ring, from the edges of which the **external spermatic fascia** is derived, *i.e.*, the *third* or *external coat* of the cord.

The **inguinal triangle** is the site of one form of inguinal hernia. It is bounded below by the inguinal ligament, medially by the rectus abdominis muscle, and laterally by the inferior epigastric artery coursing upwards and medially behind the fascia transversalis. The spermatic cord passes over the base of the triangle, covered over by the aponeurosis of the external oblique. Behind the cord, and forming the floor of the triangle, is the fascia transversalis, partially covered, in the medial portion of the triangle, by the conjoint tendon. The floor is divided into medial and lateral parts by the lateral umbilical ligament.

Quadratus Lumborum.—The quadratus lumborum extends between the iliac crest and the last rib, and lies alongside the tips of the lumbar transverse processes. It **arises** from the posterior part of the iliac crest, from the ilio-lumbar ligament, and from the transverse processes of the lower lumbar vertebræ. It is **inserted** into the medial part of the lower border of the last rib and the transverse processes of the lumbar vertebræ. Its lateral border is directed obliquely upwards and medially.

It is enclosed between the anterior and middle layers of the lumbar fascia, and is overlapped, medially, by the psoas major in front and the sacro-spinalis behind.

Nerve-Supply.—The nerve-supply of the foregoing muscles is derived from the anterior primary rami of the **lower six thoracic** and **upper four lumbar nerves.** The external oblique and the rectus are supplied by the lower five intercostal nerves (T. 7-11), the internal oblique and the **transversus** by the lower **five** intercostal, the subcostal (T. 12), and the ilio-hypogastric and ilio-inguinal (L. 1). The pyramidalis muscle is innervated by the **subcostal nerve** (T. 12). The cremaster muscle receives its supply from the **genital branch of the genito-femoral nerve** (L. 1, 2). The quadratus lumborum is supplied by the subcostal nerve and the first three or four lumbar nerves.

Actions.—(1) By virtue of their normal tone, the anterior and lateral muscles of the abdominal wall support the abdominal viscera and help to retain them in position.

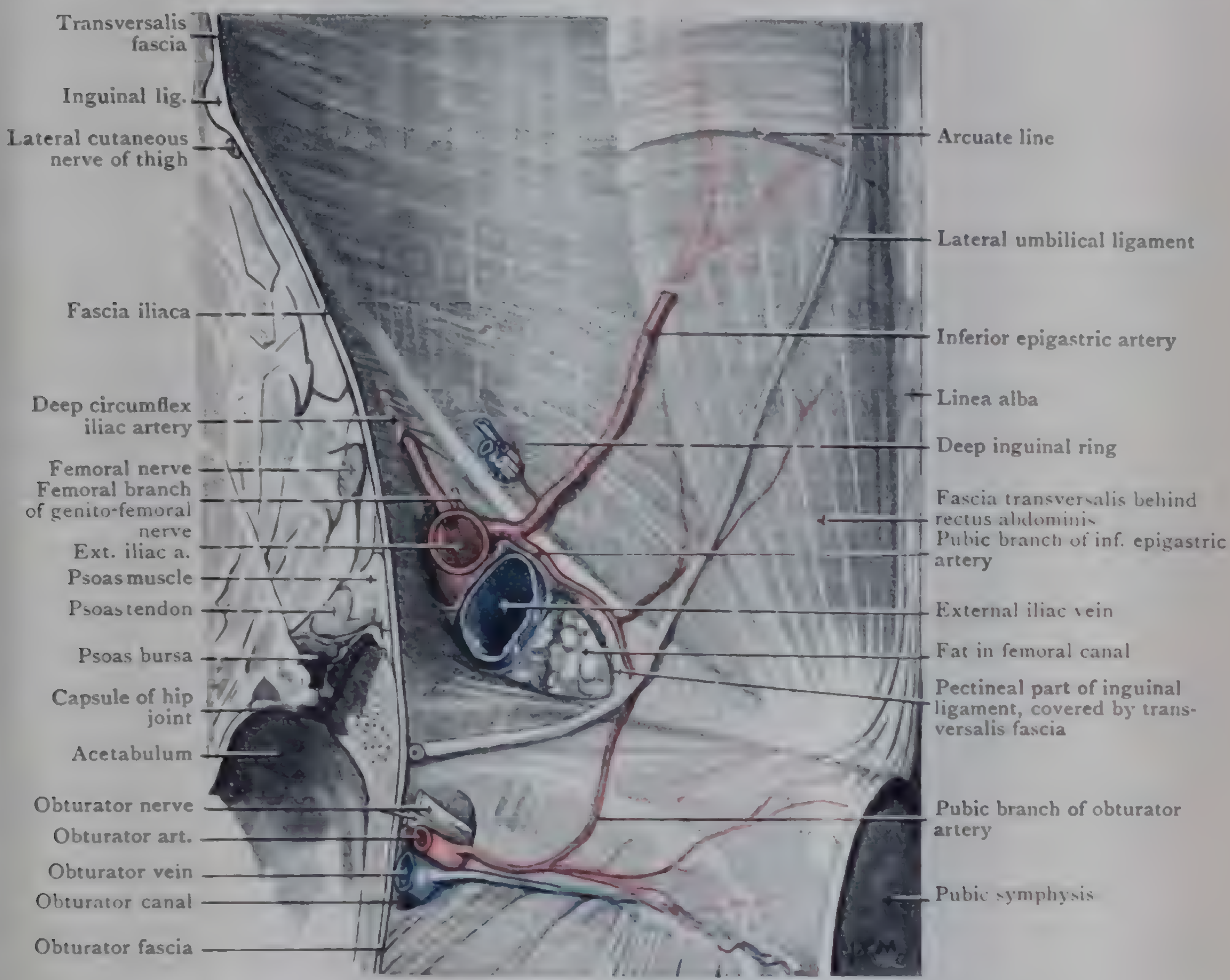


FIG. 393.—DEEP INGUINAL RING, FEMORAL RING, AND OBTURATOR CANAL SEEN FROM INSIDE THE ABDOMEN.

(2) Acting in concert with but against the diaphragm, they can compress the contents of the abdomen (Pl. XXXVII, p. 456, Fig. 4), and are powerful agents in vomiting, defæcation, micturition, and parturition. (3) They take part in forced expiration. (4) Contraction of the abdominal muscles increases the pressure in that cavity, and automatically compresses the walls of the inguinal canal; if, however, the closure of the canal is imperfect, the same forces may produce hernia through the canal. (5) In bending the body forwards, the important factor is relaxation of the post-vertebral muscles; but, when the movement is resisted, the anterior muscles come into play as flexors of the vertebral column. They flex the pelvis in jumping and climbing and act powerfully in the exercise of raising both lower limbs when the body is supine because of their rôle (an exhausting one) of fixation of the pelvis and vertebral column. The vertebral column and pelvis are laterally flexed when one set of muscles acts alone. The oblique muscles produce a certain amount of rotation of the vertebral column, the internal oblique of one side acting in association with the external oblique of the other side. The quadratus lumborum is a lateral flexor of the vertebral column, and assists in inspiration by fixing the twelfth rib and so facilitating the action of the diaphragm. For the postural action of the flexors of the trunk, see p. 409.

FASCIÆ OF ABDOMINAL WALL

The fasciæ of the abdominal wall are—*externally*, the superficial and deep fasciæ, *internally*, the fascia transversalis. The fascia transversalis clothes the deep surface of the anterior and lateral walls of the abdominal cavity, is continuous with the diaphragmatic, lumbar, psoas, iliac, and pelvic fasciæ, and is lined with **extraperitoneal tissue**. In this way a fascial envelope is formed which encloses the abdominal and pelvic cavities, the viscera, and the great vessels.

The **superficial fascia** of the abdomen is liable to contain a large quantity

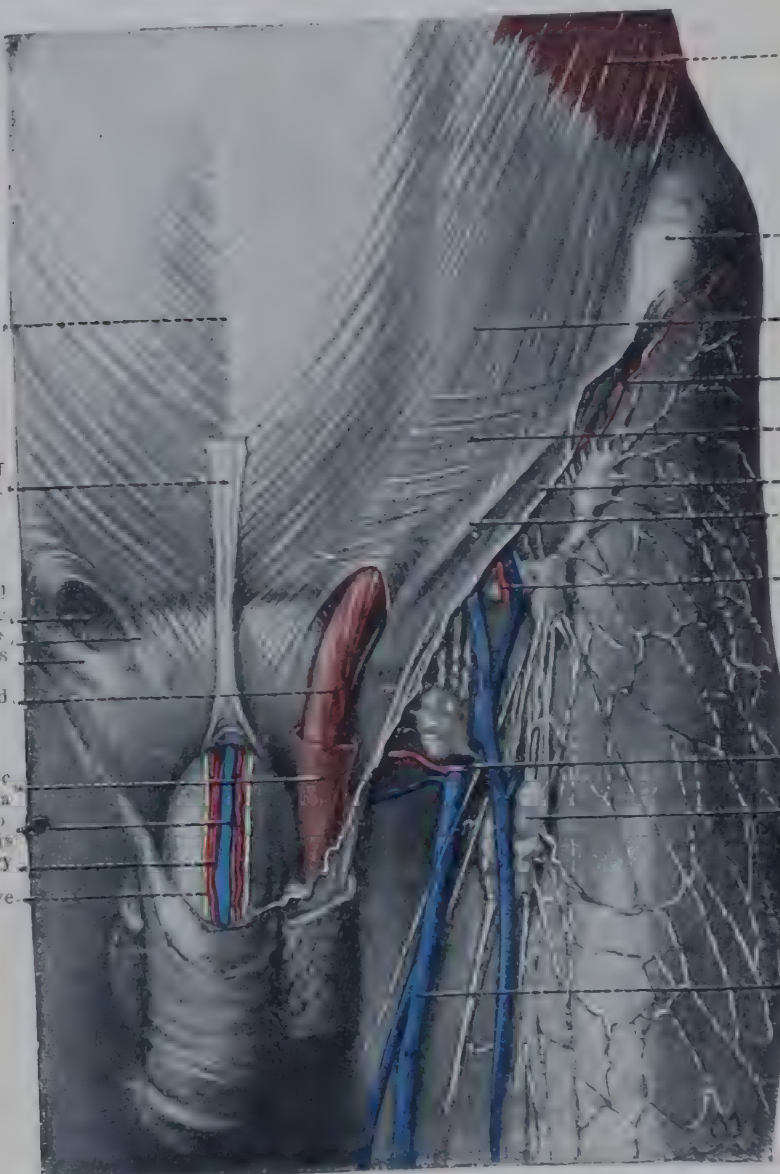


Fig. 394.—Superficial Anatomy of the Groin.

of fat. In the groin it is separated into *two layers*: a superficial, **fatty layer** continuous over the inguinal ligament with the fascia of the anterior surface of the thigh, and a deeper, **membranous layer** attached to the fascia lata of the thigh just distal to the inguinal ligament (Fig. 398). The two layers are separated by the lymph-glands and the superficial vessels of the groin. Higher up in the abdominal wall the two layers blend together. In the median plane the membranous layer, adherent to the linea alba except just above the pubis, descends as the *fundiform ligament* to the dorsum of the penis and makes a sling continuous with the superficial fascia of the penis. The fundiform ligament is separated by an areolar space from the suspensory ligament of the penis, which is formed by the deep fascia (Fig. 402). As the layers pass downwards over the spermatic cord, they are replaced by the fascia and *dartos muscle* of the scrotum [δαρτός = flayed]. The attachment of the fascia to the groin prevents the passage into the thigh of fluid extravasated beneath the membranous layer of the abdominal wall (p. 469 and

Fig. 398). The membranous layer represents the elastic tunic which supports the abdominal wall and inguinal mammary glands in such animals as the cow.

The **deep fascia** of the abdominal wall resembles similar fasciæ in other situations. It forms an investment for the external oblique muscle, and becomes thin and almost imperceptible in relation to the aponeurosis of that muscle.

From the front of the symphysis the fascia descends as a triangular band—the *suspensory ligament*—to be attached to the deep fascia of the penis.

The **fascial lining** of the abdominal cavity is a continuous layer of membrane which receives different names in different parts of its extent. The **transversalis fascia** covers the deep surface of the transversus muscle, and is continuous medially with the fasciæ of the quadratus lumborum and the psoas muscles. It is continuous above with the fascia of the diaphragm, and below with the **fascia iliaca** at the iliac crest and the inguinal ligament (see p. 531). Along with the fascia iliaca it forms the **femoral sheath**. It is evaginated by the spermatic cord, or by the round ligament of the uterus, at the deep inguinal ring, and its prolongation into the inguinal canal around the cord forms the **internal spermatic fascia**. Internally, it is lined with the peritoneum, from which it is separated by a layer of extraperitoneal tissue.

The **extraperitoneal tissue** is usually loaded with fat; it envelops the kidneys, ureters, suprarenal glands, abdominal aorta, and inferior vena cava and their branches, and forms sheaths for the vessels and ducts (ureter, vas deferens, etc.). It is continued upwards into the posterior mediastinum of the thorax through the aortic opening in the diaphragm, and is in continuity with the extraperitoneal tissue in the pelvis. It not only completely invests the kidneys and suprarenal glands, but also becomes insinuated between the layers of peritoneum that uphold and envelop the intestines. On the anterior wall, below the level of the umbilicus, it contains the inferior epigastric vessels, the lateral and median umbilical ligaments, and the upper part of the bladder when it is distended. This tissue is absent in relation to the diaphragm, on the under surface of which there is no fat.

MUSCLES AND FASCIÆ OF PERINEUM AND PELVIS

MUSCLES OF PERINEUM

The perineum is the lowest part of the trunk, and is a diamond-shaped space whose boundaries are those of the outlet of the pelvis. It is divided by an imaginary line into an *anal triangle* behind and a *urogenital triangle* in front. In the anal triangle there is only one perineal muscle—the external sphincter ani. A fibrous sheet called the *perineal membrane* stretches across the pubic arch and divides the urogenital triangle into upper and lower pouches (p. 467). The lower or superficial pouch contains three pairs of muscles—ischio-cavernosus, bulbo-spongiosus, and the superficial transversus perinei. The upper or deep pouch contains the sphincter urethræ and a pair of deep transverse perineal muscles.

Sphincter Ani Externus.—This muscle is fusiform in outline, flattened, and obliquely placed around the anus and anal canal. It can be separated into three layers—subcutaneous, superficial, and deep. (1) The most superficial lamina consists of subcutaneous fibres decussating posterior and anterior to the anus, but without bony attachments. (2) The main portion of the muscle is attached posteriorly to the coccyx, and anteriorly to the perineal body. (3) The deepest fibres form, for the most part, a complete sphincter for the anal canal—encircling its lower two-thirds, blending anteriorly with the perineal body and the superficial transversus perinei muscle, and closely associated behind with the fibres of the pubo-rectales.

Superficial Transversus Perinei.—The superficial transversus perinei, not always present, is a feeble bundle of fibres that **arises** from the fore part of the

medial side of the ischial tuberosity and passes medially below the posterior border of the perineal membrane to be **inserted** into the perineal body.

Bulbo-Spongiosus.—*In the male*, the right and left bulbo-spongiosus muscles are united together by a fibrous median raphe, and they cover the bulb of the penis and the adjoining part of the corpus spongiosum. They **arise** from the raphe and the perineal body, and their fibres, curving upwards and forwards round the sides of the bulb, have a triple **insertion**: from behind forwards, (1) into the lower surface of the perineal membrane; (2) into the dorsal surface of the corpus spongiosum penis; and (3), after encircling the corpora cavernosa penis, into the deep fascia on the dorsum of the penis.

In the female, the bulbo-spongiosus muscles are separate. Each is a thin layer

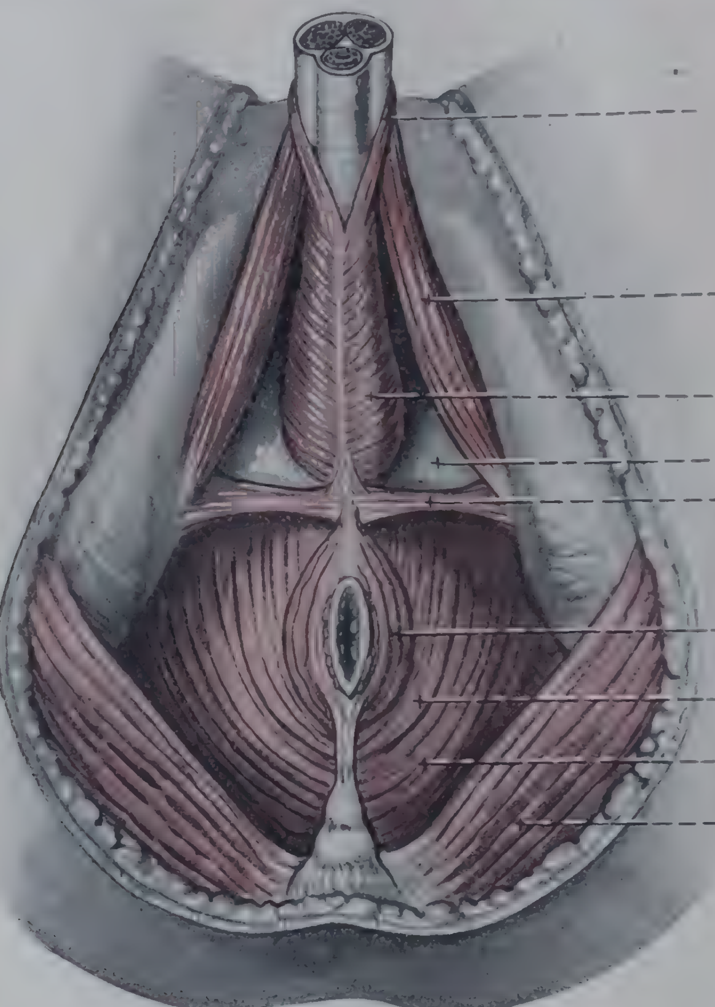


Fig. 395.—Muscles of the Male Perineum.

that lies at the side of the lower part of the vagina and covers the bulb of the vestibule. It **arises** from the perineal body, and, passing forwards, its fibres separate to be **inserted** into the side of the pubic arch and into the root and dorsum of the clitoris.

Ischio-Cavernosus.—The ischio-cavernosus, partly fleshy, partly tendinous, covers the crus of the penis or of the clitoris. It **arises** from the medial side of the ischial tuberosity, and passes forwards over the crus to be **inserted** into the margin of the pubic arch on each side of the crus and into the corpus cavernosum (Figs. 395, 396, and 403).

Perineal Body.—The perineal body is a fibro-muscular node of considerable importance in the anatomy of the perineum, especially in the female, for it may be torn during child-birth. It is placed between the anal canal and the perineal membrane: it is inseparably blended with the membrane (and, in the male, with the fascial sheath of the prostate), and both striated and plain muscle-fibres enter into its constitution. The superficial and deep transverse perineal muscles, the bulbo-spongiosus, the external sphincter ani and the levator ani all contribute to it;

and, in addition, prolongations of the longitudinal fibres of the gut (superior and inferior recto-urethralis muscles) are continued into it.

Perineal Membrane.—This membrane stretches across the pubic arch. In the male it almost completely fills the archway, but in the female it is defective in the middle to give passage to the vagina and the urethra. Its posterior border is fused with the posterior borders of (1) the membranous layer of the superficial fascia of the perineum, and (2) the layer of fascia that covers the upper surface of the sphincter urethræ and deep transversus perinei. In the median plane this border is thickened, and is united with the perineal body. Its anterior border is thickened to form a band called the *transverse perineal ligament*; this ligament is separated from the inferior pubic ligament by an oval gap that transmits the dorsal vein of the clitoris or the deep dorsal vein of the penis; and this border also is fused with the fascia that covers the sphincter urethræ. The space between the membrane and that fascia is therefore closed; it is called the **deep perineal pouch**, and contains the sphincter urethræ and the deep transversus perinei, the internal pudendal vessels and the dorsal nerve of the penis or of the clitoris, the terminal branches of the perineal nerve and the vessels of the bulb; in the male, it contains, also, the membranous part of the urethra and the bulbo-urethral glands; and, in the female, it is divided into two parts by the vagina and urethra. The **superficial perineal pouch** is the space between the perineal membrane and the membranous layer of the superficial fascia; a slight median septum divides it posteriorly into right and left pockets. In the male it is occupied by the root of the penis, the three pairs of muscles already described, and superficial vessels and nerves. In the female, the vagina divides it into halves; each half contains the corresponding muscles, vessels, and nerves, the crus of the clitoris, the bulb of the vestibule and the greater vestibular gland. The perineal membrane is pierced, in the male, by the urethra, the arteries to the bulb, the internal pudendal vessels, the dorsal nerves of the penis, and the ducts of the bulbo-urethral glands, and, in the female, by corresponding vessels and nerves and the vagina and urethra.

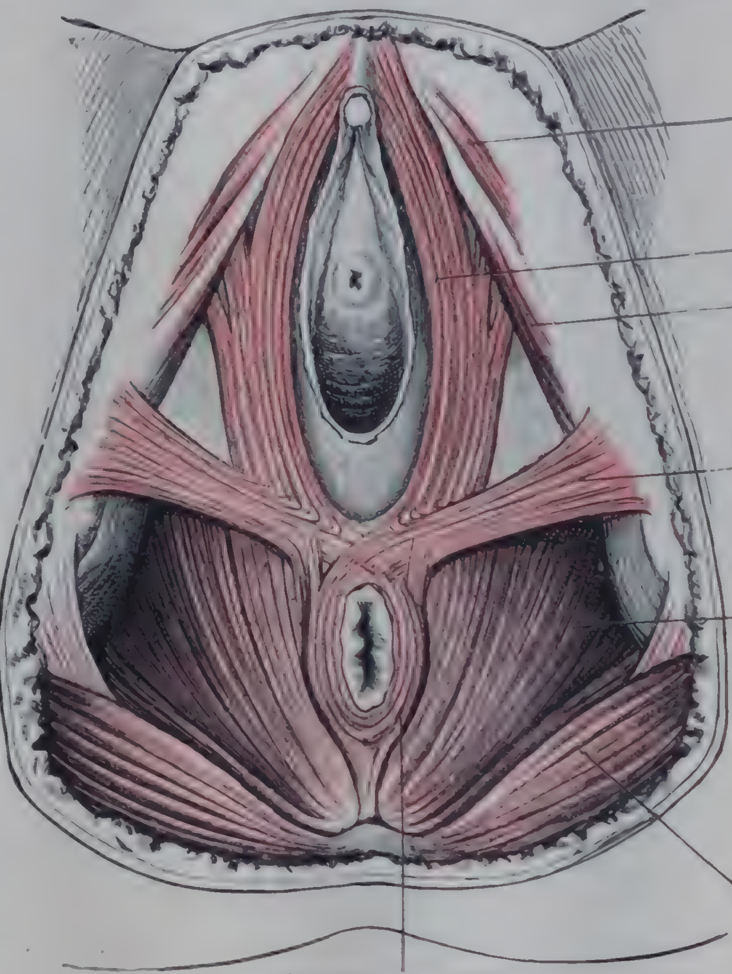


Fig. 396.—Muscles of Female Perineum.
(After Peter Thompson, 1899.)

Sphincter Urethræ.—The sphincter of the urethra **arises** from the inferior pubic ramus, and is directed medially—its fibres radiating towards the urethra.

In the male it is **inserted** into a median raphe, partly in front of the urethra, but for the most part behind it. The fibres most intimately related to the urethra form a muscular sheath for the canal, and have no bony attachments. This is the sphincter proper of the urethra, a striated muscle, and the most important voluntary control of micturition. *In the female* it encloses the urethra, but, together

with the deep transversus perinei, it is also attached to the side of the vagina. The **deep transversus perinei** is a small muscular slip closely connected with the posterior fibres of the sphincter; *in the male* it is inserted into the perineal body.

Nerve-Supply.—All the muscles of the perineum are supplied from the **anterior primary rami** of the **third** and **fourth sacral nerves**. The external sphincter of the anus has three nerves of supply — from the perineal and inferior hæmorrhoidal nerves (branches of the pudendal nerve S. 3. 4.), and the perineal branch of the fourth sacral nerve. All the other muscles are supplied by the **perineal nerve**.

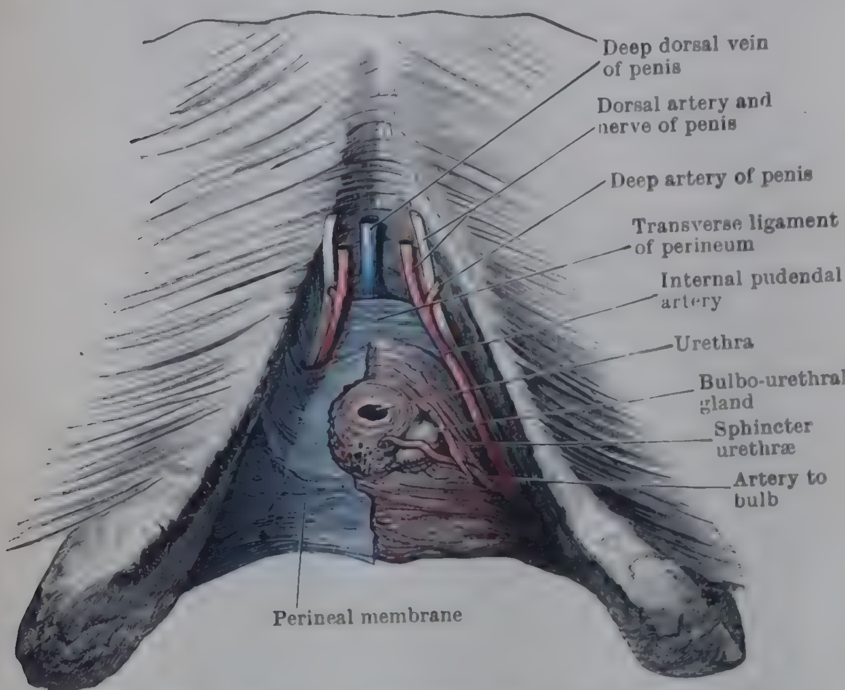


Fig. 397.—Perineal Membrane and Sphincter Urethræ.

Action of the Perineal Muscles. — The sphincter ani externus keeps the anal orifice firmly closed by its tonic contraction—which may be voluntarily increased. The bulbo-spongiosus in the male, relaxed during the course of micturition, contracts to expel the last drops of urine; it acts also as an accessory muscle in erection of the penis by compressing the bulb and impeding the venous return; in the female it compresses the bulb of the vestibule and constricts the vaginal orifice—forming with the pubo-coccygeus a kind of sphincter. The ischio-cavernosus, by compressing the crus and impeding venous return, is the chief muscular agent in erection of the penis or the clitoris. The sphincter urethræ compresses the urethra at the end of micturition. The deep transversus perinei assists other muscles attached to the perineal body in fixing that body and in supporting the prostate.

FASCIÆ OF PERINEUM

The **superficial fascia** of the perineum possesses certain special features (Figs. 398, 402, 403). It is continuous with the superficial fascia of the abdominal wall, thigh, and buttock, and is prolonged on to the penis and scrotum. In the penis, it is devoid of fat and consists only of areolar tissue. In the scrotum, it is intermingled with involuntary muscular fibres, and constitutes the **dartos muscle**, which assists in suspending the testes and corrugates the skin of the scrotum. This fascia also forms the **septum of the scrotum**, which, extending upwards, incompletely separates the two testes and their coverings. In the female, the superficial fascia, in which there is a considerable quantity of fat, takes a large share in the formation of the mons pubis and the labia majora.

The superficial fascia over the posterior part of the perineum fills up the ischio-rectal fossæ, in the form of a pair of **ischio-rectal pads of fat**, at the sides of the rectum and anal canal. Over the ischial tuberosities the fat is intermingled with bands of fibrous tissue closely adherent to the subjacent deep fascia.

The fascia in the anterior part of the perineum closely resembles the same fascia in the groin. It is divisible into a superficial, **fatty layer** and a deep, **membranous layer**. The **fatty layer** is continuous with the same layer in the thigh, and with the fat of the ischio-rectal fossa. The **membranous layer** is attached on each side to the deep fascia on the front of the pubis and to the side of the pubic arch, posteriorly to the posterior border of the perineal membrane, and in the median plane to the median raphe of the bulbo-spongiosus muscles and to the septum of the scrotum. Anteriorly the fascia invests the scrotum and gives a

tubular covering to the penis. Finally it is continued over the spermatic cords to the anterior abdominal wall. The importance of this fascia lies in relation to the extravasation of urine from a rupture of the urethra in the perineum. By the fascial attachments the fluid is prevented from passing backwards into the ischio-rectal fossa, or sidewards into the thigh. It is directed forwards—invading the subcutaneous tissues of the scrotum (the septum of the scrotum being incomplete, the fluid can pass across the median plane to the opposite half of the perineum and scrotum) and gravitating into the fascial covering of the penis as far as the glans, and lastly mounting upwards around the spermatic cord to the anterior abdominal wall, where it is kept from entering the front of the thigh

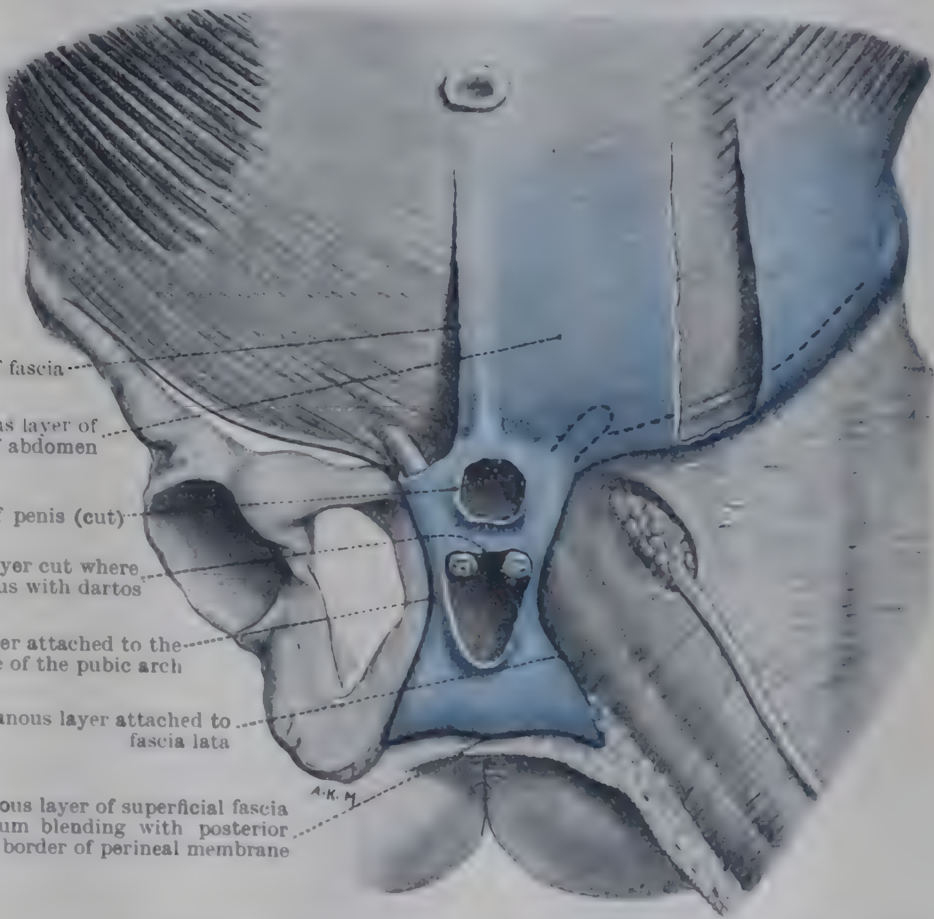


FIG. 398.—DIAGRAM SHOWING CONTINUITY OF MEMBRANOUS LAYER OF THE SUPERFICIAL FASCIA OF ABDOMINAL WALL AND PERINEUM.

by the fusion of the membranous layer of the superficial fascia with the fascia lata (p. 464).

The **deep fascia** of the perineum exists only in the form of the delicate fasciæ of the muscles.

MUSCLES OF PELVIS

Pelvic Diaphragm.—The pelvic diaphragm is formed by the levator ani and coccygeus muscles, which serve to uphold the pelvic floor and are related to the rectum and to the prostate or the vagina.

Levator Ani.—The levatores ani muscles form a thin sheet which stretches across the pelvic cavity and separates it from the posterior part of the perineum. Anteriorly, the two muscles are separated by a narrow interval which is occupied, in the male, by the lower part of the prostate and the anal canal, and, in the female, by the urethra, the vagina, and the anal canal. Posteriorly, they meet each other in the **ano-coccygeal body**—a fibro-muscular body mingled with fat placed between the anal canal and the tip of the coccyx. The postero-lateral border is free, and is separated from the coccygeus muscle by areolar tissue. The *superior* (pelvic) surface of the levator ani is separated by fascia from the peritoneum, rectum, and bladder in both sexes; from the prostate and seminal vesicle in the male;

and from the vagina in the female. Its *inferior* (perineal) surface is separated by fascia from the ischio-rectal pad of fat.

The muscle **arises** anteriorly from the pelvic surface of the pubic bone, and posteriorly from the pelvic surface of the ischial spine; between those two bony attachments it takes origin from the *obturator fascia—i.e.*, the thick fascia which covers the obturator internus muscle.

Its fibres run backwards and medially and very slightly downwards, with

FIG. 399.—LEFT LEVATOR ANI MUSCLE.

varying degrees of obliquity, and are **inserted** (1) into the perineal body, (2) into the ano-coccygeal body, and (3) into the front and sides of the coccyx. In addition, some of the fibres form a sling around the upper end of the anal canal.

The levator ani is divisible into two distinct portions, namely, the **ilio-coccygeus** and the **pubo-coccygeus**, and the latter can be subdivided into three parts, imperfectly separated from one another, viz.—the *pubo-coccygeus proper*, the *pubo-rectalis*, and the *levator prostatæ*.

The **ilio-coccygeus** is the posterior part of the levator ani, and its origin extends as far forwards as the obturator canal. It is usually a thin sheet in which the muscular fibres are

feebly developed and often separated by membranous intervals. The strong fascia from which it arises represents the upward continuation of the muscle to reach the arcuate line of the pelvis, and has, secondarily, become blended with the obturator fascia. This attachment to the arcuate line is the primitive origin of the ilio-coccygeus and is the normal condition

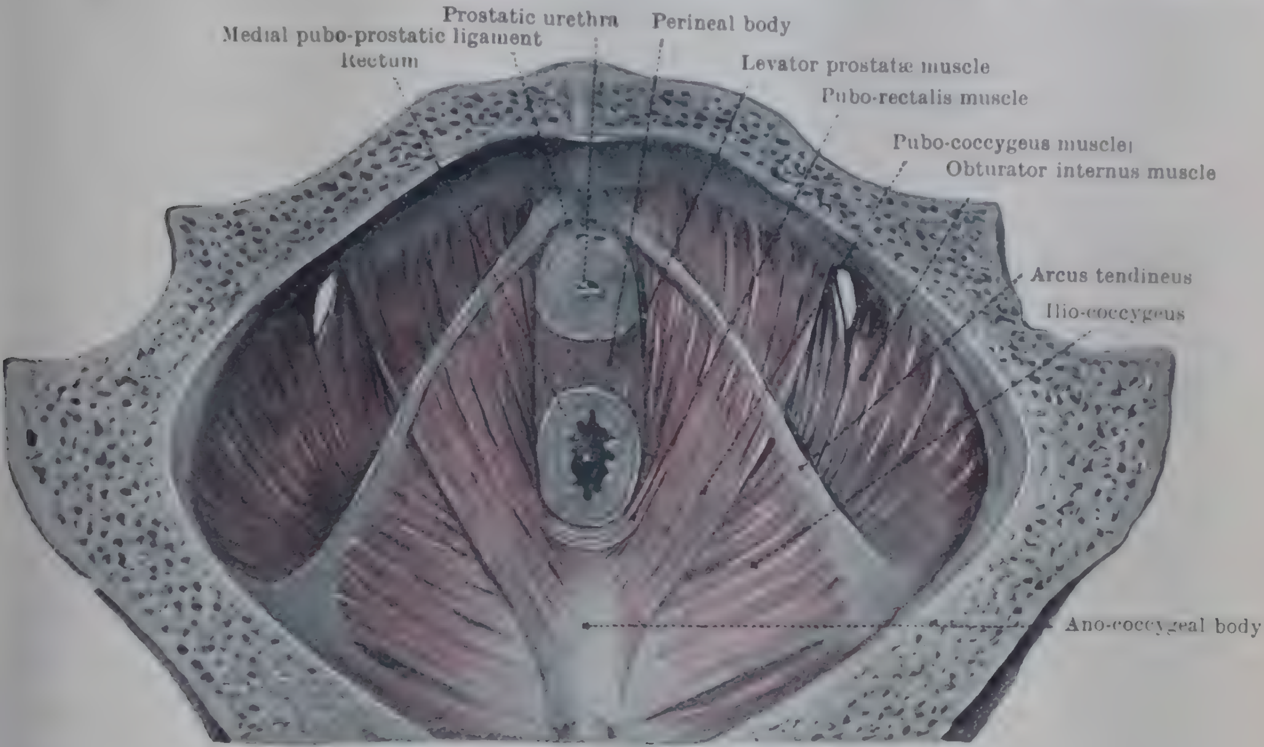


FIG. 400.—LEVATOR ANI MUSCLE VIEWED FROM ABOVE.

in many mammals. The fibres run medially to be inserted into the side of the coccyx and the ano-coccygeal body, but, at their insertion, they are covered on their pelvic aspect by the backward-running fibres of the pubo-coccygeus (Figs. 399, 400).

The **pubo-coccygeus** is composed of those fibres of the levator ani which arise in front of the obturator canal. The most anterior (medial) fibres pass backwards in contact with the side

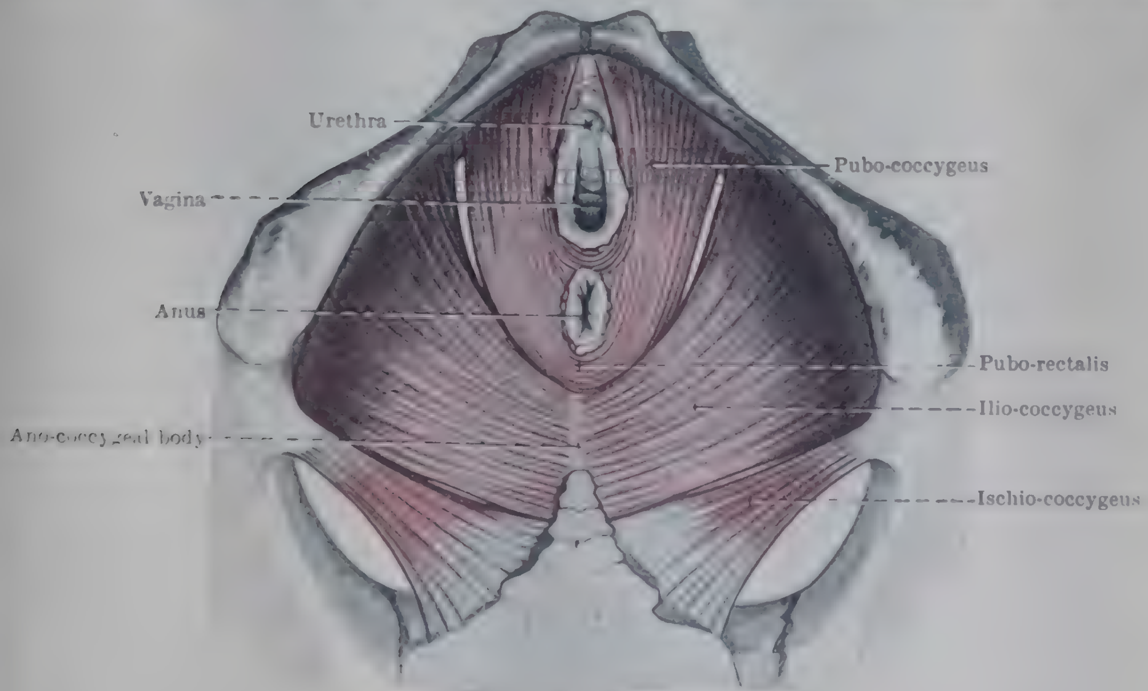


FIG. 401.—DISSECTION OF FEMALE PELVIC DIAPHRAGM FROM BELOW. (After Peter Thompson, 1899.)

of the prostate (*levator prostatæ*) or of the vagina (*sphincter vaginæ*), and are inserted into the perineal body, where they mingle with the deeper fibres of the sphincter ani externus.

The fibres which have a more lateral origin from the pubic bone form the *pubo-rectalis*. This muscle sweeps backwards over the side of the prostate (or vagina) and the upper part of the anal canal, behind which it becomes directly continuous with the corresponding muscle of the opposite side. The pubo-rectales form therefore a U-shaped sling for the ano-rectal junction (Figs. 400,

401), and, associated with deep fibres of the external sphincter, they can constrict the anal canal in the male, and the vagina and anal canal in the female. Together, they constitute the most highly developed part of the pelvic diaphragm.

The *pubo-coccygeus proper* is the remainder of this part of the levator ani muscle. Its fibres run backwards and medially, above the fibres of the ilio-coccygeus, and are inserted (1) into the ano-coccygeal body, where they meet the fibres of the opposite side, and (2) into the sides and front of the coccyx.

The **coccygeus** (ischio-coccygeus), which lies on the same plane as the

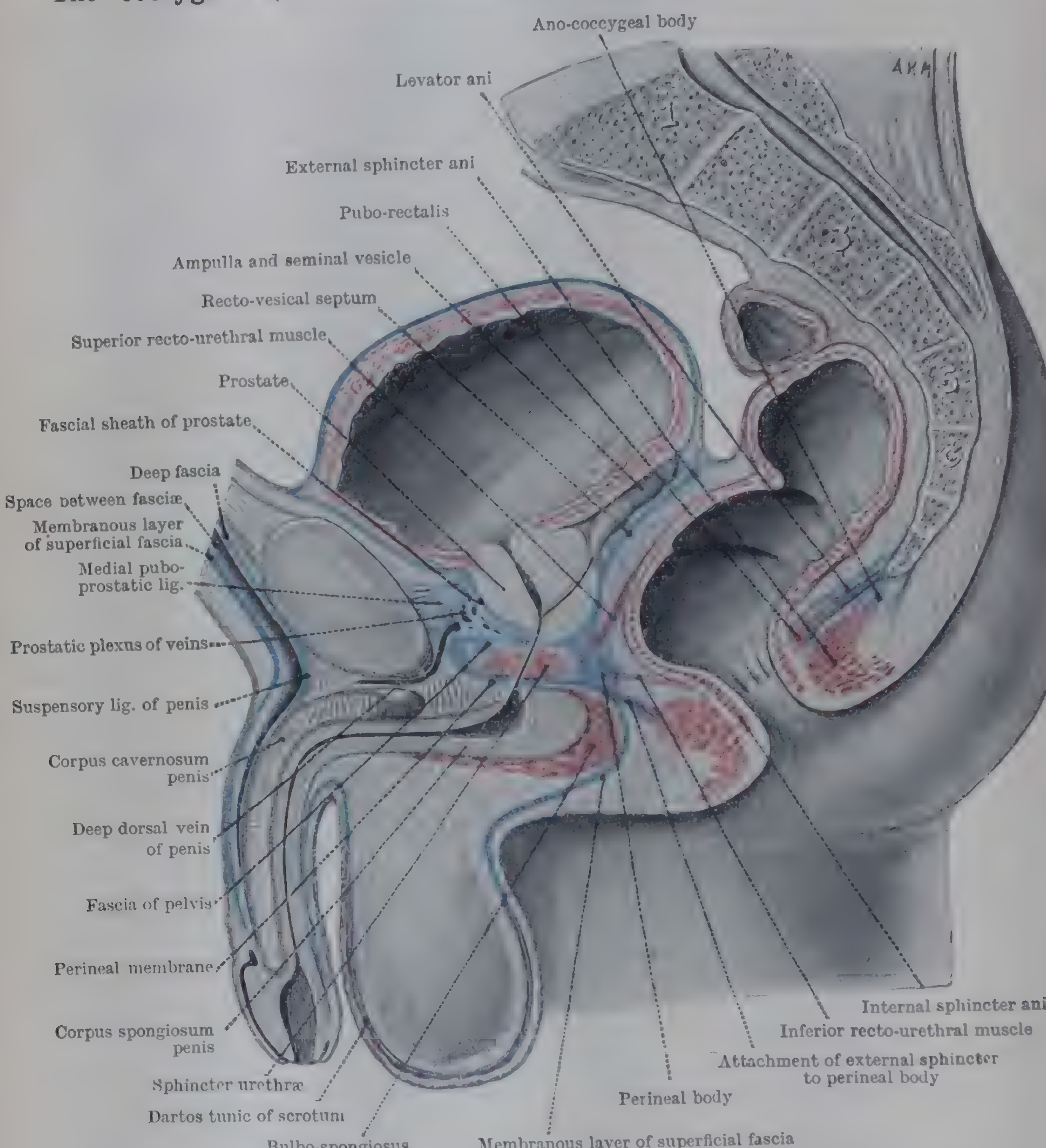


FIG. 402.—SAGITTAL SECTION OF MALE PELVIS SHOWING FASCIÆ IN BLUE (SEMIDIAGRAMMATIC).

ilio-coccygeus, is a fan-shaped muscle. It **arises** from the pelvic surface of the ischial spine and is **inserted** into the margin of the lower two pieces of the sacrum and the upper two pieces of the coccyx.

Nerve-Supply.—The pelvic diaphragm, like the perineal muscles, is supplied from the anterior primary rami of the **third** and **fourth sacral nerves**. Direct branches enter the levator ani and the coccygeus on their pelvic surfaces, and in addition the anterior part of the levator ani is supplied on its perineal surface by the perineal branch of the pudendal nerve.

Actions.—Both these muscles play a very important part in retaining the pelvic viscera in position, especially in the female. In addition, the pubo-rectales reinforce the sphincters of the vagina and anal canal, and the fibres which are inserted into the perineal

body draw it upwards and forwards. This latter action assists in the later stages of expulsion during defæcation and parturition.

Comparative Morphology.—In pronograde mammals the ilio-coccygei and pubo-coccygei are inserted into the caudal vertebræ and act, respectively, as abductors and flexors of the tail. The ischial origin of the ilio-coccygeus in Man is secondary; the true ischio-coccygeus is the 'abductor caudæ' of tailed mammals. Although the pubo-coccygei may have a compressing effect on the vagina and rectum, such action is purely secondary. In pronograde animals there is not the same need for a muscular pelvic diaphragm, and, consequently, the two muscles are separated from each other both dorsal and ventral to the rectum.

The adoption of the erect attitude necessitates the provision of a strong, but elastic, pelvic floor, to maintain the pelvic viscera in position and to permit the downward passage of the fœtus. This function is assumed by the ilio- and the ischio-coccygei, which are no longer needed to act on a tail; and the pubo-coccygei become specialized in relation to the anal and vaginal canals. For further information the student should consult Thompson (1899).

Ischio-Rectal Fossæ.—The ischio-rectal fossæ are the pair of wedge-shaped spaces that occupy the lateral parts of the anal triangle of the perineum. The lateral wall of each fossa is the obturator fascia; the medial wall is the fascia that covers the perineal surface of the levator ani; the edge of the wedge is at the junction of these fasciæ; and the base is the skin of the perineum. The fossa is filled with the plug of fat known as the ischio-rectal pad. It is crossed transversely by the inferior hæmorrhoidal nerve and the inferior rectal vessels; the perineal branch of the fourth sacral nerve and the perforating cutaneous nerve appear in its posterior part, and the posterior scrotal (or labial) nerves and vessels in its anterior part; the internal pudendal vessels, the perineal nerve, and the dorsal nerve of the penis (or clitoris) traverse the pudendal canal in its lateral wall. Posteriorly, it extends backwards for a little distance above the sacro-tuberous ligament and the gluteus maximus. Anteriorly, it sends forward a 'diverticulum' (Fig. 403) above the deep perineal pouch as far as the pubis; this extension retains the lateral and medial boundaries of the fossa—the fascia of the obturator internus and levator ani—and is occupied by loose, vascular fatty tissue.

FASCIÆ OF PELVIS

The extraperitoneal tissue in the pelvic cavity is of great importance. The internal iliac vessels and their branches, the visceral nerves and plexuses, the ureters, and vasa deferentia lie in this tissue. It forms in relation to **the rectum** a thick sheath, for the most part devoid of fat, which completely encloses the lower part of the rectum. It forms a kind of packing for the parts of **the bladder** that are not covered with peritoneum, and it surrounds the prostate with a strong sheath. In the female it forms, in addition, the fibrous basis of the **broad ligament**, and also occurs as a layer, devoid of fat, which loosely connects the anterior surface of the **cervix uteri** with the base of the bladder.

The **fascia of the pelvis** covers the free surfaces of the muscles—*fascia of pelvic muscles*—and is condensed around the viscera, vessels, and nerves to ensheath them—*visceral fascia*; and between the pubis and the neck of the bladder it is thickened to form a pair of strong bands called the **medial pubo-vesical ligaments** in the female, and **medial pubo-prostatic ligaments** in the male.

The muscles which line the walls (obturator internus, piriformis, coccygeus, sphincter urethræ, and deep transversus perinei) and those which form the floor of the pelvis (levatores ani) are covered on their 'visceral' surfaces by a layer of fascia which is thicker over the obturator internus than it is elsewhere. This thickened part is, in reality, the aponeurosis of origin of the ilio-coccygeus muscle (p. 471), and it is continued upwards to reach the arcuate line of the pelvis. The surface of this aponeurosis is crossed by a linear thickening (*arcus tendineus*) which extends from the ischial spine to the body of the pubis, where it blends with the medial pubo-prostatic ligament. In its posterior part this arc marks the origin of the fleshy fibres of the ilio-coccygeus, but its anterior part crosses the pelvic surface of the pubo-coccygeus at least 1·5 cm. below its origin from the bone. The anterior portion of the arcus tendineus may represent an additional tendon of origin for the ilio-coccygeus (Thompson, 1901).

A strong fascial sheath is provided for the prostate. The **fascial sheath of the prostate** is largely derived from the fibrous tissue which is condensed around the prostatic venous plexus. It is continuous inferiorly with the roof of the deep perineal pouch (Fig. 403), on each side with the fascia of the levator ani, and superiorly with the fascia condensed around the vesical plexus of veins on the infero-lateral surfaces of the bladder. Anteriorly it is attached to the pelvic surface of the pubic bones near the symphysis by the **medial pubo-prostatic ligaments**. These two strong bands and the fascia which connects them to each other and to that covering the levatores ani contain a number of plain muscle-fibres. The term *lateral pubo-prostatic ligament* is applied to the fascia on the anterior part of the levator ani muscle.

The posterior part of the sheath of the prostate differs from the rest of the sheath in its mode of formation, and is a definite layer easily demonstrated by dissection. In a four months' fœtus the recto-vesical peritoneal pouch is very much deeper than it is in the adult, and the subsequent

alteration in level is brought about by the occlusion of the lower part of the pouch. The fused walls of the occluded portion persist as a fairly strong sheet, called the **recto-vesical septum**, which extends from the perineal body to the floor of the recto-vesical pouch—thus retaining its primitive connexion with the peritoneum. It is separated by areolar tissue from the prostate, seminal vesicles, and vasa deferentia anteriorly and from the ampulla of the rectum posteriorly.

In enucleating the prostate, the surgeon endeavours to leave the fascial sheath of the prostate (and also the capsule of the gland) *in situ*.

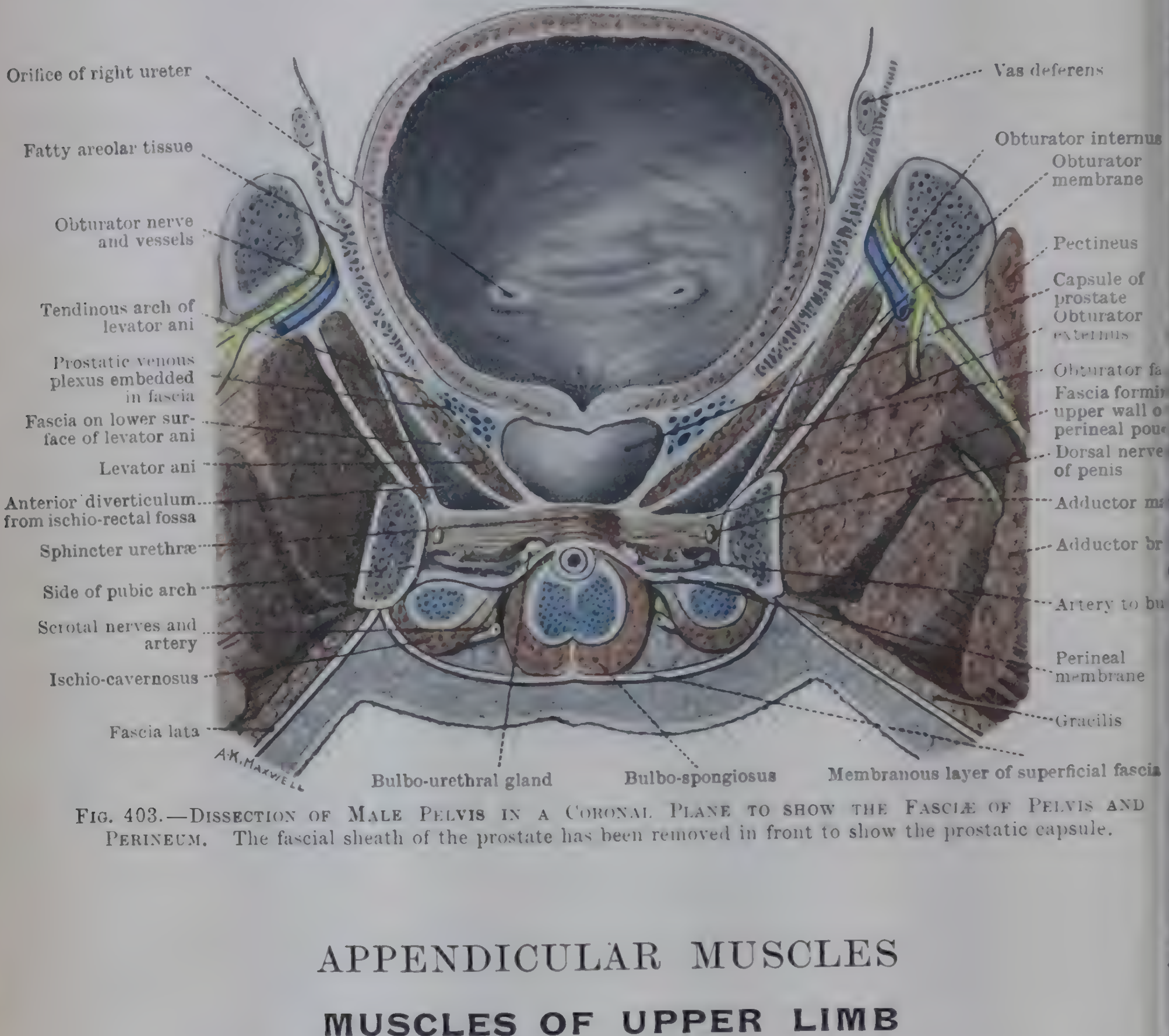


FIG. 403.—DISSECTION OF MALE PELVIS IN A CORONAL PLANE TO SHOW THE FASCIÆ OF PELVIS AND PERINEUM. The fascial sheath of the prostate has been removed in front to show the prostatic capsule.

APPENDICULAR MUSCLES

MUSCLES OF UPPER LIMB

The muscles of the upper limb are divisible into the following series and groups, according to their regional arrangement and their functions. 1. Muscles connecting the limb to the trunk—Dorsal Group (superficial muscles of the back), and Ventral Group (Muscles of the Pectoral Region). 2. Muscles of the Shoulder. 3. Muscles of the Upper Arm (flexor and extensor groups). 4. Muscles of the Forearm (flexor and extensor groups). 5. Short muscles of the Hand.

MUSCLES CONNECTING UPPER LIMB TO TRUNK

Two groups of muscles connect the upper limb to the trunk—a dorsal group arising primarily from the vertebral column, and a ventral group arising mainly from the thoracic skeleton. With two exceptions (one in each group), all the muscles are inserted into the shoulder girdle (clavicle and scapula). The exceptions are the latissimus dorsi and the pectoralis major, which are inserted into the humerus; and each of them has an additional origin from the shoulder girdle itself—the pectoralis major from the clavicle and the latissimus dorsi from the scapula.

I. Superficial Muscles of the Back

The dorsal group comprises the first two layers of the muscles of the back—(1) trapezius and latissimus dorsi; (2) levator scapulæ and rhomboidei (major and minor).

Trapezius.—The trapezius is a large, triangular muscle situated in the upper part of the back and the back of the neck. It **arises** from the medial third of the superior nuchal line of the occipital bone, from the external occipital protuberance (Fig. 405), from the ligamentum nuchæ, from the spines of the seventh cervical and all the thoracic vertebræ, and the intervening supraspinous ligaments. The origin is by tendinous fibres which are mainly short, but in the lower part of the neck the tendinous fibres extend towards the shoulder to afford a larger area of origin for the thickest part of the muscle; between the two muscles there is thus formed

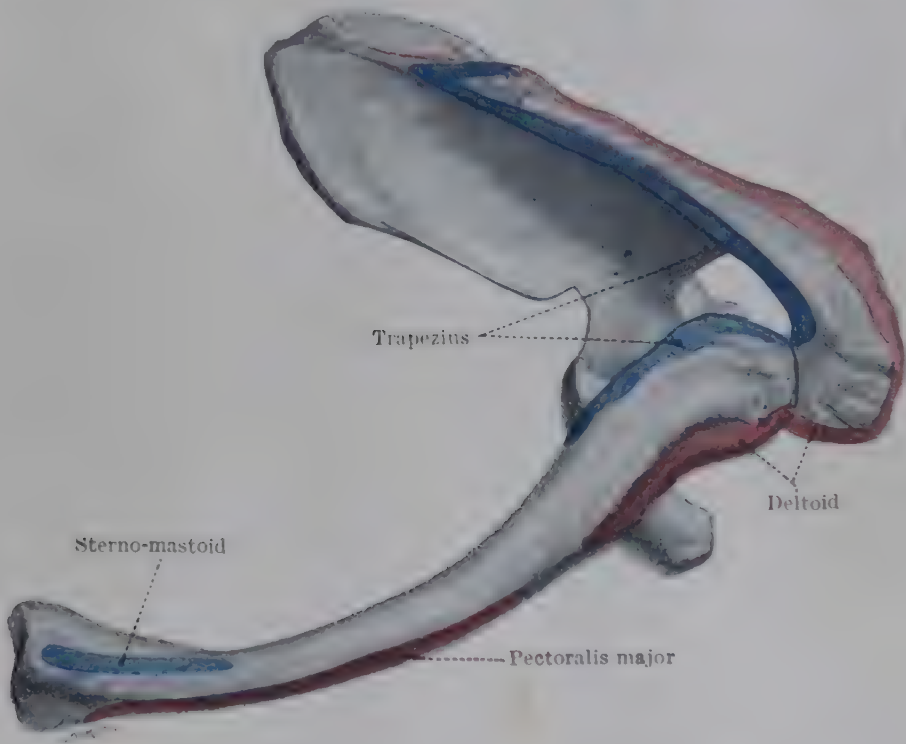


FIG. 404.—SHOULDER GIRDLE FROM ABOVE SHOWING MUSCLE-ATTACHMENTS.

a characteristic, irregular, diamond-shaped tendinous area which surrounds the seventh cervical spine, and forms the floor of a shallow depression seen in the living subject (Pl. XXXVII, p. 456, Fig. 2).

The muscular fibres converge towards the bones of the shoulder to be **inserted** continuously from before backwards as follows: (1) The occipital and upper cervical fibres—into the posterior border of the lateral third of the clavicle (Figs. 404, 405); (2) the lower cervical and upper thoracic fibres—into the medial border of the acromion, and the upper border of the crest of the spine of the scapula; and (3) the lower thoracic fibres, by a triangular, flat tendon, separated by a small *bursa* from the smooth area at the root of the spine—into the tubercle of the crest of the scapula. The fibres inserted into the clavicle, acromion, and the upper border of the spine of the scapula spread over the adjacent subcutaneous surfaces of these bones for a variable distance. The occipital portion of the muscle may be in the form of a separate slip, or it may be absent.

The trapezius is superficial in its whole extent. Its upper lateral border forms the posterior limit of the posterior triangle of the neck. The lower lateral border, passing over the upper edge of the latissimus dorsi and the medial margin of the scapula, forms a boundary of the so-called *triangle of auscultation*, which is completed below by the latissimus dorsi, and laterally by the rhomboideus major; that space is increased when the arms are folded to pull the scapulæ forwards. The trapezius overlaps the upper margin of the latissimus dorsi, and covers the rhomboidei,

levator scapulæ, splenius capitis, semispinalis capitis, and the deeper axial muscles of the back, along with the superficial and the deep branches of the transverse

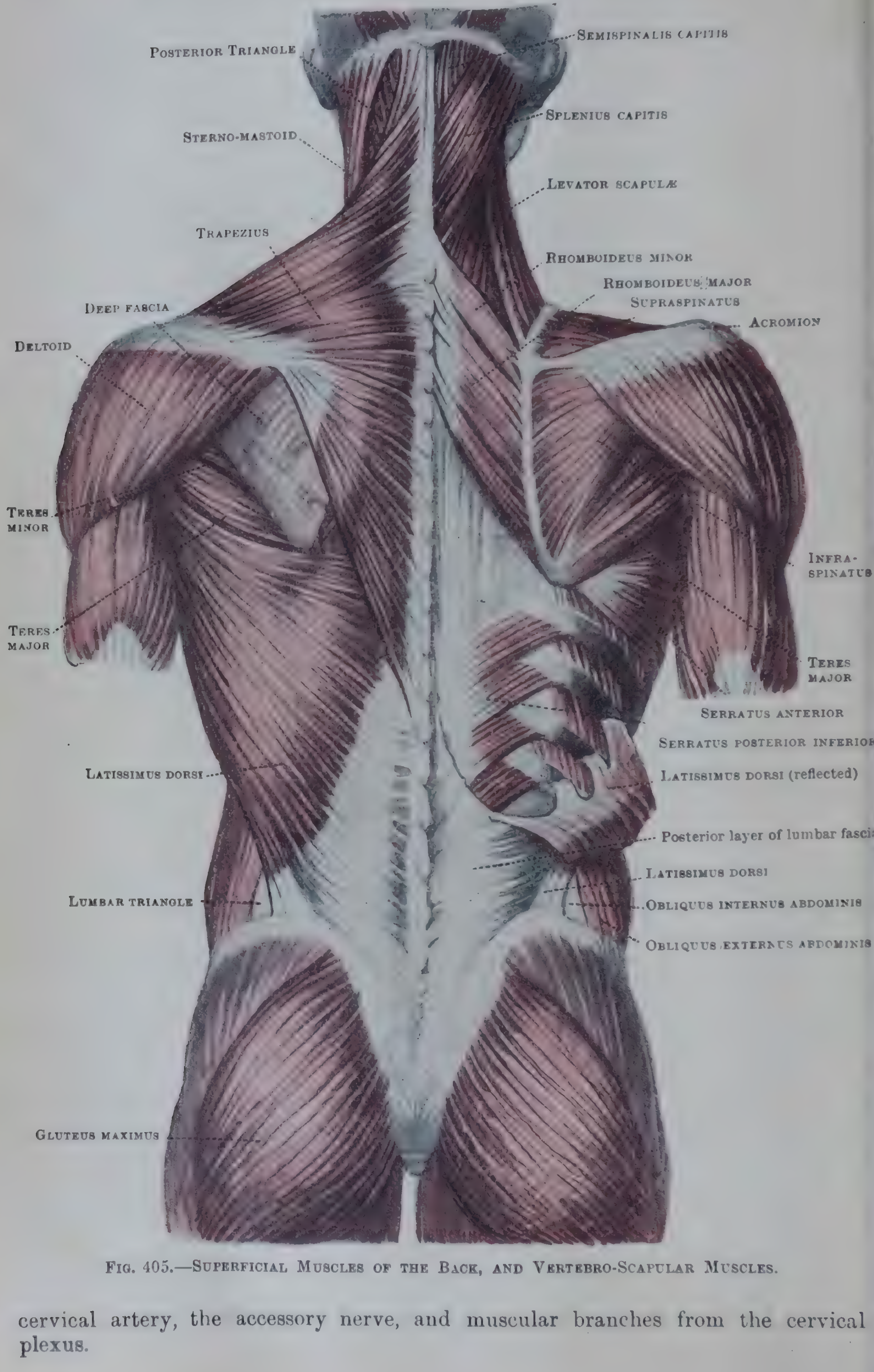


Fig. 405.—Superficial Muscles of the Back, and Vertebro-Scapular Muscles.

cervical artery, the accessory nerve, and muscular branches from the cervical plexus.

Latissimus Dorsi.—The latissimus dorsi is a wide triangular muscle which lies in the lower part of the back. The greater part of the muscle **arises**—(1) from the spines of the lower six thoracic vertebræ, and, through the posterior layer of the lumbar fascia, from the spines of the lumbar and sacral vertebræ and the iliac crest. Its lateral border also arises directly by tendinous fibres from the posterior part of the outer lip of the iliac crest. From this main origin the muscle is directed upwards and laterally, its fibres converging towards the lower border of the axilla. In relation to its lateral and upper borders additional fibres arise. (2) *Along the lateral border* muscular slips arise from the lower three or four ribs, interdigitating with the slips of origin of the obliquus externus abdominis. (Fig. 405 and Pl. XL, p. 457, Figs. 1, 2.) (3) As *the superior border* of the muscle passes horizontally over the inferior angle of the scapula, an additional fleshy slip usually takes origin from that part of the bone and joins the muscle on its deep surface (Fig. 406).

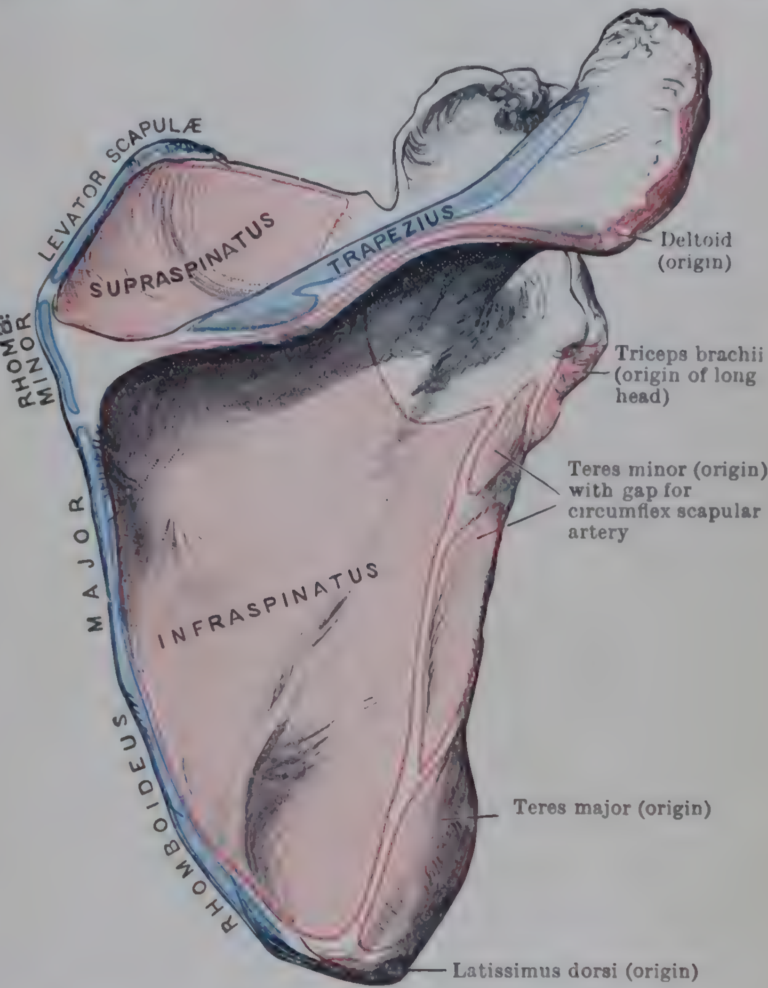


FIG. 406.—MUSCLE-ATTACHMENTS TO DORSAL SURFACE OF RIGHT SCAPULA.

Beyond the inferior angle of the scapula the latissimus dorsi, greatly narrowed, curves spirally round the teres major muscle in the lower edge of the posterior axillary fold. It ends in a ribbon-like tendon which is closely adherent at first to the teres major and is **inserted** into the floor of the bicipital groove of the humerus (Fig. 415). It is placed behind the axillary vessels and nerves, and in front of the insertion of the teres major—a *bursa* intervening. Because of the spiral turn, the anterior surface of the tendon of insertion is continuous with the posterior surface of the rest of the muscle.

In the back the latissimus dorsi is superficial, except that its upper part is concealed by the trapezius. It covers part of the lumbar fascia, the serratus posterior inferior, the lower ribs, and the inferior angle of the scapula. At its upper border is the *triangle of auscultation*; at its lateral border is the *lumbar triangle*—a small space bounded by the iliac crest, the latissimus dorsi, and the obliquus externus abdominis. That space is sometimes the site of a lumbar hernia.

Levator Scapulæ.—This strap-like muscle **arises** by tendinous slips from the posterior tubercles of the transverse processes of the first three or four cervical vertebræ, between the attachments of the scalenus medius in front and the splenius cervicis behind. It is directed downwards to be **inserted** into the medial margin of the scapula, from the upper angle to the spine (Figs. 405, 406).

It is concealed in its upper third by the sterno-mastoid muscle. Its middle third forms part of the floor of the posterior triangle of the neck. Its lower third is hidden by the trapezius, and conceals the nerve to the rhomboids and the deep branch of the transverse cervical artery.

Rhomboidei.—The **rhomboideus minor** may be regarded as a separated slip of the rhomboideus major, with which it is often continuous. It **arises** from the

lower part of the *ligamentum nuchæ,* the spines of the seventh cervical and first thoracic vertebræ, and the supraspinous ligament between them. Passing obliquely downwards and laterally, it is **inserted** into the medial border of the scapula opposite the root of the spine (Figs. 405, 406). The **rhomboideus major arises** from the spines of the thoracic vertebræ from the second to the fifth inclusive, and from the corresponding supraspinous ligaments. It also passes downwards and laterally to be **inserted** into the medial border of the scapula, between the spine and the inferior angle (Figs. 405, 406). The muscle is inserted directly into the scapula by means of its lower fibres only. Its upper part is attached to a membranous band which is connected to the medial border of the scapula, for the most part by loose areolar tissue, but is fixed to the bone near the spine and at the inferior angle.

The rhomboid muscles are concealed to a large extent by the trapezius; they cover the serratus posterior superior and the sacro-spinalis.

Nerve-Supply.—Associated in the movements of the upper limb on the trunk, the superficial muscles of the back are all supplied by nerves that are derived from the cervical region of the spinal cord but reach the muscles by various routes. The trapezius has a double nerve-supply, similar to that of the sterno-mastoid: (1) from the terminal fibres of the **spinal portion** of the **accessory** nerve and (2) from the **cervical plexus** (anterior primary rami, C. **3** and **4**). The cervical nerves communicate with the accessory nerve in the posterior triangle of the neck and beneath the trapezius; and it is probable that they are mainly concerned in conveying afferent impulses from the muscle.

The latissimus dorsi has a single nerve—the **nerve to the latissimus dorsi**—which supplies it on its deep surface; it is a branch from the posterior cord of the brachial plexus (C. (6), 7, 8). The levator scapulæ and the rhomboid muscles are associated together in their nerve-supply, which is derived in succession from the anterior primary rami of the **third, fourth,** and **fifth cervical** nerves. The **nerve to the rhomboids** from the brachial plexus (C. (4) 5), passing beneath the levator scapulæ and the rhomboids, supplies all three muscles on their deep surfaces. The upper part of the levator scapulæ is supplied in addition by small branches from the anterior primary rami of the third and fourth cervical nerves which enter the muscle on its superficial surface near its origin.

It should be noted that the cervical nerves which supply this group of muscles, in spite of the fact that it is situated mainly in the back, are derived through the cervical and brachial plexuses from the *anterior* primary rami of the spinal nerves concerned; the explanation is to be found in the developmental origin of the muscles from the ventro-lateral sheet of musculature and their subsequent migration to obtain secondary attachment to the vertebral column (pp. 553, 555).

MUSCLES AND FASCIÆ OF PECTORAL REGION

2. Muscles of Pectoral Region

The ventral group of muscles connecting the upper limb to the trunk comprises the pectoralis major, pectoralis minor, subclavius, and the serratus anterior. The sterno-mastoid, by virtue of its attachment to the clavicle, may be considered a member of this group; it has already been described (p. 434).

Pectoralis Major.—The pectoralis major is a large fan-shaped muscle **arising** in two main portions—a small clavicular and a large sterno-costal—separated by a distinct interval. (1) The *clavicular part* arises from the front of the clavicle in its medial half or two-thirds (Figs. 404, 408, 409). (2) The *sterno-costal part* is larger, and arises from the anterior surface of the manubrium and body of the sternum by tendinous fibres that decussate with those of the opposite muscle (Figs. 407, 408); more deeply, from the cartilages of the first six ribs; and by a small slip, sometimes separate (*abdominal part*), from the aponeurosis of the external oblique muscle of the abdominal wall.

The fibres converge towards the proximal part of the arm, and are inseparably blended at a point half an inch from their **insertion** into the lateral lip of the bicipital groove of the humerus.

The arrangement of the fibres of the muscle at its insertion is peculiar. The clavicular part is attached to the humerus in front of the sterno-costal part and blends, inferiorly, with the tendinous insertion of the deltoid, the lateral fibres

of origin being inserted proximal to the medial fibres. The upper sterno-costal fibres disappear under cover of the clavicular part near its insertion and are blended with the deep surface of its tendon. The lower sterno-costal fibres and the abdominal part curve upwards behind the upper sterno-costal fibres; the abdominal part has the highest attachment to the shaft of the humerus, and helps to form a fascial expansion which extends upwards over the biceps tendon to the capsule of the shoulder joint. In this way a bilaminar tendon is produced, united along its inferior border. The superficial lamina is formed by the upper sterno-costal fibres blended for the most part with the tendon of the clavicular part and the deep lamina, by the twisted, lower sterno-costal and abdominal fibres.

Placed superficially, the pectoralis major lies in the anterior wall and anterior fold of the axilla (Pl. XL, p. 457, Fig. 3, and Fig. 412, p. 483). Its upper border is separated from the edge of the deltoid muscle by an interval called the *infra-clavicular fossa* (Pl. XLI, p. 512, Fig. 3), in which lie the cephalic vein and the deltoid branches of the acromio-thoracic artery. Its deep surface is in relation with the ribs and intercostal muscles, the clavi-pectoral fascia and the structures piercing it, the pectoralis minor, the biceps and coraco-brachialis, the axillary vessels, and the nerves of the brachial plexus.

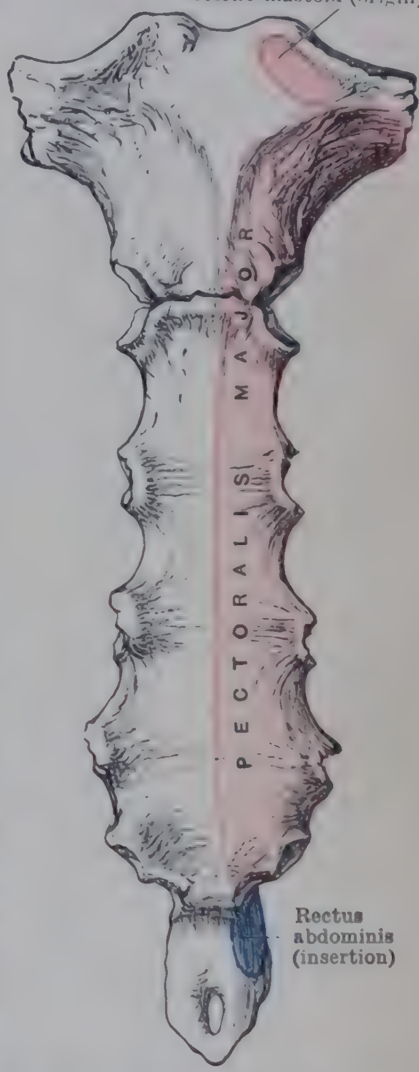


FIG. 407.—MUSCLE-ATTACHMENTS TO FRONT OF STERNUM.

Sternalis Muscle.—The sternalis is an occasional muscle (4·4%) that lies parallel to the sternum on the origin of the pectoralis major. It has variable attachments to the costal cartilages, sternum, rectus sheath, sterno-mastoid, and pectoralis major. Its **nerve-supply** is from one or both of the pectoral nerves. In certain rare cases it has been said to be innervated by intercostal nerves.

Chondro-Epitrochlearis, Dorso-Epitrochlearis, Axillary Arches, Costo-Coracoideus.—One or other of the above-named slips is occasionally present, crossing the floor of the axilla in the interval between the latissimus dorsi and the pectoralis major. They take **origin** from the costal cartilages, ribs, or borders of the pectoralis major (*chondro-epitrochlearis, axillary arches, costo-coracoideus*), or from the border of the latissimus dorsi (*dorso-epitrochlearis, axillary arches, costo-coracoideus*). Their **insertion** is variable. The *chondro-epitrochlearis* and *dorso-epitrochlearis* are inserted into the fascia of the arm, the medial intermuscular septum, or the medial epicondyle of the humerus. The *axillary arches* are inserted into the border of the pectoralis major, the fascia of the arm, or the coraco-brachialis or biceps muscle. The *costo-coracoideus*, arising from the ribs or the aponeurosis of the external oblique, or detaching itself from the border of the pectoralis major or latissimus dorsi, is inserted into the coracoid process, alone or along with one of the muscles attached to that bone. These variable slips of muscle are supplied by the medial pectoral nerve, the medial cutaneous nerve of the arm, or the intercosto-brachial nerve.

Pectoralis Minor.—The pectoralis minor (Fig. 408) is a narrow, flat, triangular muscle that lies in the anterior wall of the axilla behind the pectoralis major. It **arises**, under cover of the pectoralis major, from the third, fourth, and fifth ribs near their anterior ends, and from the fascia of the corresponding intercostal spaces. It may have an additional origin from the second rib (Fig. 359, p. 420); and that from the fifth rib is often absent. Directed upwards and laterally, it is **inserted** by a short, flat tendon into the anterior half of the medial border and upper surface of the coracoid process (Fig. 411), and usually also into the conjoint tendon of the biceps and coraco-brachialis.

It crosses the axillary vessels and the cords of the brachial plexus, and is pierced by the medial pectoral nerve. Its fascial sheath is continuous above with the clavi-pectoral fascia and below with the axillary fascia.

Either in part or wholly, the pectoralis minor may pass over the coracoid process (separated from it by a *bursa*) to pierce the coraco-acromial ligament and be attached to the capsule of the shoulder joint.

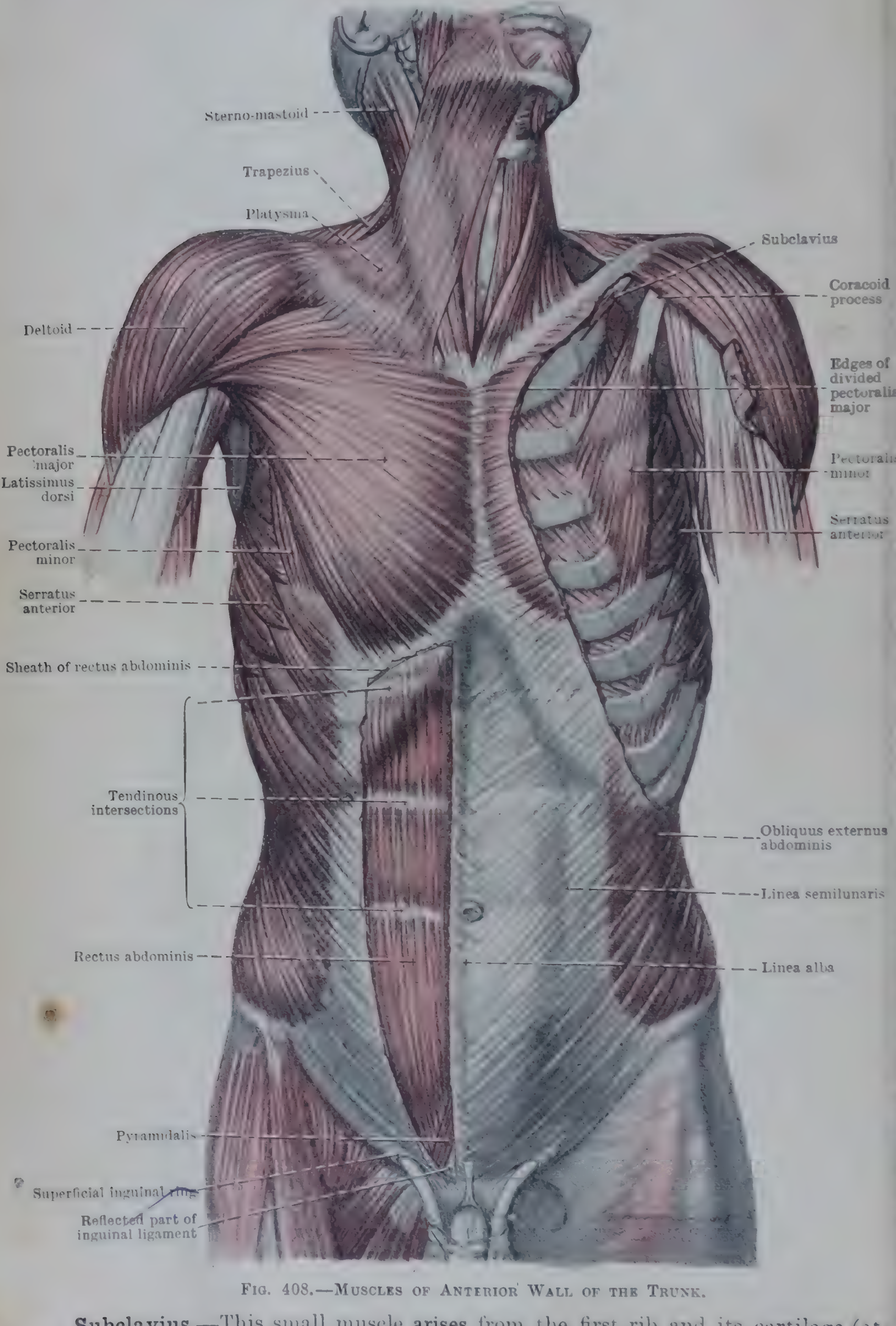


FIG. 408.—MUSCLES OF ANTERIOR WALL OF THE TRUNK.

Subclavius.—This small muscle **arises** from the first rib and its cartilage (at their junction) in front of the costo-clavicular ligament, and passes upwards and

laterally to be **inserted** into the floor of an elongated groove on the lower surface of the clavicle. It is concealed by the clavicle and the pectoralis major; and the clavi-pectoral fascia splits to enclose it.

Serratus Anterior.—The serratus anterior is a large, curved, quadrilateral

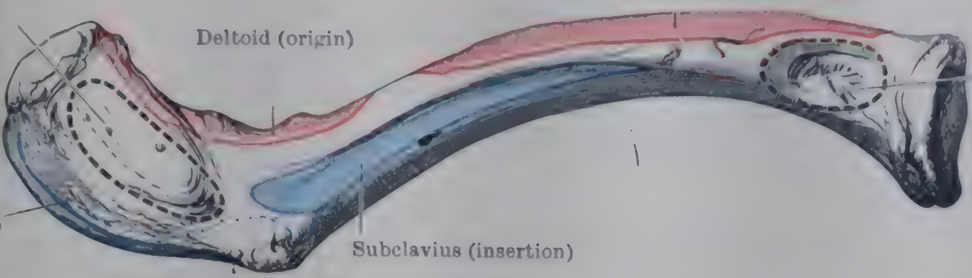


FIG. 409.—MUSCLE-ATTACHMENTS TO INFERIOR SURFACE OF RIGHT CLAVICLE.

muscle that lies on the side of the chest and in the medial wall of the axilla. It **arises** by fleshy slips from the outer surfaces of the upper eight (or nine) ribs. The first slip is a double one, arising from the first two ribs and the fascia of the intervening space (Fig. 410).

The **insertion** of the muscle is threefold. (1) The first slip is directed backwards to be inserted into the costal surface of the scapula at the superior angle. (2) The next three slips are inserted into the medial border of the scapula. (3) The last four slips are directed obliquely upwards and backwards to be inserted on the costal surface of the scapula at the inferior angle (Fig. 411).

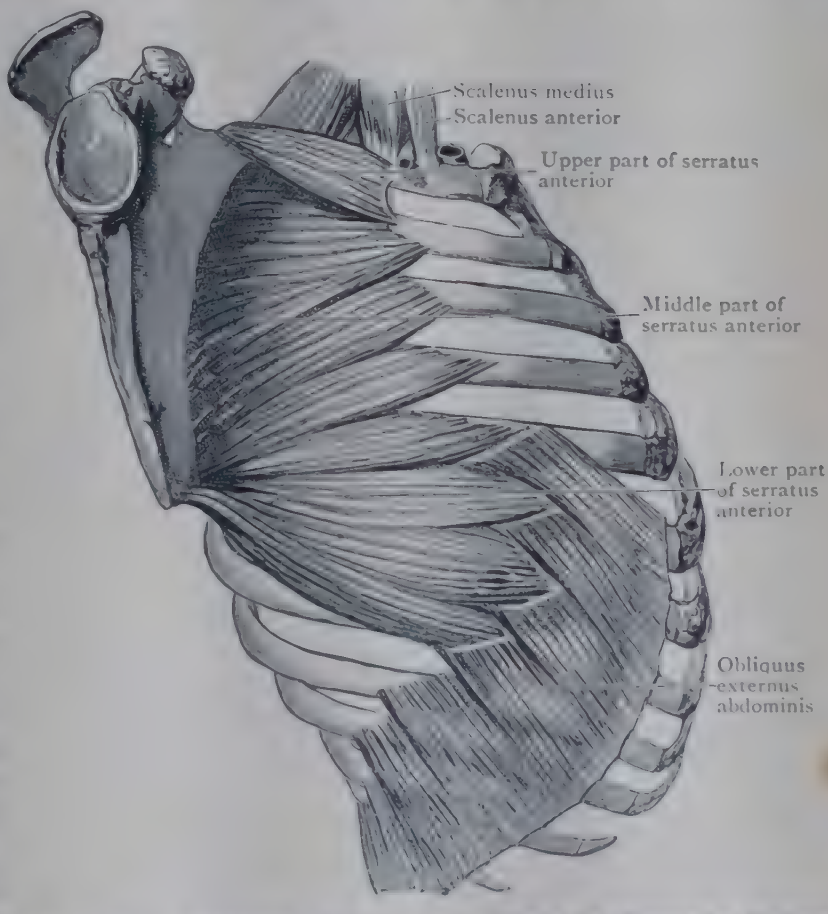


FIG. 410.—SERRATUS ANTERIOR AND ORIGIN OF EXTERNAL OBLIQUE. The Scapula is drawn away from the side of the chest.

The lateral surface of the muscle is partly superficial (Pl. XL, p. 457, Fig. 2) below the axilla, where its slips of origin interdigitate with those of the obliquus externus abdominis. Higher up, it forms the medial wall of the axilla and is partly covered by the infero-lateral part of the mammary gland. It is in contact with the pectoral muscles anteriorly and the subscapularis posteriorly. Its upper border appears in the floor of the posterior triangle of the neck, and over it the axillary artery and the cords of the brachial plexus enter the axilla. The lower border is oblique, and is in contact with the latissimus dorsi muscle. The muscle is sometimes continuous, in the neck, with the levator scapulæ.

Nerve-Supply.—The muscles of the pectoral region are all supplied by branches from the nerves of the brachial plexus (C. 5. 6. 7. 8. T. 1.). The **nerve to the subclavius** is a fine branch which arises above the clavicle from the upper trunk of the brachial plexus (C. 5. 6.), and descends in front of the subclavian artery to reach the muscle.

The pectoral muscles are each supplied by both pectoral nerves. The **lateral pectoral nerve**, derived from the lateral cord of the brachial plexus (C. 5. 6. 7.), divides into two branches, both of which pierce the clavi-pectoral fascia to supply respectively the clavicular and the upper portion of the sterno-costal part of the pectoralis major; the lower branch communicates over the axillary artery with the **medial pectoral nerve**. This nerve, a derivative of the medial cord (C. 8. T. 1.), likewise divides into two branches which supply the pectoralis minor and, piercing that muscle (the lower may wind round its inferior border), terminate in the lower part of the pectoralis major.

The serratus anterior is supplied, on its superficial aspect, by the **nerve to serratus anterior**, a branch from the anterior primary rami of the fifth, sixth, and seventh cervical nerves. The contributions from these nerves are distributed in order from above downwards—the highest fibres of the muscle being supplied by the fifth, the lowest by the seventh.

Actions of Muscles in Movements of the Shoulder Girdle.—The great range of action of the upper limb is due to a combination of free movements of the arm at the shoulder joint with movements of the shoulder girdle on the trunk. The action of the muscles which connect the limb to the trunk is most readily appreciated with reference to the movements of the scapula. From the position of rest, with the arm hanging by the side, the scapula is freely movable on the chest-wall in three directions by (1) elevation, (2) forward translation, and (3) lateral rotation (the inferior angle passing forwards and laterally). Those movements are normally combined and may be readily observed as the arm is raised above the head; they then occur as associated movements of the girdle as a whole at the sterno-clavicular joint, and as compensating or adapting movements between clavicle and scapula at the acromio-clavicular joint. All the muscles which act from the trunk upon the limb are so arranged that they tend to produce or to antagonize this combination of three movements of the scapula.

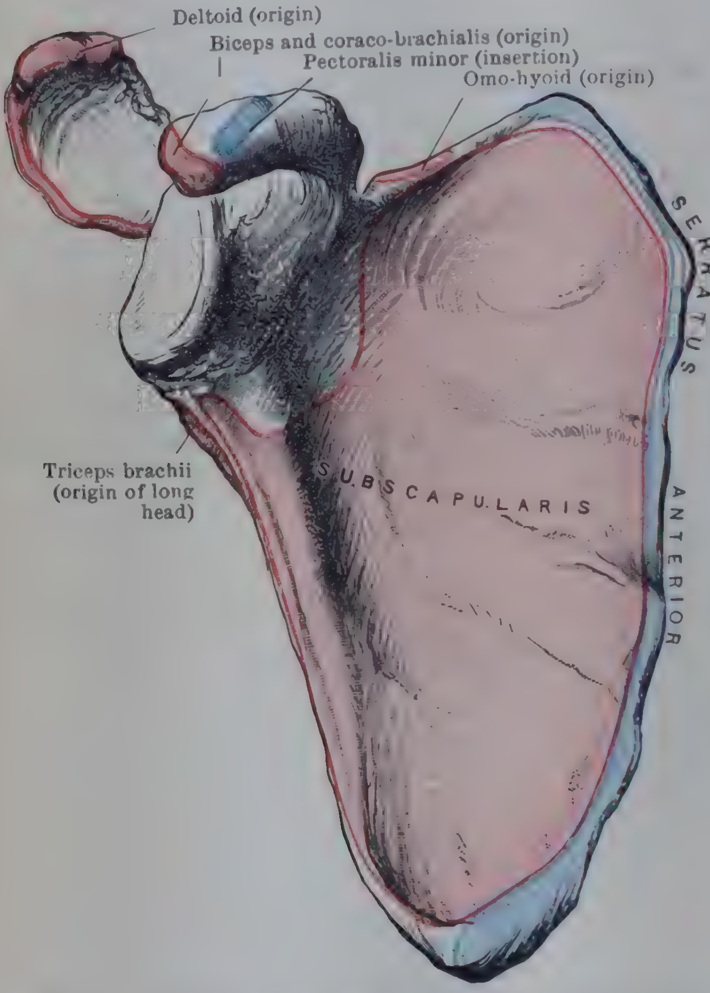


Fig. 411.—Muscle-Attachments to Costal Surface of Right Scapula.

The **trapezius** muscles, by their tonic or postural action alone, keep the shoulders braced and thus help to suspend the upper limbs—drooping shoulders are an outward sign of diminished nervous and muscular tone. When a weight is shouldered, the muscle has to work harder to maintain the position of the shoulder.

The lever afforded by the spine of the scapula is like a winged nut for the grip of this muscle in rotating the scapula during elevation of the upper limb (Fig. 209, p. 241; and Pl. XXXVII, p. 456, Fig. 2). The lateral angle is then raised, the superior angle lowered, and the inferior angle directed laterally; and the various fibres, converging on the spine, co-operate in producing this movement (cf. Pl. XXXII, p. 347, and Fig. 404, p. 475).

The **levator scapulæ** and the **rhomboids** act in concert with their antagonist (the trapezius) in pulling the shoulders backwards—the movement being the resultant of their opposed forces. In the rotatory movement of shrugging the shoulders, the trapezius and the serratus anterior, followed by the levator and the rhomboids, act in sequence, first one group predominating, then the other, with at times the opposed action of both groups securing a resultant movement—the approximation of the scapulæ. When the trapezius is paralysed the lateral angle of the scapula is lower than on the unaffected side, and the other angles are higher; this tilting is brought about by the levator and the rhomboids—assisted by the weight of the limb.

The **serratus anterior** is a powerful factor in steadying the scapula, in pulling it forwards, and, acting with the trapezius, in raising its inferior angle as the limb is elevated (Pl. XL, p. 457, Fig. 2). When the limb is raised forwards to the horizontal, the serratus gives the extra forward thrust as in fencing, and is brought into use in pushing movements. It acts from its insertion in forced inspiration, or in hand balance exercises ("standing on the hands")—in which most of the muscles of the arm reverse their actions. In paralysis of the serratus anterior, the medial border of the scapula stands farther away from the chest-wall ("winged scapula") than it does in paralysis of the trapezius, and the patient has difficulty in raising his arm much beyond the horizontal position, whereas the arm may be completely raised (though clumsily) in trapezius paralysis. As a rule, when abduction of the arm begins, its weight causes a slight medial movement of the inferior angle of the scapula, but in a few cases it moves immediately lateralwards. The muscles that rotate the scapula are active throughout elevation of the arm, and so also are the muscles that produce this movement at the shoulder joint (cf. Actions, p. 487).

The **pectoralis minor** assists in drawing the shoulder forwards, and is an opponent of the trapezius by depressing the shoulder and rotating the scapula medially. Its action

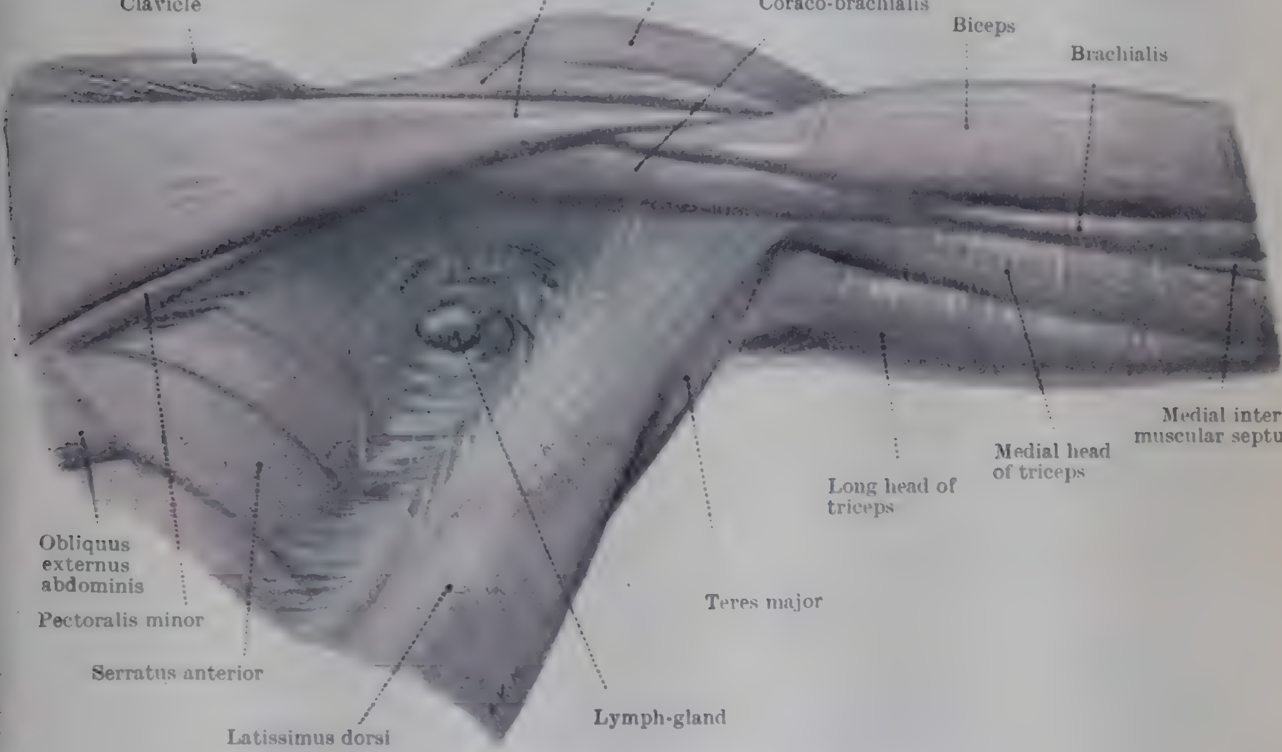


FIG. 412.—FASCIA AND MUSCLES OF LEFT AXILLA.

is very difficult to appreciate in the living subject, since it lies under cover of the pectoralis major and is never paralysed alone.

The **subclavius** is a depressor of the lateral end of the clavicle, and by drawing the bone medially towards the sternum it steadies it in movements of the shoulder girdle.

Two of the muscles that attach the upper limb to the trunk (**latissimus dorsi** and **pectoralis major**) act primarily at the shoulder joint, but also take part indirectly in the movements of the shoulder girdle. The latissimus dorsi (Pl. XL, p. 457, Fig. 1) assists in backward movements of the girdle, the pectoralis major in forward movement (Pl. XLI, p. 512, Fig. 3), and together they take part in the movement of depression of the shoulder (Pl. XLI, Fig. 2). Both these muscles can act, from their insertions, upon the trunk: (1) they are the chief climbing muscles—drawing the body upwards when the arms are fixed; (2) when the shoulders are elevated and fixed they act as accessory muscles of respiration (p. 454). The pectoralis major, with the minor, assists violent inspiratory efforts by raising the upper ribs, and the costal slips of the latissimus dorsi raise the lower ribs. The latissimus dorsi muscles appear also to assist the abdominal muscles in violent expiratory efforts by their general compressing effect on the thorax (p. 454).

It is a most interesting feature of the pectoralis major that the clavicular fibres assist in raising the arm forwards to the horizontal, while the sterno-costal fibres, acting against resistance, depress the arm. When the subject carries out both these opposite movements simultaneously, one with each arm, against resistance, the lop-sided effect

produced upon the great pectoral muscles is remarkable (Pl. XLII, p. 513, Fig. 1). (This exercise also produces marked asymmetry of the thoracic cage). It is noteworthy also that when the erect arm is being depressed against resistance, the clavicular fibres, though anatomically in a position to assist, are in fact inactive.

FASCIÆ OF PECTORAL REGION

The **superficial fascia** of the chest usually contains a quantity of fat in which the mammary gland is embedded. The fibres of the platysma muscle lie beneath the upper part of the fascia, and many of them pierce it to take origin from the skin.

The **deep fascia** is attached above to the clavicle, and medially to the sternum. It invests the pectoralis major, and is continuous below with the fascia of the abdominal wall. Beyond the lateral border of the great pectoral muscle it is thickened and forms the floor of the axillary space **(axillary fascia)**—continued posteriorly on to the posterior fold of the axilla and laterally into connexion with the deep fascia of the upper arm.

Clavi-Pectoral Fascia.—Beneath the pectoralis major a deeper stratum of fascia invests the pectoralis minor muscle. At the supero-medial border of that muscle it forms the clavi-pectoral fascia, which passes upwards to the inferior border of the subclavius muscle, where it splits into two layers, attached in front of and behind that muscle to the borders of the inferior surface of the clavicle. The membrane, traced medially along the subclavius muscle, is attached to the first costal cartilage; passing laterally along the pectoralis minor, it reaches the coracoid process and the coraco-clavicular ligament; and the part of the membrane that extends directly between the first costal cartilage and the coracoid process is thicker than the rest of it. The clavi-pectoral fascia is pierced by the cephalic vein, acromio-thoracic artery, and branches of the lateral pectoral nerve. Its deep surface is connected with the sheath of the axillary vessels.

At the infero-lateral border of the pectoralis minor there is a further extension of the deep fascia beneath the pectoralis major. It passes downwards to join the fascia of the floor of the axilla, and it is continued laterally into the fascia that covers the biceps and coraco-brachialis muscles.

MUSCLES AND FASCIÆ OF SHOULDER

Muscles of Shoulder

The **muscles** proper to the shoulder are the deltoid, supraspinatus, infraspinatus, teres minor, teres major, and subscapularis.

Deltoid Muscle.—The deltoid, a coarsely fasciculated, multipennate muscle, has an extensive **origin** from: (1) the front of the clavicle in its lateral third (Fig. 404); (2) the lateral border of the acromion; (3) the lower lip of the crest of the spine of the scapula and the fascia of the infraspinatus muscle. Its origin embraces the insertion of the trapezius.

The fibres of the muscle converge on the lateral surface of the shaft of the humerus to be **inserted** into the deltoid tuberosity. The insertion is partly united with the tendon of the pectoralis major (Fig. 418, p. 491).

The most anterior part of the deltoid muscle is formed of parallel fibres, not uncommonly separate from the rest of the muscle at their origin. Those fibres may be continuous across the clavicle with the trapezius. The most posterior fibres have a membranous origin, and converge on the main tendon. The middle fibres are multipennate, being attached above and below to three or four septal tendons which extend for a variable distance downwards and upwards from the origin and insertion of the muscle—an arrangement that increases the number of the fibres and consequently the power of the deltoid. The increased power is necessary owing to the obvious mechanical disadvantage at which the muscle acts, and the fact that its action is usually exerted against the force of gravity.

The deltoid is superficial in its whole extent. It is spread out over the greater tuberosity of the humerus and so forms the prominence of the shoulder. Its anterior border is separated from the pectoralis major by a narrow interval

occupied by the cephalic vein and deltoid branch of the acromio-thoracic artery. The deep surface of the muscle is related to—(1) the *coracoid process*, associated with which are the coraco-acromial ligament, and the attachments of the pectoralis minor, the coraco-brachialis, and the short head of the biceps muscle; (2) the subscapularis, supraspinatus, infraspinatus, and teres minor, which cover the capsule of the shoulder joint; and (3) the proximal part of the lateral surface of the *shaft of the humerus* and the posterior circumflex humeral vessels and the circumflex nerve. The *sub-acromial bursa* separates the middle fibres of the deltoid, the acromion and the coraco-acromial ligament from the supraspinatus, infraspinatus, and subscapularis tendons.

FIG. 413.—LEFT SCAPULAR MUSCLES AND TRICEPS.

Supraspinatus.—The supraspinatus **arises**, by fleshy fibres, from the walls of the supraspinous fossa (except near the neck of the bone) and from the deep fascia. It is directed forwards and laterally under the trapezius muscle, the acromion and coraco-acromial ligament, to be **inserted** by a broad, thick tendon into the anterior facet on the top of the greater tuberosity of the humerus and into the capsule of the shoulder joint.

Infraspinatus.—The infraspinatus **arises** from the walls of the infraspinous fossa (excepting near the neck of the bone and the flat surface along the lateral margin) and from the thick fascia over it. The fibres of the muscle converge on the neck of the scapula and are **inserted** by tendon into the middle facet on the greater tuberosity of the humerus and into the capsule of the shoulder joint. The *bursa of the infraspinatus muscle* separates the muscle from the neck of the scapula, and occasionally communicates with the cavity of the shoulder joint.

The supraspinatus and the upper part of the infraspinatus muscles are covered by the trapezius, acromion, and deltoid and, in turn, conceal the neck of the scapula, the suprascapular vessels and nerve, and the capsule of the shoulder joint.

Teres Minor.—This small muscle **arises**, by fleshy fibres, from a raised, narrow strip situated on the dorsal surface of the scapula along the upper two-thirds of its lateral border, and from fascial septa that separate it from the infraspinatus and teres major muscles. It lies along the lateral border of the infraspinatus, and it is **inserted**, under cover of the deltoid, by a thick, flat tendon, into the lowest of the three facets on the greater tuberosity of the humerus and into the capsule of the shoulder joint, and, by fleshy fibres, into the back of the humerus below the tuberosity for about an inch.

It is separated from the teres major by the long head of the triceps and by the posterior circumflex humeral vessels and the circumflex nerve. At its origin it is pierced by the circumflex scapular vessels. The muscle is invested by the fascia of the infraspinatus, and is sometimes inseparable from that muscle.

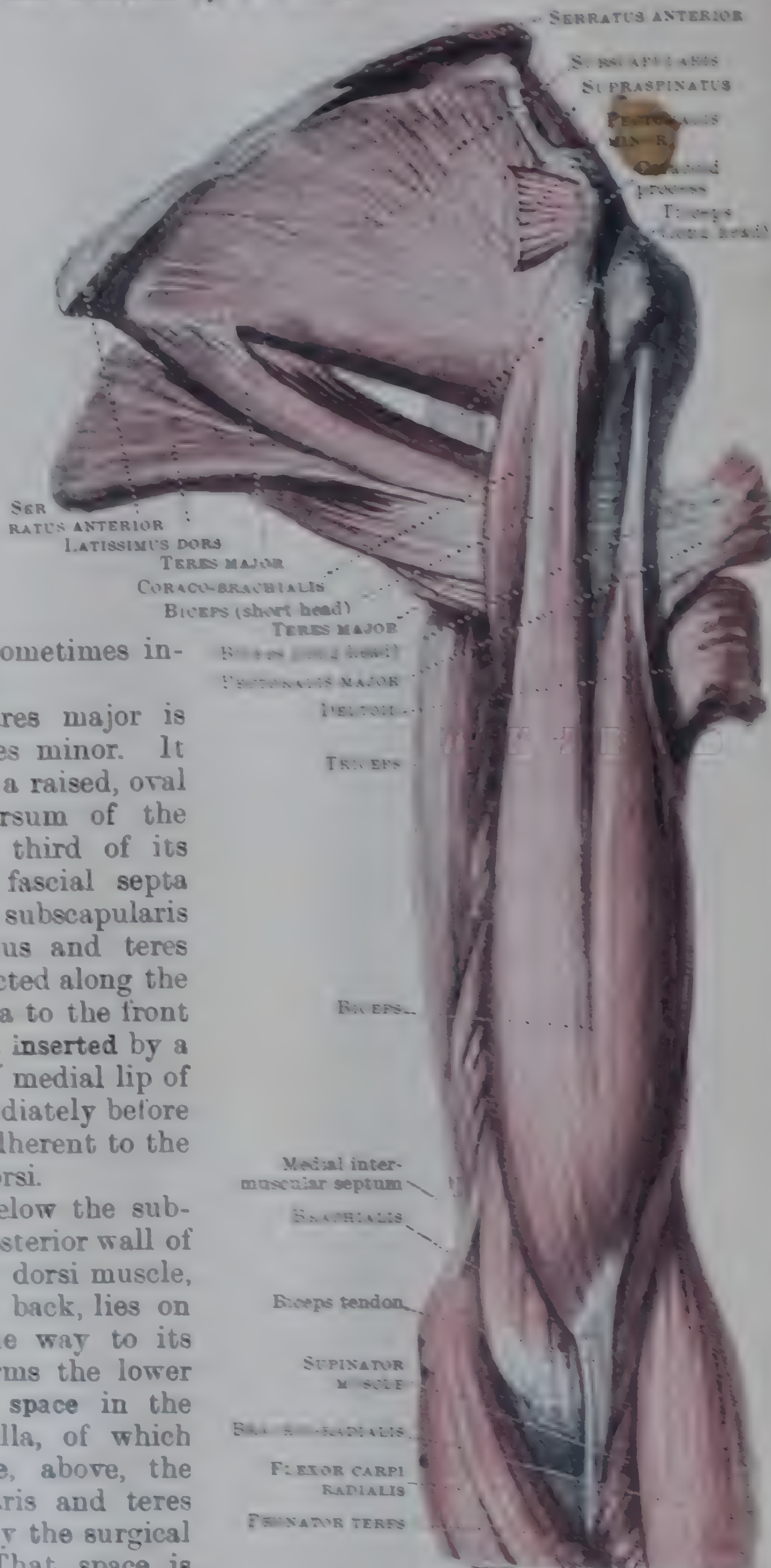


FIG. 414.—MUSCLES OF POSTERIOR WALL OF LEFT AXILLA AND FRONT OF ARM.

Teres Major.—The teres major is much larger than the teres minor. It **arises** by fleshy fibres from a raised, oval area situated on the dorsum of the scapula along the lower third of its lateral border, and from fascial septa which separate it from the subscapularis and from the infraspinatus and teres minor. The muscle is directed along the lateral border of the scapula to the front of the humerus, where it is **inserted** by a broad, flat tendon into the medial lip of the bicipital groove. Immediately before its insertion it is closely adherent to the tendon of the latissimus dorsi.

The teres major lies below the subscapularis muscle in the posterior wall of the axilla. The latissimus dorsi muscle, sweeping round from the back, lies on its axillary surface on the way to its insertion. The muscle forms the lower boundary of a **triangular space** in the posterior wall of the axilla, of which the other boundaries are, above, the borders of the subscapularis and teres minor muscles, and laterally the surgical neck of the humerus. That space is divided by the long head of the triceps, which passes behind the teres major muscle, into (*a*) a **quadrangular space** laterally, for the passage of the circumflex nerve and posterior humeral circumflex vessels, and (*b*) a smaller triangular space medially for the circumflex scapular vessels.

Subscapularis.—The subscapularis is a large triangular muscle which covers

the costal surface of the scapula. It **arises**, by fleshy fibres, from the whole of the floor of the subscapular fossa and the groove along the lateral border, excepting the surfaces at the angles of the bone. Several fibrous septa that spring from ridges in the fossa project into the substance of the muscle and increase the extent of its attachment. Converging on the upper end of the humerus, the muscular fibres are **inserted** by a broad, thick tendon into the lesser tuberosity of the humerus and into the capsule of the shoulder joint, and, by fleshy fibres, into the front of the humerus below the tuberosity for about an inch, under cover of the coraco-brachialis and short head of the biceps.

This muscle forms the greater part of the posterior wall of the axilla. Its medial or anterior surface is in contact with the serratus anterior and the axillary vessels and nerves. It is separated from the neck of the scapula by the *subscapular bursa*, which communicates with the shoulder joint.

Nerve-Supply.—All muscles of the shoulder are supplied by the anterior primary rami of the **fifth** and **sixth cervical nerves** through branches of the brachial plexus. The supraspinatus and infraspinatus are supplied by the **suprascapular nerve**, which takes origin from the upper trunk of the plexus; the remaining muscles by branches from the posterior cord. The deltoid is supplied by the terminal branches of the **circumflex nerve**; that nerve supplies also the teres minor by a branch which is distinguished by a fibrous swelling or 'pseudo-ganglion' on its trunk. The subscapularis is supplied by the two **subscapular nerves**; the upper subscapular is often double, and the lower subscapular, after supplying the lower lateral portion of the subscapularis, ends in the teres major.

The Actions of Muscles in Movements at the Shoulder Joint.—Free movements at the shoulder joint are always accompanied by movements of the acromio-clavicular and sterno-clavicular joints. When the limb is raised till it points upwards, about 90° of the movement takes place at the shoulder joint and the other 90° at the joints of the shoulder girdle, but the joints of the girdle are in action from the beginning (Cathcart, 1884; Lockhart, 1930, 1933; Martin 1932, 1940; Johnston, 1937). (Pl. XXXII, p. 347, Figs. 1, 2, 3, show relative positions of the bones at these joints when the limb has been raised from the dependent position to the horizontal, and then to the erect position.) The deltoid, trapezius, and the serratus anterior are in contraction throughout the whole movement. With the humerus fixed, the shoulder muscles, reversing their action, assist in forced respiration. The shoulder joint is called into use also in many of the movements carried out mainly at joints lower down in the limb, for example, supination and pronation, and even fine movements of the fingers. Paralysis of the infraspinatus and the teres minor prevents a person from writing a continuous line without lifting the hand along every two or three words or else pulling the paper to the left.

The muscles of the shoulder joint have been divided into functional groups: 1. The subscapularis, supraspinatus, infraspinatus and teres minor keep the head of the humerus in contact with the glenoid cavity during all movements at the joint executed not only by them but also by other muscles of the arm. Dislocation occurs when these muscles, described as *articular muscles* by Winslow (1743), are taken off their guard or when their strength is overcome. 2. The deltoid, pectoralis major, latissimus dorsi and teres major are the chief effectors of humero-glenoid movement. 3. The deltoid, triceps, biceps and coraco-brachialis, and also the articular muscles, especially supraspinatus, by tonic action, assist in sustaining the weight of the limb in the erect posture.

The **deltoid muscle** is the most powerful abductor of the shoulder joint, but it is important to note that the initiation of this movement depends upon the **supraspinatus**, which helps to prevent displacement of the head of the humerus during strong deltoid action. In paralysis of the deltoid, abduction is limited to about 45°. The anterior fibres of the deltoid assist the clavicular part of pectoralis major in flexion and medial rotation of the humerus; the posterior fibres act with the extensors and lateral rotators. In paralysis of the supraspinatus the patient secures the initial abduction required for elevation of the arm by leaning slightly to the side, thereby harnessing gravity to replace the missing supraspinatus.

The **pectoralis major** is a powerful adductor and medial rotator of the upper arm. The clavicular part assists the anterior fibres of the deltoid to flex the humerus, a movement in which the limb is carried forwards and medially; the sterno-costal part takes part in flexion from full extension until the arm reaches the side, but is a powerful extensor of the fully flexed humerus.

The **latissimus dorsi** is a powerful adductor and extensor of the humerus, its characteristic action being well illustrated in the downstroke in swimming. It assists also in medial rotation of the upper arm.

The **teres major** acts with the pectoralis major and the latissimus dorsi in adduction and medial rotation of the humerus.

In addition to their general action of keeping the head of the humerus in close relation with the glenoid cavity, the muscles immediately surrounding the joint have special actions according to their situation. The **supraspinatus** is an abductor of the arm, the **infraspinatus** a lateral rotator, and the **teres minor** a lateral rotator and an adductor. The **subscapularis** is a medial rotator of the humerus, and when the arm is abducted through 90° it acts with the pectoralis major in drawing the arm horizontally forwards. Its chief function, however, is to prevent forward displacement of the head of the humerus.

The biceps, coraco-brachialis, and triceps also act upon the shoulder joint. The actions of the **biceps** on the joint are weak; the short head helps in flexion and adduction, and the long head in abduction; but the long head has an additional, mechanical influence in steadying the movements at the joint. The **coraco-brachialis** assists in flexion and adduction of the arm, and, when the humerus is rotated laterally, it can produce medial rotation until the position of rest is reached. The long head of the **triceps** acts as an adductor of the humerus. (See Pl. XLII, Fig. 2, p. 513.)

FASCIA OF SHOULDER

The **deep fascia** of the shoulder region is especially strong where it covers the infraspinatus and teres minor muscles below the posterior border of the deltoid. In that situation it is tendinous in appearance and character, and is firmly attached to the medial and lateral borders of the scapula. Superiorly it ensheaths the deltoid and is attached to the clavicle, the acromion, and the spine of the scapula.

MUSCLES AND FASCIÆ OF UPPER ARM

Muscles of Upper Arm

The muscles of the upper arm are the biceps, coraco-brachialis, and brachialis on the front, and the triceps on the back. Except at its ends, the biceps is superficial, and it forms a rounded fleshy mass on the front of the arm. The coraco-brachialis is visible in the proximal half of the upper arm on its medial side, particularly when the limb is raised. The brachialis is concealed by the biceps. The triceps is the thick mass of muscle on the back of the upper arm.

Coraco-Brachialis.—The coraco-brachialis **arises**, under cover of the deltoid, from the tip of the coracoid process, by fleshy fibres, in common with the short head of the biceps. The fleshy belly is pierced by the musculo-cutaneous nerve, and it ends in a flat tendon which is **inserted** into a faint linear impression about an inch in length on the middle of the medial border of the shaft of the humerus (Fig. 415). Some fibres are often continued into the medial intermuscular septum.

The **coraco-brachialis** is the remains of a *threefold muscle.* Usually only two elements are present in man, but in anomalous cases all the parts may be more or less fully developed. The passage of the musculo-cutaneous nerve through the muscle is an indication of its separation into the persisting middle and distal elements. In the commonest variation the more superficial part of the muscle (*coraco-brachialis inferior* or *longus*) extends farther down than usual, so as to be inserted into the medial intermuscular septum, or even into the medial epicondyle of the humerus. A third slip (*coraco-brachialis superior* or *brevis*) may more rarely be present; it springs from the root of the coracoid process and is inserted into the medial side of the humerus immediately below the capsule of the shoulder joint.

Biceps Brachii.—The biceps muscle **arises** by two tendinous *heads.* The **short head** is attached in common with the coraco-brachialis to the tip of the coracoid process of the scapula (Fig. 411, p. 482). Concealed by the deltoid and tendinous at first, this head forms a separate fleshy belly which is united to the long head by an investment of the deep fascia. The **long head** arises by a round tendon from the supraglenoid tubercle and from the labrum glenoidale. Its tendon lies within the capsule of the shoulder joint, and (invested by a prolongation of the synovial membrane) emerges from the joint beneath the transverse ligament. It then occupies the bicipital groove of the humerus, where it is covered by a fascial prolongation of the tendon of the pectoralis major; emerging from the

groove, it forms a fleshy belly which unites with the short head immediately below the middle of the upper arm.

The **insertion** also is twofold. (1) The united bellies become connected to a strong *tendon*, which, in the supine position of the forearm, is twisted upon itself —its anterior surface being directed laterally—as it passes deeply in the hollow of the elbow to be attached to the posterior part of the tuberosity of the radius (Figs. 422, 425, pp. 494, 497). A small bursa (*bicipito-radial*) separates the tendon from the anterior portion of the tuberosity. As the forearm is pronated the tendon of the biceps is untwisted. (2) From the medial and anterior part of the tendon, and partly in continuity with the fleshy fibres of the muscle, a strong membranous band spreads downwards and medially over the hollow of the elbow to join the deep fascia covering the origins of the flexor and pronator muscles of the forearm. This band is called the *bicipital aponeurosis*; its upper part is thickened and can be felt subcutaneously as a crescentic border which crosses in front of the brachial artery and the median nerve.

The biceps conceals the brachialis muscle and the musculo-cutaneous nerve. Its medial border is the guide to the position of the brachial artery and median nerve.

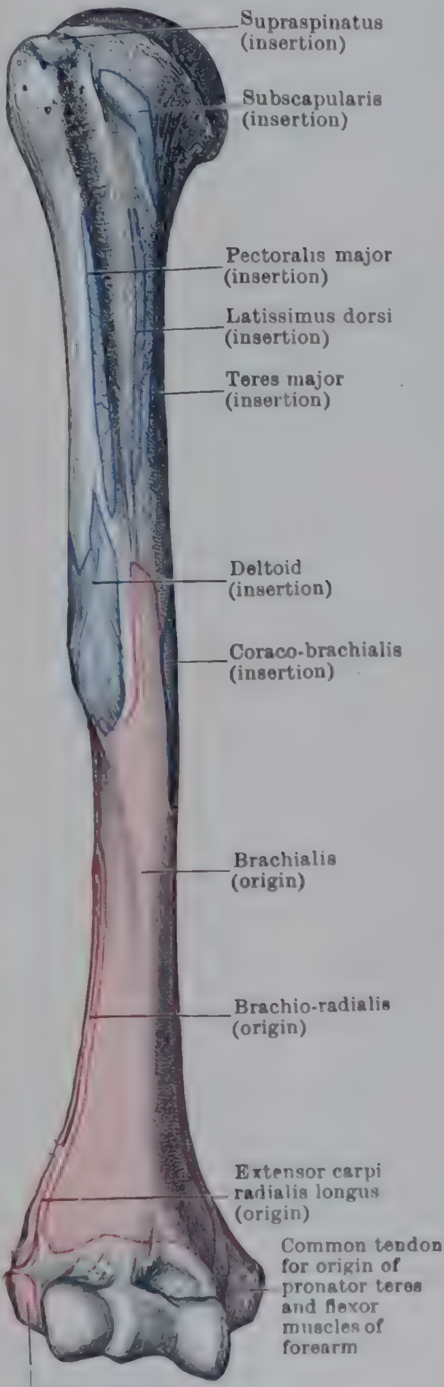


FIG. 415.—MUSCLE-ATTACHMENTS TO FRONT OF RIGHT HUMERUS.

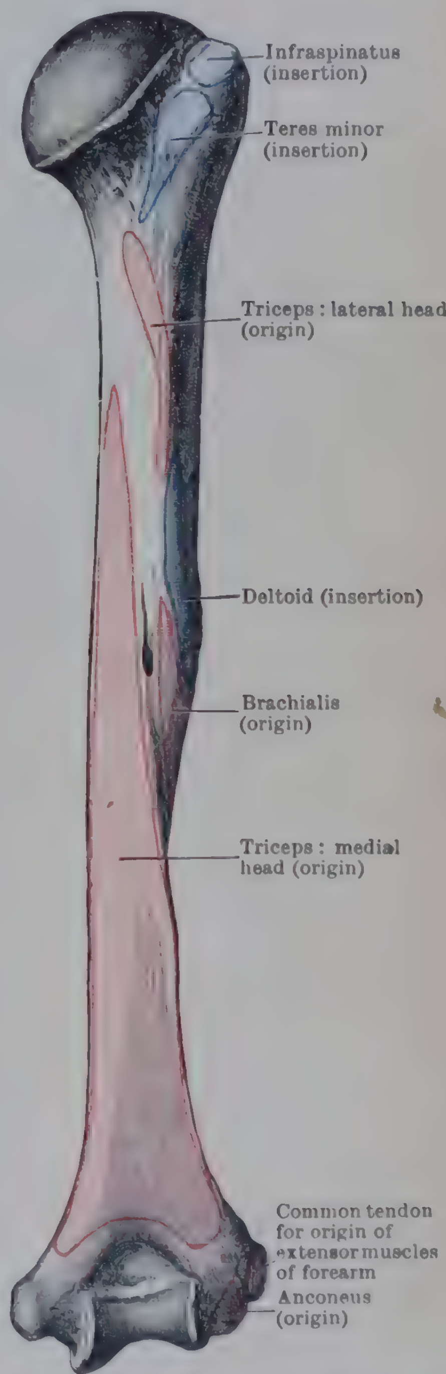


FIG. 416.—MUSCLE-ATTACHMENTS TO BACK OF RIGHT HUMERUS.

A third (or humeral) **head** is a common variation of the biceps (10 per cent); its usual site of origin is at the insertion of the coraco-brachialis, and it is inserted mainly with the bicipital aponeurosis. Two or even three additional heads may be present in the same subject. The long head of the muscle may be absent, or it may take origin from the bicipital groove. The muscle may have an additional insertion into the medial epicondyle of the humerus or into the fascia of the forearm.

Brachialis.—This large muscle **arises** from the distal two-thirds of the front of the shaft of the humerus and from the intermuscular septum on each side

(Fig. 415). Its proximal end clasps the insertion of the deltoid, and it ends distally in a strong tendon which is **inserted** into the lower surface of the coronoid process and into the tuberosity of the ulna (Fig. 425). Some fleshy fibres are inserted into the anterior ligament of the elbow joint; and the lateral part of the muscle, arising from the lateral supracondylar ridge and lateral intermuscular septum, forms a slip, more or less separate, which may be partially fused with the brachio-radialis muscle.

It is concealed for the most part by the biceps in the upper arm. Its distal part lies on the capsular ligament of the elbow joint and in the floor of the intermuscular depression in front of the elbow called the *cubital fossa*.

Triceps.—The triceps is the only muscle on the back of the upper arm. It **arises** by three heads—*lateral* and *medial* from the humerus, and *long* from the scapula. (1) The **long head** springs by a strong tendon from the infraglenoid tubercle of the scapula, and, giving rise to a fleshy belly, it passes between the teres major and teres minor muscles to occupy the middle of the back of the upper arm (Fig. 413, p. 485, and Fig. 417). (2) The **lateral head** arises by tendinous and fleshy fibres from the lateral border of the humerus between the insertion of the teres minor proximally and the spiral groove distally, and it receives additional fibres from the back of the lateral intermuscular septum; it is directed downwards and medially over the spiral groove—concealing the radial nerve, the profunda brachii vessels, and the medial head of the muscle (Figs. 416, 417). (3) The **medial head** arises, by fleshy fibres, from an elongated triangular area on the back of the humerus between the insertion of the teres major and the olecranon fossa, and also extensively from the back of the intermuscular septa—the whole length of the medial septum (Fig. 418), and from the part of the lateral septum below the passage of the radial nerve.

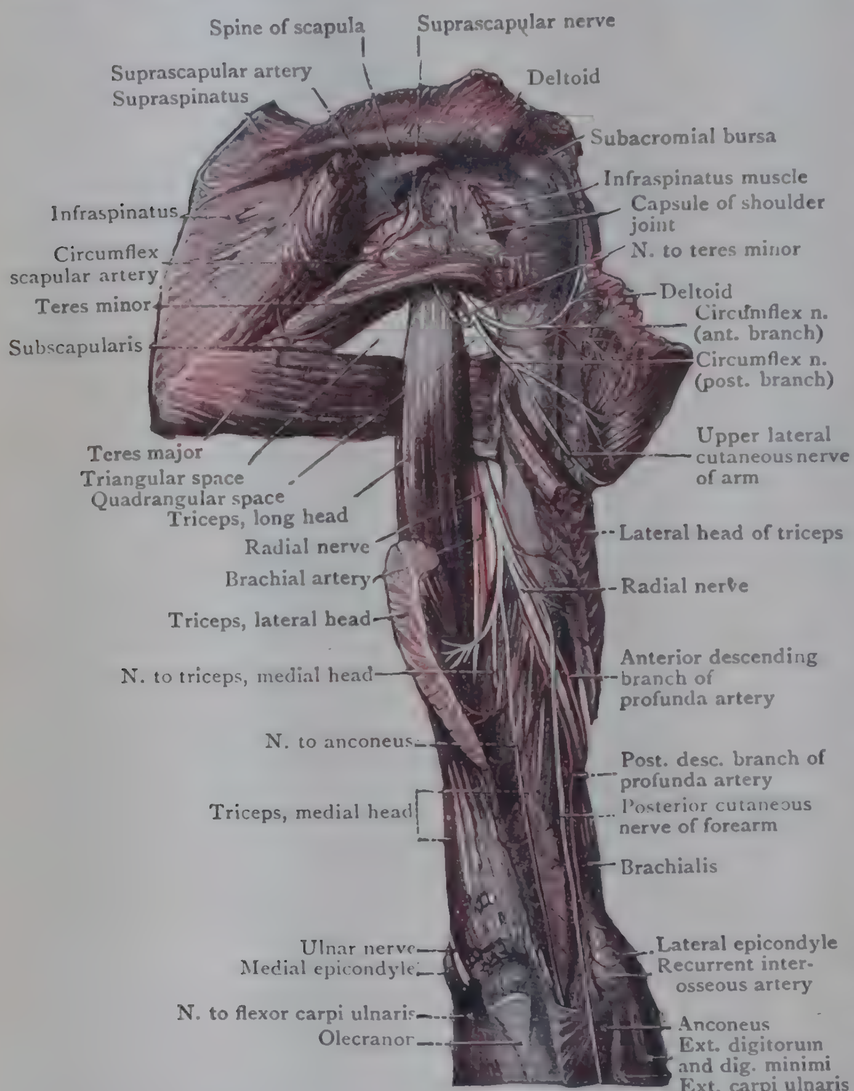


FIG. 417.—DISSECTION OF BACK OF SHOULDER AND UPPER ARM.

The three heads of origin are **inserted**, by a broad, flattened common tendon, into an impression occupying the posterior part of the proximal surface of the olecranon, and into the deep fascia of the forearm on each side of it. Occasionally a small part (**subanconeus**) of the medial head is inserted into the posterior ligament of the elbow joint. The long and lateral heads join the borders of the tendon, and the medial head is attached to its deep surface. A small, thick-walled *bursa of the tendon of the triceps* separates the tendon from the posterior ligament of the elbow joint.

The triceps is superficial in almost its whole extent (Pl. XL, p. 457, Fig. 3)

The long head is concealed at its origin by the deltoid and teres minor muscles; and the medial head is covered by the other two heads and by the tendon of insertion. The upper part of the lateral head intervenes between the circumflex nerve and the

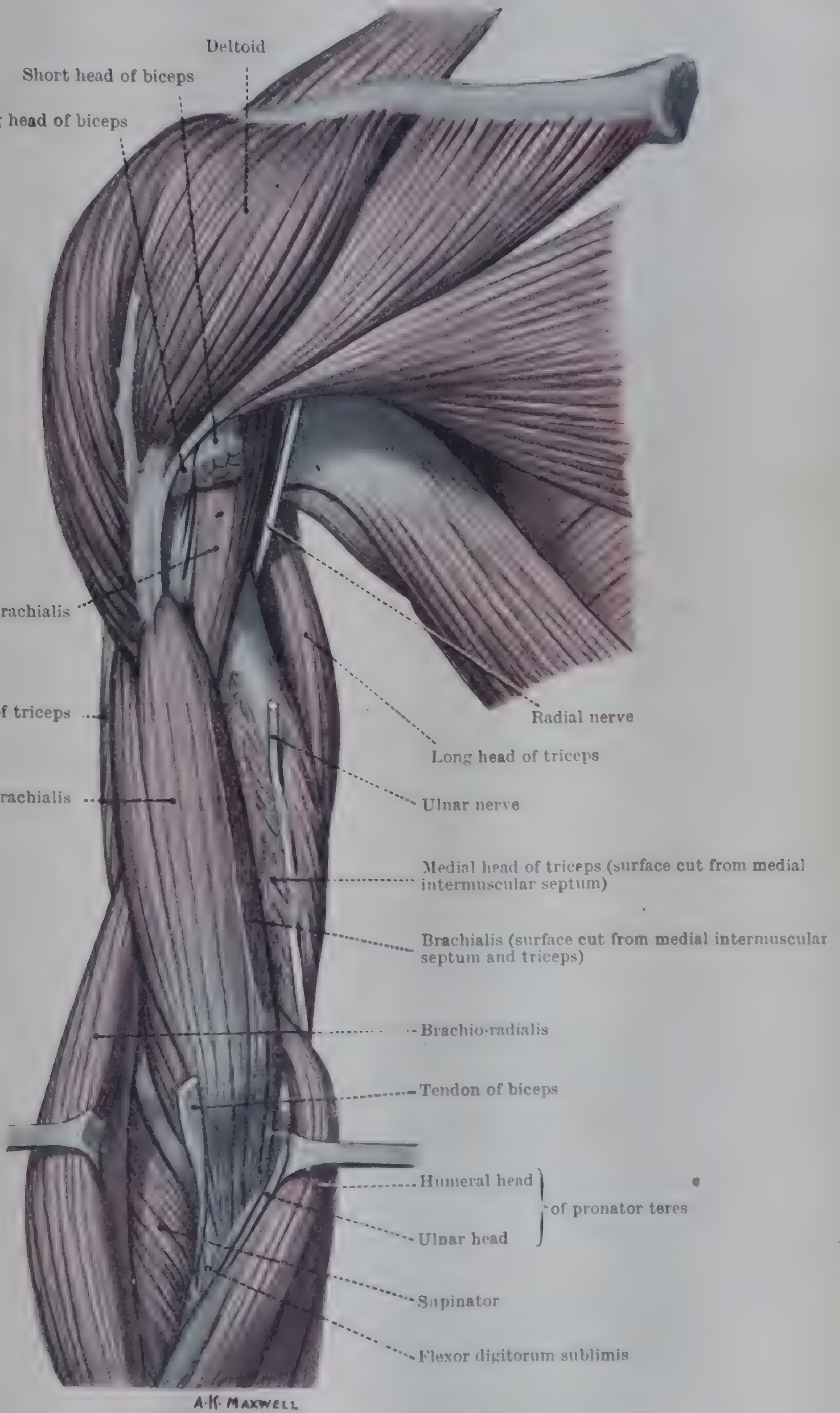


FIG. 418.—DISSECTION OF MUSCLES OF FRONT OF UPPER ARM.
The biceps has been removed to show the brachialis.

shaft of the humerus; and the upper part of the medial head intervenes between the radial nerve and the shaft of the bone.

Anconeus.—The anconeus is a small, triangular muscle which arises from the distal part of the back of the lateral epicondyle of the humerus and from the

posterior ligament of the elbow joint. It partially conceals the posterior ligament, the annular ligament of the radius, and the upper part of the ulna; and it is **inserted**, by fleshy fibres, into a triangular surface on the lateral side of the olecranon and posterior surface of the ulna as far down as the oblique line (Fig. 428, p. 500), and also into the fascia which covers it.

Nerve-Supply.—The nerves of supply to the muscles of the upper arm are derived from cervical nerves, 5, 6, 7, 8, through the lateral and posterior cords of the brachial plexus. The muscles in the anterior (flexor) part of the limb are supplied by branches of the lateral cord, and those on the back (extensor) from the posterior cord through the radial nerve.

The **nerve to the coraco-brachialis** (C. (6), 7) is usually incorporated with the musculo-cutaneous, from which it separates to supply the muscle before the latter nerve pierces it. A branch from the **musculo-cutaneous** (C. 5, 6) divides to supply each head of the biceps, and other branches supply the brachialis. As a rule, the brachialis receives at its lateral border a fine, additional branch (C (5), 6) from the **radial nerve** which may indicate a double origin of the muscle (cf. the biceps muscle of the thigh); but it may be an afferent nerve.

The several heads of the triceps are supplied separately by branches of the **radial nerve**. The lateral head receives fibres from C. (6), 7, 8, the long and medial heads from C. 7, 8. The medial head has a double nerve-supply: one branch has a long extra-muscular course before it enters the distal part of the muscle; the main nerve to the medial head enters its proximal part and is continued through the muscle to terminate in the anconeus.

Actions of Muscles in Movements at the Elbow Joint.—The **biceps** and the **brachialis** act together in flexion of the forearm, and are assisted in that action by the **brachio-radialis** and the **pronator teres**, and in lesser degrees by members of the flexor and extensor groups of the forearm that arise from the medial and lateral epicondyles of the humerus; for example, the radial extensors of the carpus may also assist in flexion at the elbow (see p. 408). It is of clinical interest to note that the biceps may retain its power of flexion when its supinating action is lost (Beevor). The brachialis, a pure flexor, is the most powerful flexor at the elbow, while the biceps acts also in flexion of the shoulder joint, and on the radio-ulnar joints as a supinator. The brachio-radialis is primarily a flexor of the elbow joint. It may also act as a semi-pronator and semi-supinator of the forearm, bringing the limb from a supine or prone position into an intermediate position.

The **triceps**, assisted by the **anconeus**, is the extensor of the elbow joint. It is said that the lateral head of the triceps, mainly with pale fibres, contracts quickly, the medial head with red fibres slowly (p. 409). (See Pl. XLII, Fig. 2, p. 513.)

FASCIÆ OF UPPER ARM

The **superficial fascia** is separated from the back of the olecranon by a subcutaneous *bursa*, and occasionally by others from the epicondyles of the humerus.

The **deep fascia** forms a strong tubular investment for the muscles on the front and back of the humerus. It is continuous above with the deep fascia of the shoulder and axilla, and it is strengthened by fibres derived from the insertions of the pectoralis major, latissimus dorsi, and deltoid muscles. At the elbow it gains attachment to the epicondyles of the humerus and the olecranon; and becomes continuous with the deep fascia of the forearm. It is strengthened also by important bands associated with the insertions of the biceps anteriorly and the triceps posteriorly. About the middle of the upper arm on the medial side, it is perforated by the basilic vein and the medial cutaneous nerve of the forearm.

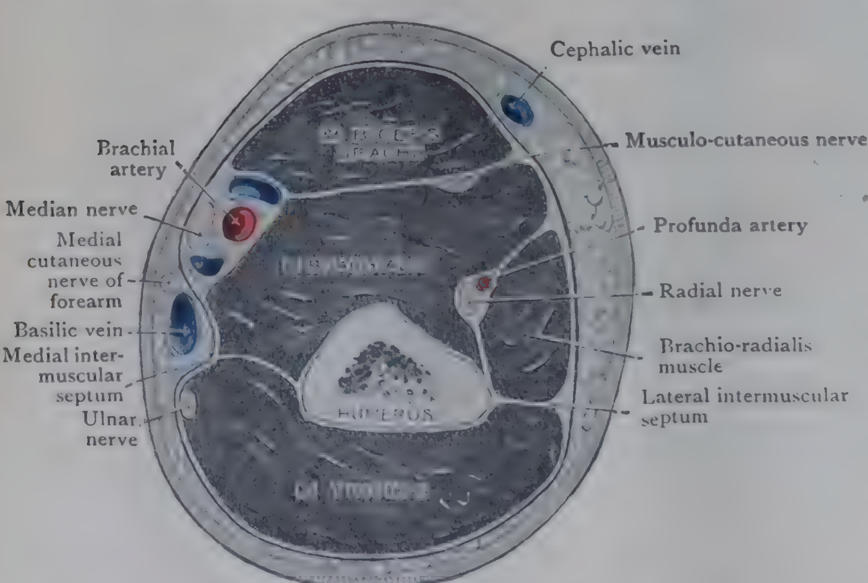


FIG. 419.—SECTION THROUGH DISTAL THIRD OF RIGHT UPPER ARM.

The **intermuscular septa** are processes of the deep fascia attached to the supracondylar ridges of the humerus. The **medial septum** (of the upper arm) is the stronger. It is placed between the brachialis and the medial head of the triceps and gives origin to both (Fig. 418). It extends up to the insertion of the coraco-brachialis (which is often continued into it), and its upper part is pierced by the ulnar nerve and ulnar collateral vessels. The **lateral septum** separates the brachialis and brachio-radialis from the medial and lateral heads of the triceps and gives origin to all of them. It extends up to the insertion of the deltoid, and is pierced by the radial nerve and profunda brachii vessels.

MUSCLES AND FASCIÆ OF FOREARM AND HAND

Muscles on Front and Medial Side of Forearm

The muscles on the front and medial side of the forearm are the pronators and the flexors of the wrist and fingers. In the forearm they are arranged in three strata: (1) A superficial layer of four muscles which radiate from a common tendon attached to the medial epicondyle of the humerus. They are named, from radial to ulnar side, pronator teres, flexor carpi radialis, palmaris longus, and flexor carpi ulnaris. They conceal the muscle which by itself constitutes (2) the middle stratum—the flexor digitorum sublimis. That in turn conceals, for the most part, (3) the deep layer of muscles comprising the flexor digitorum profundus on the ulna, the flexor pollicis longus on the radius, and the pronator quadratus, which is more deeply placed and stretches across the forearm between the distal portions of the radius and ulna.

1. SUPERFICIAL LAYER

Pronator Teres.—The pronator teres, the shortest muscle of this group, has a double **origin.** The **humeral head** forms almost the whole muscle; it arises

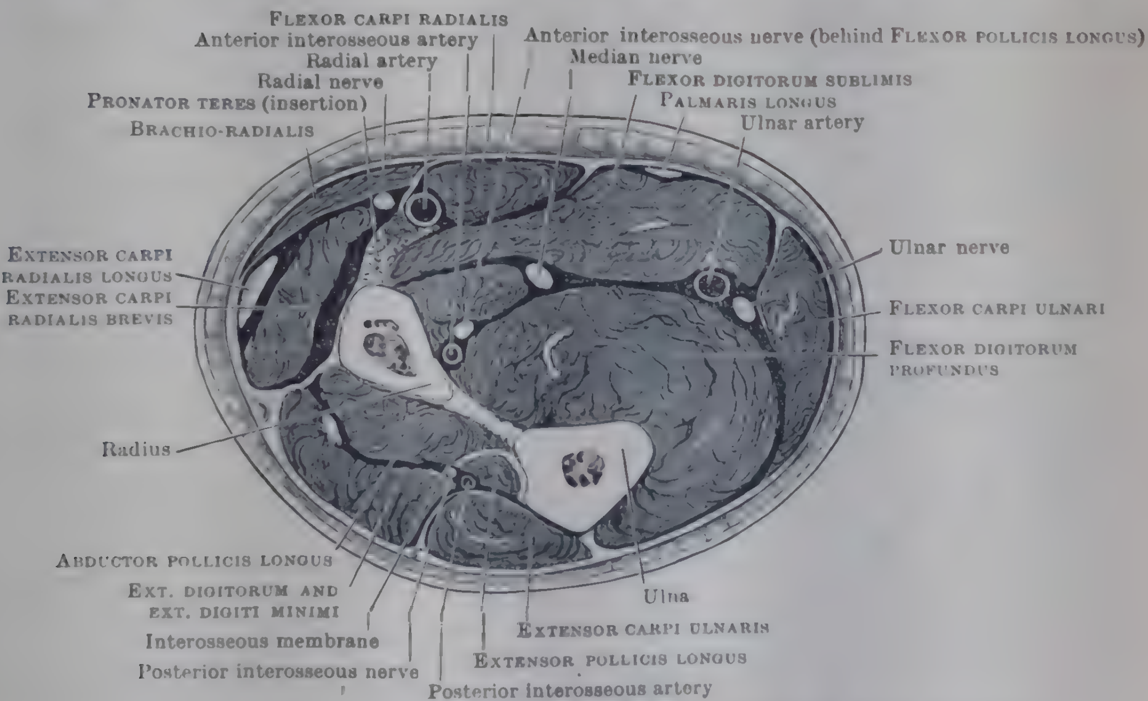


Fig. 420.—Distal Surface of Section through Middle Third of Left Forearm.

by fleshy and tendinous fibres from the lowest part of the medial supracondylar ridge and medial intermuscular septum, from the medial epicondyle of the humerus, from the fascia over it, and from the fascial septum between it and the flexor carpi radialis (Fig. 422). The **ulnar head** is a slender slip that springs from the coronoid process of the ulna and joins the humeral head on its deep surface (Fig. 422). The median nerve passes between the two heads.

The muscle passes downwards and laterally to be **inserted** by a flattened tendon

into an oval impression on the middle of the lateral surface of the shaft of the radius (Figs. 422, 425)—the most superficial humeral fibres passing to the distal part of the tendon of insertion.

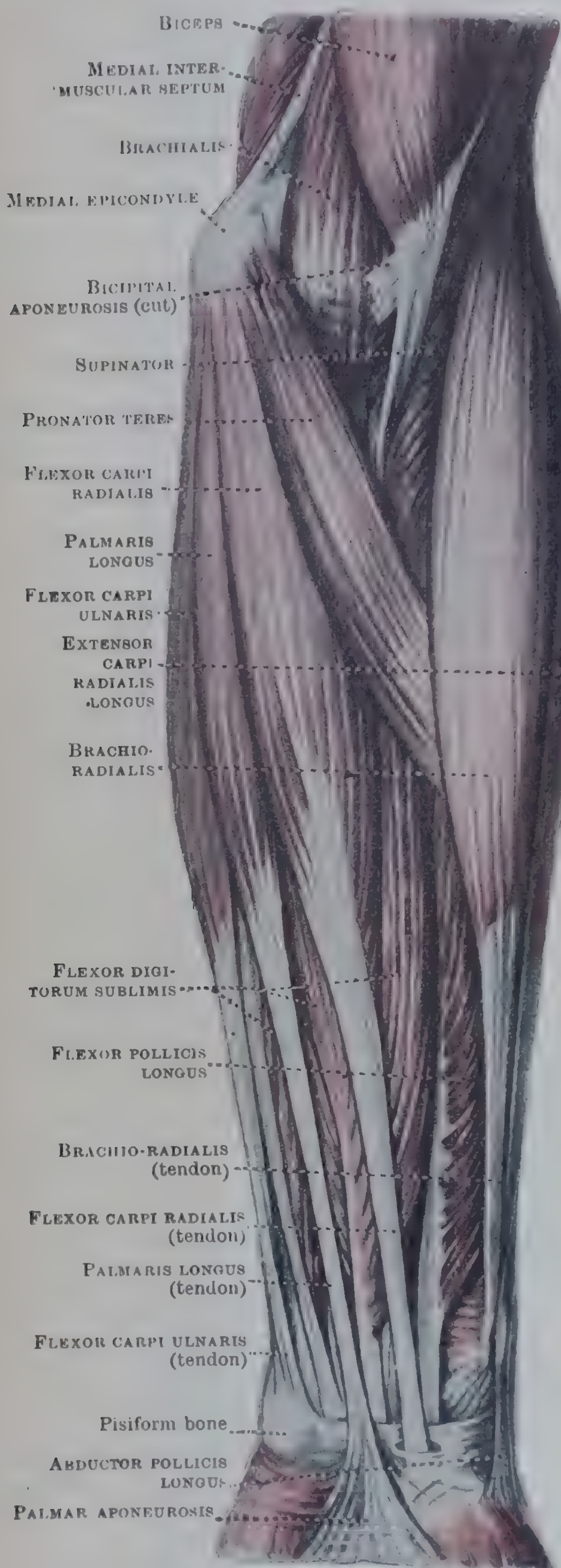


FIG. 421.—SUPERFICIAL MUSCLES OF FRONT OF LEFT FOREARM.

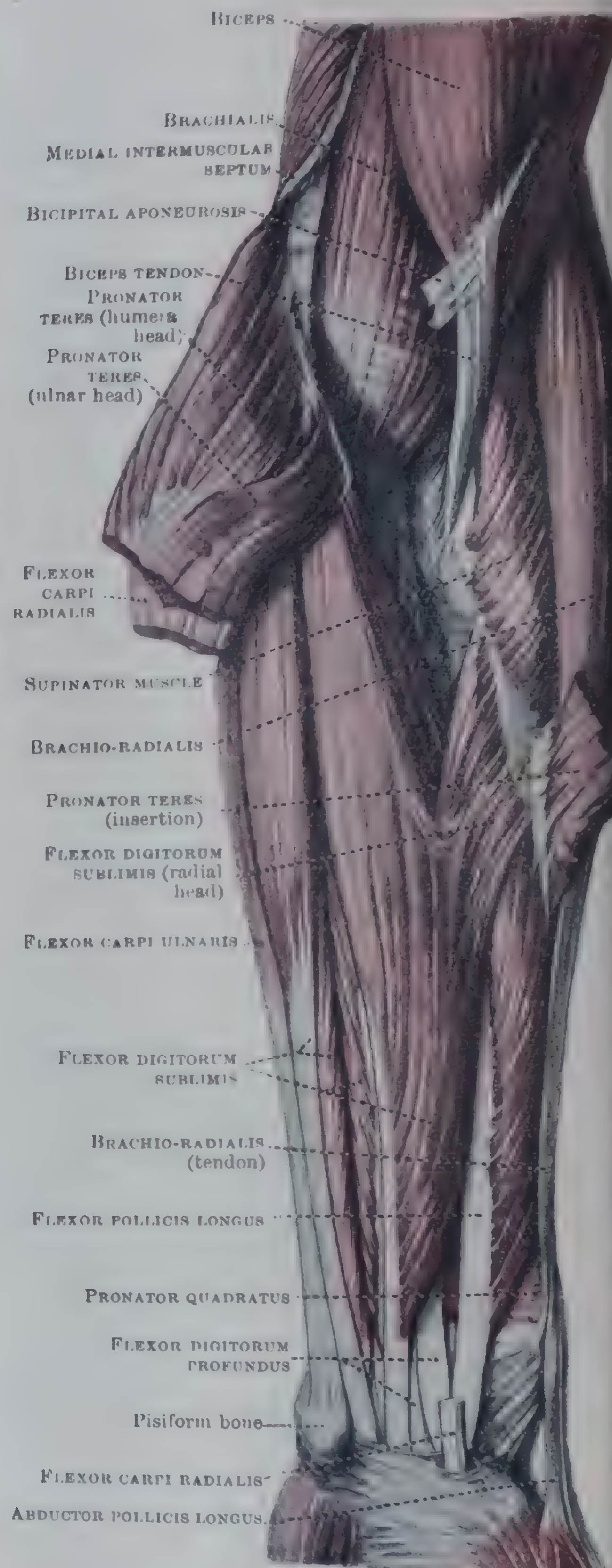


FIG. 422.—DEEPER MUSCLES OF FRONT OF LEFT FOREARM.

The pronator teres forms the medial boundary of the cubital fossa. It is superficially placed except near its insertion, where it is covered by the brachio-radialis muscle and by the radial vessels.

Flexor Carpi Radialis.—The flexor carpi radialis muscle takes **origin** from the medial epicondyle of the humerus by the common tendon, from the fascia

over it, and from the fascial septum on each side. About the middle of the forearm, the fleshy belly gives place to a flattened tendon which becomes more cord-like as it approaches the wrist. Passing into the hand, the tendon enters a special compartment in the lateral border of the flexor retinaculum, which it appears to split into two layers as it lies in the groove on the trapezium surrounded by a synovial sheath. Finally, it is **inserted** into the base of the second metacarpal bone and usually into the base of the third.

The muscle is superficial except near its insertion. Its tendon, in the distal half of the forearm, is an important guide to the radial vessels, which are placed to its radial side. After passing through the flexor retinaculum the tendon is concealed by the origins of the short muscles of the thumb, and is crossed, from medial to lateral side, by the tendon of the flexor pollicis longus. Besides the synovial sheath that envelops the tendon on the trapezium, a synovial *bursa* is placed behind the tendon at its insertion.

Palmaris Longus.—The palmaris longus also **arises** from the medial epicondyle of the humerus by the common flexor tendon, from the deep fascia, and the septum on each side. The fleshy belly is short and fusiform, and it ends at the middle of the forearm in a long, flat tendon. The tendon passes superficial to the flexor retinaculum and is **inserted** (1) into the surface of that band and (2) into the apex of the palmar aponeurosis. A tendinous slip is frequently sent to the short muscles of the thumb and the fascia covering them.

The palmaris longus is the most slender of the muscles of the front of the forearm. In the distal part of the forearm, the median nerve is behind its tendon, at the radial border of the tendons of the flexor digitorum sublimis.

The palmaris longus is the most variable muscle in the body, and is often absent (about 11 per cent). It represents a flexor of the proximal phalanges, but in Man it has become very much reduced, owing to differentiation of the other digital flexors and to finer control of the movements of the fingers by the lumbricals and interossei.

Flexor Carpi Ulnaris.—The flexor carpi ulnaris muscle **arises** by two heads—humeral and ulnar—joined by a tendinous arch, under cover of which the ulnar nerve enters the forearm. (1) The **humeral head** springs from the medial epicondyle of the humerus by the common tendon, from the covering fascia, and from a lateral intermuscular septum. (2) The **ulnar head**, by means of the deep fascia of the forearm, obtains an origin from the medial border of the olecranon and the posterior border of the ulna in its upper three-fifths. The fleshy fibres join a tendon which runs down the anterior border of the distal half of the muscle to be **inserted** into the pisiform bone, and thence, in the form of two ligamentous bands (piso-hamate and piso-metacarpal), into the hook of the hamate bone and the proximal end of the fifth metacarpal bone (Fig. 431, p. 505); a small slip often passes to the flexor retinaculum.

The muscle is superficially placed along the medial border of the forearm. It conceals the ulnar nerve and vessels (which lie on the lateral side of the tendon of insertion). The tendon serves as a guide to these structures in the distal half of the forearm.

M. Epitrochleo-anconeus.—This small muscle is seldom present; it **arises** from the back of the medial epicondyle and is **inserted** into the olecranon; it is usually represented by a band of transverse fibres in the fascia.

2. MIDDLE LAYER

Flexor Digitorum Sublimis.—The flexor digitorum sublimis **arises** by two heads—humero-ulnar and radial—connected by a fibrous bridge that crosses the median nerve and ulnar vessels. (1) The **humero-ulnar head**—the chief origin—springs from the medial epicondyle of the humerus by the common tendon, from adjacent fascial septa, from the medial ligament of the elbow joint, and by a slender slip from the medial border of the coronoid process (Fig. 425). (2) The **radial head** is a thin fibro-muscular sheet that takes origin from the upper two-thirds of the **anterior border** of the radius (Fig. 425).

In the distal third of the forearm the muscle gives rise to four tendons, one for each of the medial four digits. Those for the middle and ring fingers lie side by side and are superficial to the tendons for the index and the little finger. The upper part of the muscle is similarly divisible into two strata, of which the more superficial comprises the radial head and part of the humeral head. The whole of the radial head is usually destined for the middle finger alone, but sometimes also acts on the ring finger. The same arrangement holds at the wrist, where the tendons pass under cover of the flexor retinaculum and are enclosed in a large synovial sheath together with the tendons of the flexor digitorum profundus, which lie behind them.

Under cover of the palmar aponeurosis the tendons diverge. In company with the corresponding tendon of the deep flexor, each enters the fibrous flexor sheath of its own digit. Opposite the proximal phalanx each tendon splits into two parts which pass, with a spiral twist, round the sides of the tendon of the flexor profundus to be **inserted** into the margins of the palmar surface of the middle phalanx. The reversed edges of the two portions of the split tendon are partially

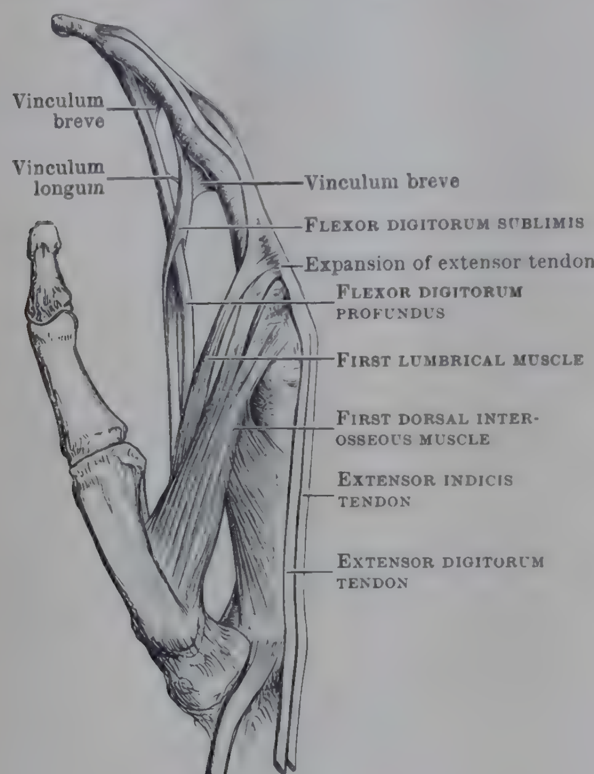


FIG. 423.—THE TENDONS ATTACHED TO THE INDEX FINGER.

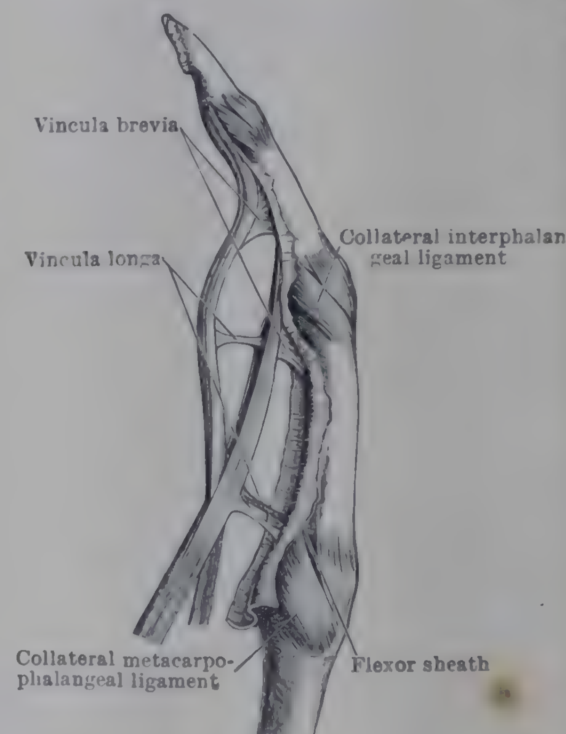


FIG. 424.—FLEXOR TENDONS OF FINGER WITH VINCULA TENDINUM.

reunited by decussating fibres behind the tendon of the flexor profundus: the oblique, tubular passage thus made in the tendon of the flexor sublimis, for the passage of the profundus tendon, is such that it cannot be obliterated by tension.

The **vincula tendinum** form additional attachments of the tendons, to which they also convey small blood-vessels. They are delicate bands of fibrous tissue enveloped in folds of the synovial sheath, and they are known as the **vincula longa** and **brevia**. Each vinculum breve is a triangular band of fibres containing yellow elastic tissue; it occupies the interval between the tendon and the digit for a short distance close to the insertion. It is attached to the front of the interphalangeal joint and the distal part of the proximal phalanx. The vinculum longum is a variable, narrow, double band that extends from the back of the tendon to the proximal part of the palmar surface of the proximal phalanx.

The upper part of the muscle lies deep to the brachio-radialis, pronator teres, flexor carpi radialis, palmaris longus and flexor carpi ulnaris: the lower part lies between the flexor carpi radialis and flexor carpi ulnaris, and is overlapped by the palmaris longus alone. It is crossed by the radial vessels, and it crosses the ulnar vessels and nerve. At the wrist, the tendons are medial to the tendon of flexor pollicis longus and the median nerve. In the hand, the tendons are superficial to the tendons of the flexor digitorum profundus and the lumbrical muscles,

and deep to the superficial palmar arch and the digital branches of the median and ulnar nerves.

3. DEEP LAYER

Flexor Digitorum Profundus.—The flexor digitorum profundus is a large muscle that **arises** from the ulna, the interosseous membrane, and the deep fascia of the forearm, under cover of the flexor digitorum sublimis and the flexor carpi ulnaris. The ulnar origin is the upper two-thirds of the medial and anterior surfaces of the ulna—reaching the medial side of the olecranon and embracing the insertion of the brachialis at the upper end and extending almost to the pronator quadratus below. It arises also, laterally, from the medial half of the interosseous membrane in its middle third (Figs. 425, 426), and medially from the deep fascia which attaches the flexor carpi ulnaris to the posterior border of the ulna.

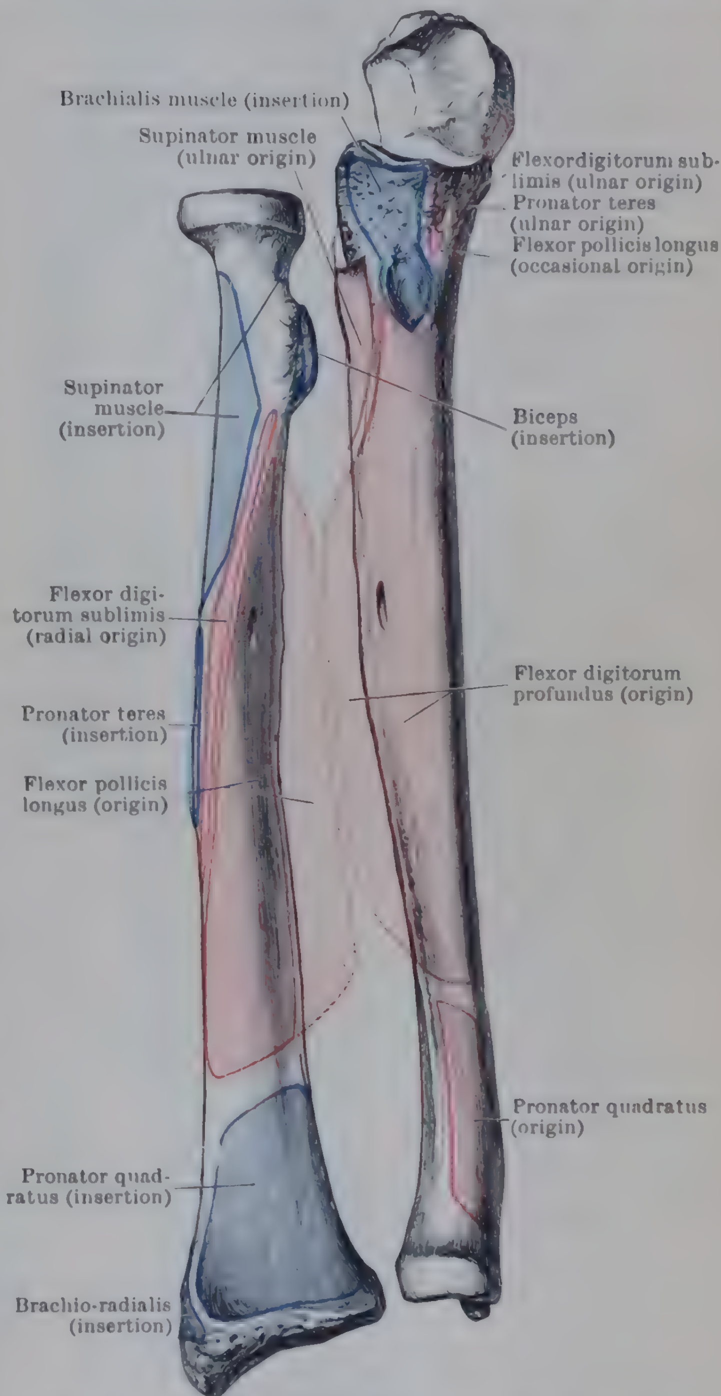


FIG. 425.—MUSCLE-ATTACHMENTS TO FRONT OF RIGHT RADIUS AND ULNA.

The muscle becomes a broad thick tendon which lies behind the tendons of the flexor digitorum sublimis and is enveloped with them in the common flexor synovial sheath; with them it descends behind the flexor retinaculum into the palm, where it divides into separate tendons for **insertion** into the distal phalanges of the four fingers. The tendon for the forefinger is, however, usually separate in its whole length, and it is mainly derived from those fibres which arise from the interosseous membrane.

Each tendon enters the fibrous flexor sheath of the finger, deep to the tendon of the flexor digitorum sublimis, which it pierces opposite the proximal phalanx, and is finally inserted into the base of the distal phalanx. Like the tendons of the flexor sublimis, those of the deep flexor are provided with **vincula**, viz., **vincula brevia** attached to the capsule of the second interphalangeal joint and **vincula longa** connected to the tendons of the flexor digitorum sublimis and their vincula brevia (Fig. 424).

Lumbricals.—The lumbricals are four small, cylindrical muscles associated with the tendons of the flexor digitorum profundus in the palm of the hand. *The lateral two muscles* **arise**, each by a single head, from the radial sides of the tendons of the flexor digitorum profundus destined respectively for the forefinger and middle finger; *the medial two muscles* **arise**, each by two heads, from the

adjacent sides of the tendons between which they lie (viz., the tendons of the middle, ring, and little fingers).

Each lumbrical becomes a slender, flattened tendon which passes obliquely backwards across the lateral side of the corresponding metacarpo-phalangeal joint in front of the deep transverse ligament of the palm and, becoming connected with the expansion of the extensor tendon, it is **inserted** with the tendon of an interosseous muscle into the base of a terminal phalanx. The lumbricals may be increased to six or diminished to two.

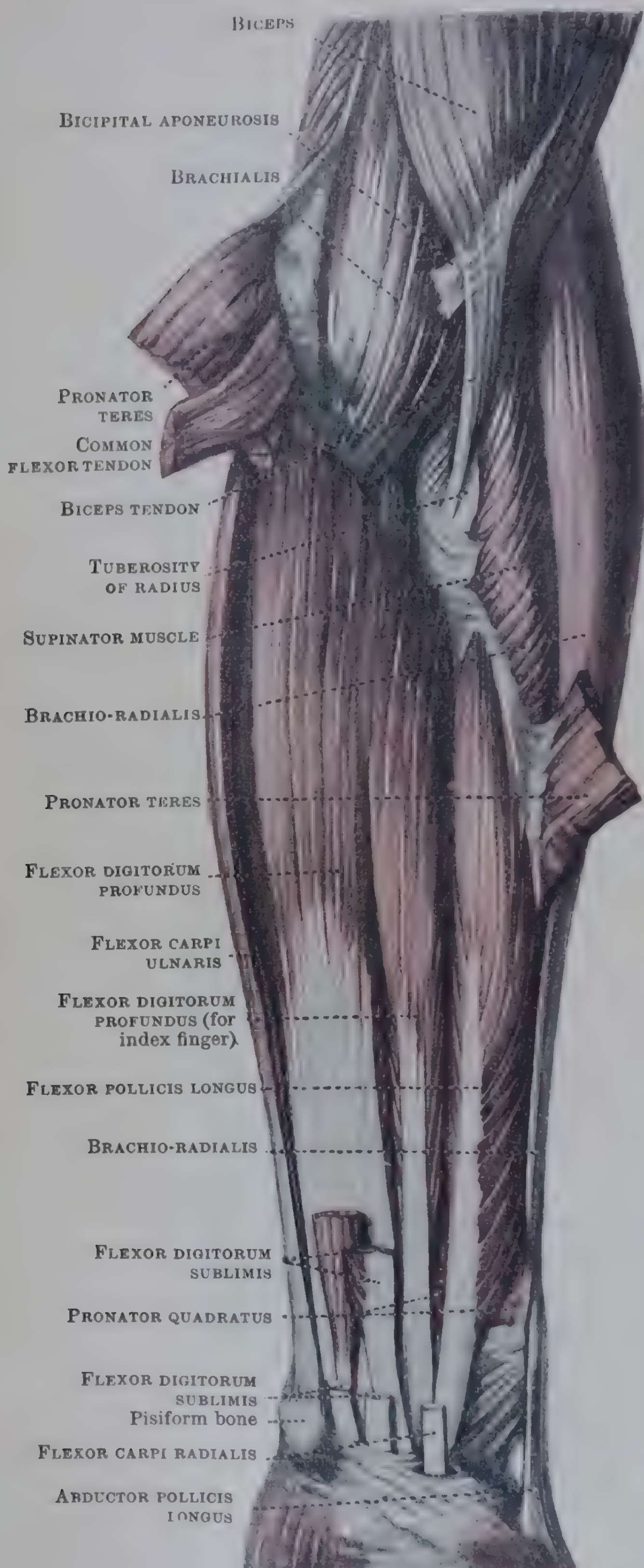


Fig. 426.—Deepest Muscles of Front of Left Forearm.

Flexor Pollicis Longus.—The flexor pollicis longus **arises**, by fleshy fibres, from the anterior surface of the shaft of the radius between the radial tuberosity and the upper border of the pronator quadratus, and also from a corresponding portion of the interosseous membrane. Usually it has a slip that arises in common with the flexor digitorum sublimis from the medial border of the coronoid process or the medial epicondyle, or from both.

Distally, the muscle is placed between the brachio-radialis laterally, the overlapping flexor carpi radialis medially, and the radial vessels anteriorly, while the anterior interosseous nerve and vessels descend on the interosseous membrane between the flexor pollicis longus and flexor digitorum profundus.

The muscle ends above the wrist in a tendon which passes in front of the pronator quadratus into the hand behind the flexor retinaculum, enveloped in a special synovial sheath.

In the hand, the tendon, directed downwards along the medial side of the thenar eminence between the flexor brevis and adductor muscles of the thumb, and between the two sesamoid bones of the metacarpo-phalangeal joint, enters a fibrous sheath to be **inserted** into the base of the distal phalanx of the thumb on its palmar surface.

Pronator Quadratus. — The pronator quadratus is a quadrilateral fleshy muscle that lies deeply in the distal part of the forearm behind the flexor tendons and the radial vessels. It **arises** from the distal fourth of the anterior border and surface of the ulna, and its fibres run transversely to be **inserted** into the distal fourth of the anterior surface of the radius, and into the narrow triangular area on its medial side in front of the attachment of the interosseous membrane (Fig. 235, p. 262).

The pronator quadratus is subject to considerable variation. It frequently consists of two strata separated by the terminal part of the anterior interosseous nerve; it may be increased in size, having an additional origin from radius or ulna, or from both bones, and an insertion into the carpus; it may even be absent. (In most of the lower mammals the two pronators form one muscle.)

Muscles on Back of Forearm

The muscles at the lateral side of the elbow and on the back of the forearm and hand are the supinator muscles of the forearm and the extensors of the wrist and digits, and they are divisible into a **superficial** and a **deep layer**.

The muscles of the **superficial layer**—seven in number and named from radial to ulnar side — are the brachio-radialis, the two radial extensors of the carpus, the extensor digitorum and extensor digiti minimi, the extensor carpi ulnaris, and the anconeus. With the exception of the brachio-radialis, extensor carpi radialis longus and the anconeus, they share a common tendon of origin, which is attached to the front and lateral border of the lateral epicondyle of the humerus (Fig. 415, p. 489).

Five muscles make up the **deep layer**: one —the supinator — extends between the proximal parts of the ulna and radius; the others are the special extensors of the thumb and forefinger, viz., the abductor pollicis longus, extensor pollicis longus and extensor pollicis brevis, and extensor indicis. They cover the posterior surface of the bones of the forearm and the interosseous membrane, and they are wholly concealed by the superficial muscles, with the exception of the abductor pollicis longus and the extensor pollicis brevis, which emerge between the radial extensors of the carpus and the extensor digitorum and become superficial in the distal part of the forearm.

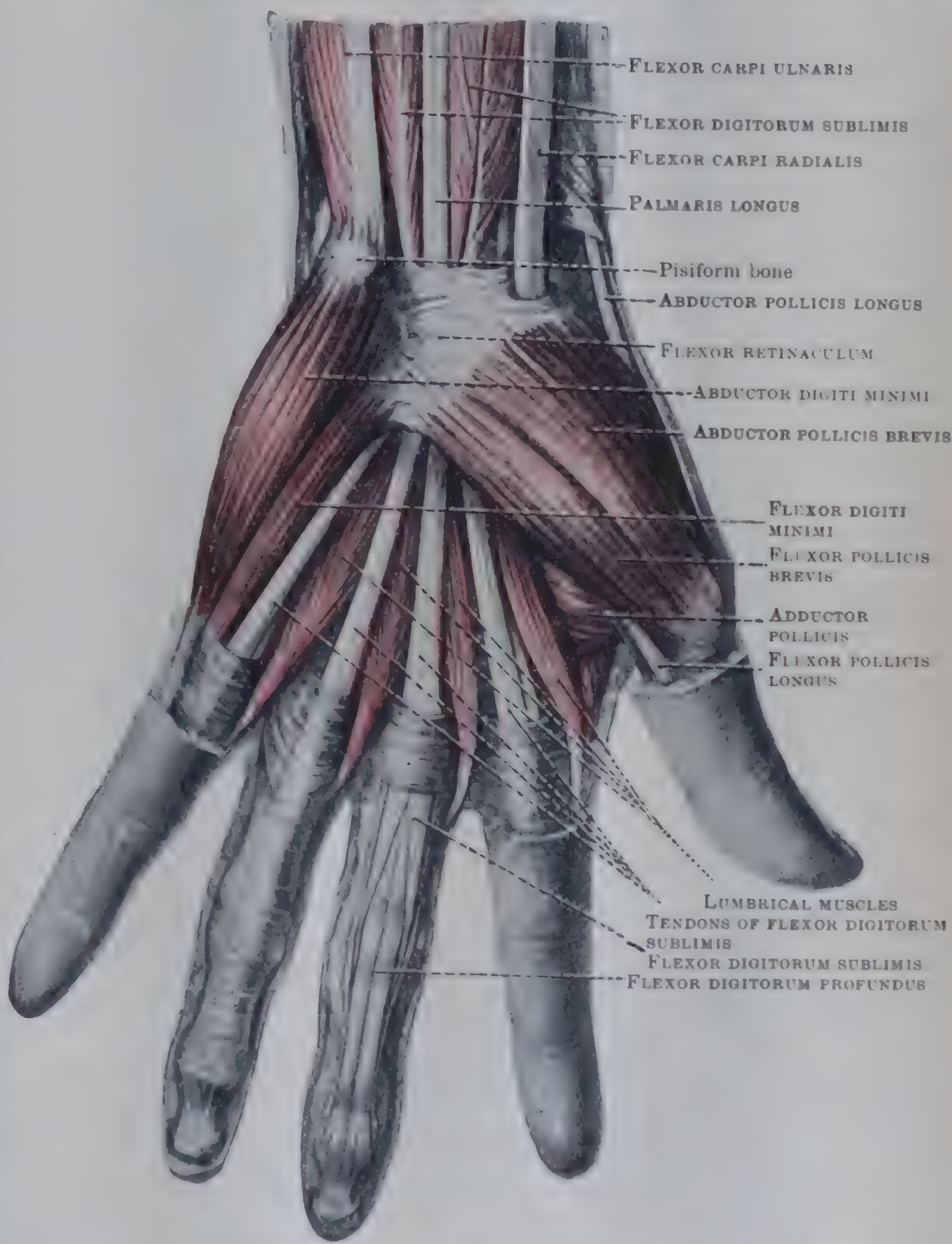


FIG. 427.—SUPERFICIAL MUSCLES AND TENDONS IN PALM OF LEFT HAND.

1. SUPERFICIAL LAYER

Brachio-Radialis.—The brachio-radialis **arises**, by fleshy fibres, from the proximal two-thirds of the front of the lateral supracondylar ridge of the humerus and the adjoining part of the lateral intermuscular septum—the radial nerve and anastomosing vessels intervening between it and the brachialis. Descending along the lateral border of the forearm, the muscle bounds the cubital fossa laterally, and ends about the middle of the forearm in a narrow flat tendon which is **inserted**, under cover of the tendons of the abductor pollicis longus and extensor pollicis brevis, into the lateral side of the lower end of the radius (Figs. 425, 428).

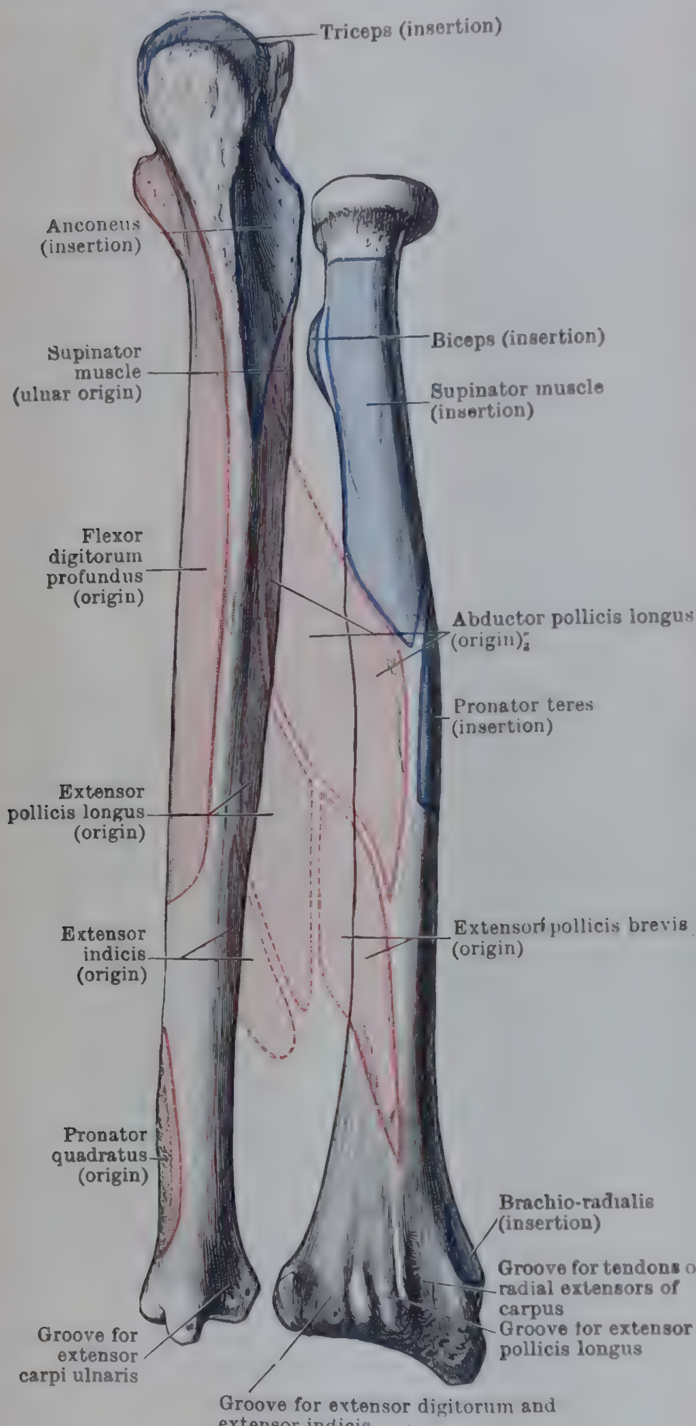


Fig. 428.—Muscle-Attachments to Back of Right Radius and Ulna.

Extensor Carpi Radialis Longus.—The extensor carpi radialis longus **arises**, by fleshy fibres, from the distal third of the front of the lateral supracondylar ridge of the humerus and from the adjoining part of the lateral intermuscular septum (Figs. 415 and 429).

In its upper part, the muscle lies close to the lateral side of the elbow joint, overlapped by the brachio-radialis and overlapping the extensor carpi radialis brevis, between which it descends into the forearm. About the middle of the forearm it ends in a flat tendon which, throughout, is closely applied to the lateral side of the extensor carpi radialis brevis; and as the two tendons descend they are crossed obliquely by the abductor pollicis longus and extensor pollicis brevis. Still side by side they pass under cover of the extensor retinaculum, where they are enclosed in a single synovial sheath and groove the distal end of the radius, and there are crossed obliquely by extensor pollicis longus; finally, the long extensor is **inserted** into the dorsal surface of the base of the second metacarpal bone on its radial side. A small *bursa* may be found under the tendon close to its insertion.

Extensor Carpi Radialis Brevis.—The extensor carpi radialis brevis **arises** from the common tendon, from the lateral ligament of the elbow joint, from the covering fascia, and from the intermuscular septum on each side. Accompanied by its long companion (the two are represented by one muscle in the lower mammals), it descends as just described, to be **inserted**, by a tendon, into the base of the third metacarpal bone—a small *bursa* lying between the tendon and the styloid process of the metacarpal bone. The tendons of the long and short radial

extensors of the wrist may split and both be attached to the second and third (Fig. 434) and sometimes the fourth metacarpal bones.

Extensor Digitorum.—The extensor digitorum lies between the radial extensors

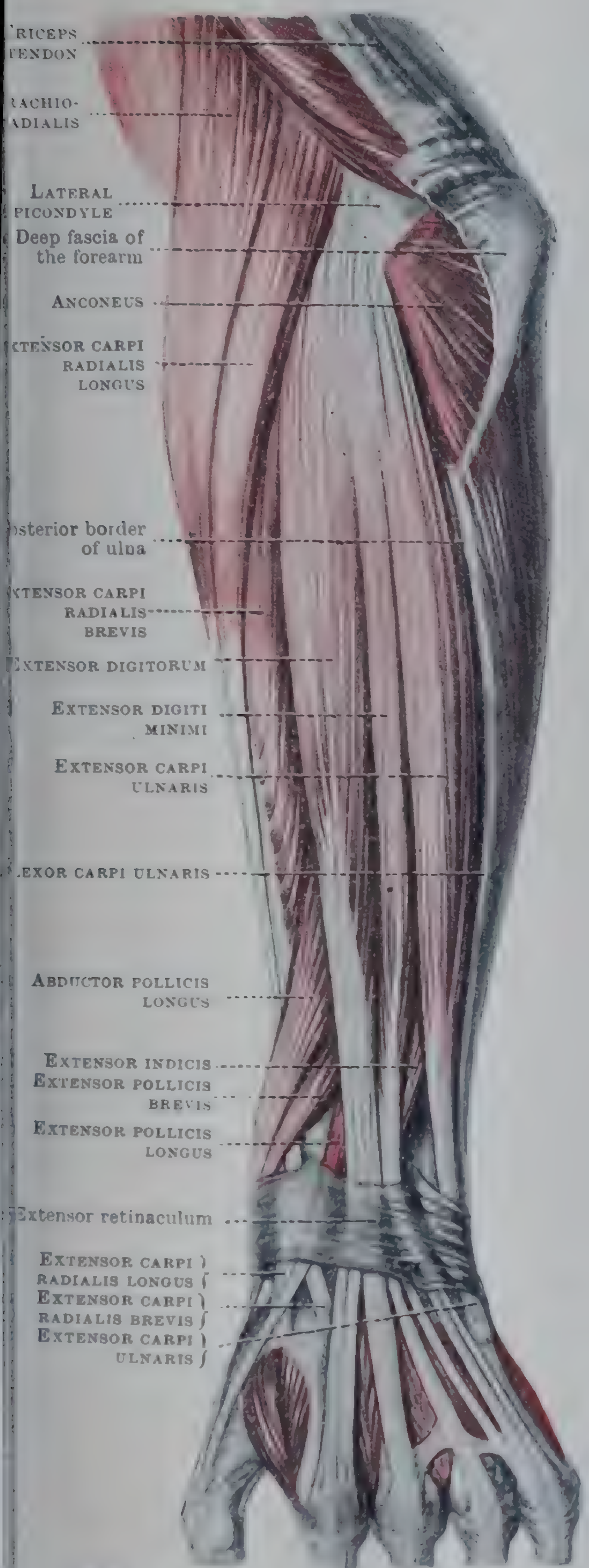


FIG. 429.—SUPERFICIAL MUSCLES ON DORSUM OF LEFT FOREARM.

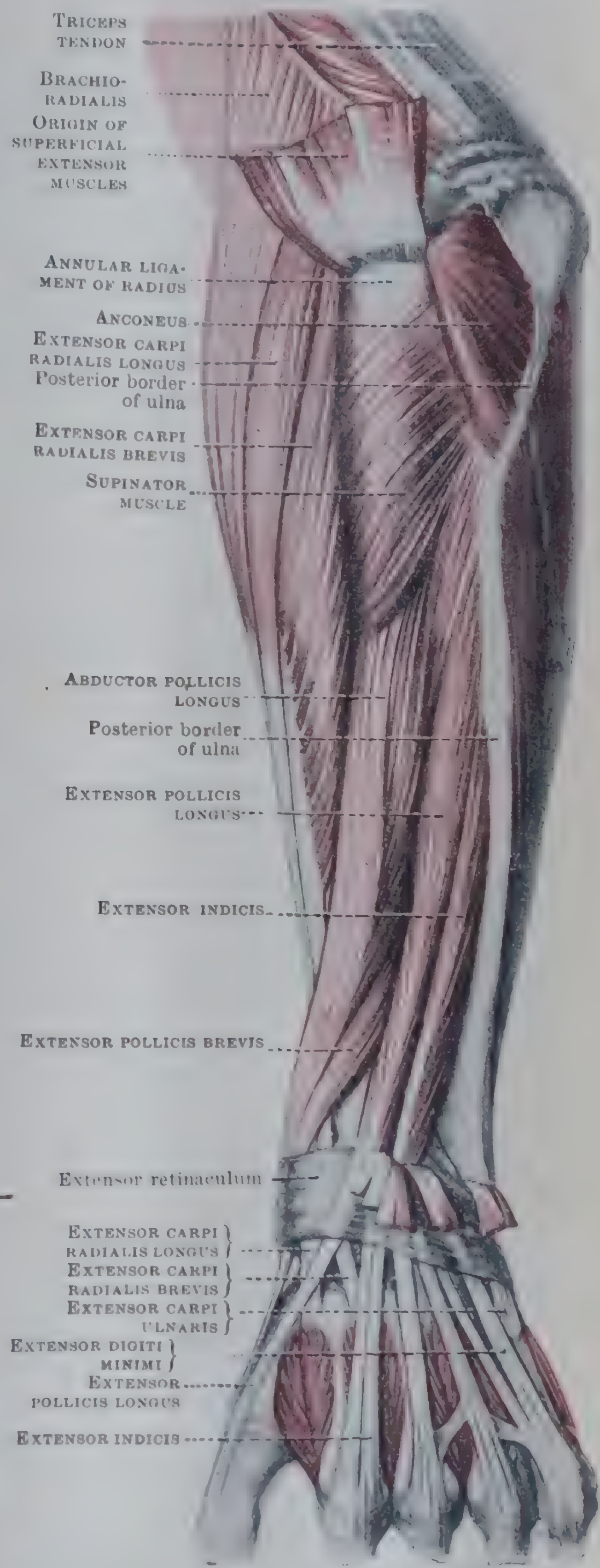


FIG. 430.—DEEP MUSCLES ON DORSUM OF LEFT FOREARM.

of the carpus and the extensor digiti minimi (Fig. 429). It **arises** from the common tendon, from the fascia over it, and from the intermuscular septa at its sides. Extending along the back of the forearm, it ends above the wrist in four tendons of which the most lateral often has a separate fleshy belly. After passing deep to

the extensor retinaculum, surrounded by a synovial sheath in the same compartment as the extensor indicis, the tendons separate on the back of the hand, where they are joined together in a variable manner by obliquely placed bands. One band passes downwards and laterally, and connects together the third and second tendons; another band, broader and shorter, passes downwards and medially, and joins the third to the fourth tendon. A band sometimes passes downwards and medially from the first to the second tendon; and, frequently, the tendon for the little finger is joined to the tendon for the ring finger, and separates from it only a short distance above the distal end of the metacarpal bone.

The tendons are **inserted** in the following manner: On the finger each tendon spreads out to form a membranous expansion over the knuckle and on the dorsum of the proximal phalanx. The border of the tendon is indefinite over the metacarpo-phalangeal joint, the dorsal ligament of which it replaces. On the back of the proximal phalanx the tendon receives at its sides the tendons of the interosseous and lumbrical muscles. At the distal end of the proximal phalanx it appears to split into ill-defined middle and collateral slips which pass over the back of the first interphalangeal joint, where they replace the dorsal ligament. The middle slip, which is directly continuous with the extensor tendon itself, is inserted into the dorsum of the base of the middle phalanx. The two collateral pieces are continuous with the tendons of the lumbrical muscles and the interossei; they all become united to form a membranous tendon on the back of the middle phalanx, which, after passing over the second interphalangeal joint, is inserted into the base of the distal phalanx.

Extensor Digiti Minimi.—The extensor digiti minimi **arises**, like the preceding muscle, from the common tendon, the fascia over it, and from intermuscular septa. It descends as a narrow fleshy slip between the extensor digitorum and the extensor carpi ulnaris, and ends in a tendon which occupies a groove between the radius and ulna in a special compartment of the extensor retinaculum and is enveloped in a long synovial sheath. On the back of the hand, the tendon is split into two parts, of which the more lateral is joined by the most medial tendon of the extensor digitorum, and both are **inserted** into the expansion of the extensor tendon on the back of the proximal phalanx of the little finger.

Extensor Carpi Ulnaris.—The extensor carpi ulnaris has a double **origin**: (1) from the lateral epicondyle of the humerus by the common tendon, from the fascia over it, and from the intermuscular septa; and (2), through the medium of the deep fascia, from the posterior border of the ulna in its middle two-fourths.

In the forearm it lies on the medial part of the posterior surface of the ulna; and it ends in a tendon which is enclosed in a synovial sheath and traverses a groove on the back of the lower end of the ulna in a special compartment of the extensor retinaculum, and is **inserted** into the medial side of the base of the fifth metacarpal bone (Fig. 434, p. 508).

2. DEEP LAYER

Supinator.—The supinator muscle is the highest of the deep layer, and is almost wholly concealed by the superficial muscles. It has a complex **origin**—(1) from the lateral epicondyle of the humerus; (2) from the lateral ligament of the elbow joint and the annular ligament of the radius; and (3) from the supinator crest and fossa of the ulna (Fig. 425, p. 497).

From that origin the muscle, spreading laterally and downwards behind the upper third of the radius, which it envelops almost completely, is **inserted** into its lateral surface which, in the upper third, encroaches on both the back and front of the bone. The attachment extends as far forwards as the tuberosity of the radius, as far upwards as the neck, and as far downwards as the oblique part of the anterior border and the insertion of the pronator teres (Figs. 425, p. 497, and 428).

The muscle is divisible into *superficial* and *deep layers*, with humeral and ulnar origins, between which the posterior interosseous nerve passes in its course to the back of the forearm.

Abductor Pollicis Longus.—The abductor pollicis longus **arises**, by fleshy fibres, distal to the supinator muscle, from the uppermost of the narrow impressions on the lateral half of the posterior surface of the ulna; from the middle third of the posterior surface of the radius, and from the intervening portion of the interosseous membrane (Fig. 428).

The muscle passes obliquely downwards and laterally, and it emerges between the radial extensors of the wrist and the extensor of the fingers to become superficial in the distal part of the forearm. With the extensor pollicis brevis tendon closely applied to its medial side, the tendon crosses extensor carpi radialis brevis and longus and covers the insertion of the brachio-radialis before passing through the most lateral compartment of the extensor retinaculum in a synovial sheath which communicates with that of extensor pollicis brevis. Then, covering the styloid process of the radius and the lateral ligament of the wrist joint, but separated from the ligament by the radial artery, it is **inserted** (sometimes by two tendons) into the lateral side of the base of the first metacarpal bone (Fig. 431). Close to its insertion, a tendinous slip passes from it to the abductor pollicis brevis and the fascia over the thenar eminence, and frequently another is attached to the trapezium.

Extensor Pollicis Brevis.—The extensor pollicis brevis, an essentially human muscle, is a specialized portion of the abductor longus. It **arises** from a rhomboid impression on the posterior surface of the radius, and from the interosseous membrane, distal to the abductor pollicis longus (Fig. 428). It is closely adherent to that muscle, and accompanies it, deep to the extensor retinaculum and over the radial artery, to the thumb. Its tendon is then continued along the back of the first metacarpal bone to be **inserted** into the dorsal surface of the base of the proximal phalanx of the thumb. Before reaching its insertion the tendon helps to form the capsule of the metacarpo-phalangeal joint.

Extensor Pollicis Longus.—The extensor pollicis longus **arises** from the lateral part of the posterior surface of the ulna in its middle third, and from the interosseous membrane distal to the abductor pollicis longus and overlapping the extensor pollicis brevis. Its tendon is enclosed in a synovial sheath and grooves the posterior surface of the radius as it descends through a special compartment of the extensor retinaculum (Figs. 428, 430). Extending obliquely across the back of the hand, the tendon crosses the tendons of the radial extensors of the carpus and the radial artery, helps to form the capsule of the first metacarpo-phalangeal joint, and is **inserted** into the dorsal surface of the base of the distal phalanx of the thumb.

At the wrist, the tendons of the muscles of the thumb—the abductor pollicis longus and extensor pollicis brevis laterally, and the extensor pollicis longus medially—bound a hollow (the "anatomical snuff-box") seen best when the thumb is extended. In this situation the pulsation of the radial artery can readily be felt.

Extensor Indicis.—The extensor indicis **arises**, distal to the extensor pollicis longus, from the lowest impression on the posterior surface of the ulna, and sometimes also from the interosseous membrane (Fig. 428). Its tendon passes through a compartment of the extensor retinaculum enclosed with the tendons of the extensor digitorum in a common synovial sheath. On the back of the hand the tendon lies on the ulnar side of the tendon of the extensor digitorum destined for the forefinger; and it is **inserted** into the membranous expansion of that tendon on the back of the proximal phalanx.

Nerve-Supply.—The muscles on the front (flexor surface) of the forearm are supplied, through the **median** and **ulnar nerves**, by the anterior—*i.e.*, lateral and medial—cords of the brachial plexus; and those on the back (extensor surface) by the posterior cord through the **radial nerve** and its **posterior interosseous** branch. The pronator teres (C. 6), flexor carpi radialis (C. 6), palmaris longus and flexor digitorum sublimis (C. 7, 8, T. 1) are all supplied by direct branches from the median nerve; the flexor pollicis longus and the pronator quadratus by its anterior interosseous branch (C. (7), 8, T. 1), and the flexor carpi ulnaris by the ulnar nerve (C. 8, T. 1). The flexor digitorum profundus and the associated lumbricals are supplied in a corresponding manner by nerves derived from the two main sources. The lateral part of the deep flexor is supplied by the interosseous branch of the median nerve (C. (7), 8, T. 1) and the lateral two lumbricals by twigs from digital branches of the median nerve (C. (7), 8, T. 1) in the hand; the

medial part of the deep flexor is supplied by the ulnar nerve (C. 8, T. 1) and the medial two lumbricals by twigs from the deep branch of the same nerve in the hand. The branches to the brachio-radialis (C. (5), 6) and the extensor carpi radialis longus (C. (5), 6, 7, (8)) are given off by the radial nerve itself above the elbow; the extensor carpi radialis brevis (C. (5), 6, 7, (8)) and the supinator (C. (5), 6) are supplied by branches of the posterior interosseous nerve before it pierces the supinator; all the remaining muscles are supplied by the posterior interosseous nerve (C. (6), 7, (8)) after it has pierced the supinator.

Actions of Muscles in Movements at the Radio-Ulnar Joints: Pronation and Supination.—The movement of pronation is performed by the **pronator** muscles—**teres** and **quadratus**—and of supination by the **biceps** and the **supinator**; other muscles which pass obliquely across the forearm from the ulnar to the radial side take part in these actions when they are performed against resistance—the **flexor carpi radialis** and **palmaris longus** assisting in pronation and the **extensors of the thumb** in supination. Both sets of muscles act at best advantage when the elbow is flexed to a right angle. The brachio-radialis also may act as a semi-pronator and semi-supinator as already mentioned. See also p. 492.

Actions of Muscles in Movements at the Wrist Joint.—The movements at the wrist joint are flexion and extension, abduction and adduction of the hand. The **radial and ulnar flexors and extensors of the carpus** are the muscles primarily concerned in these movements—abduction and adduction being performed by the combined action of the flexors and extensors of the radial and ulnar sides respectively. Other muscles of the forearm also assist in those actions.

The **flexores carpi radialis** and **ulnaris** act primarily to flex the wrist, assisted by the **palmaris longus** and by the **flexors of the fingers** (**sublimis** and **profundus**) when the movement is effected against strong resistance (Pl. XLII, Fig. 2, p. 513). The **abductor pollicis longus** also is a flexor of the wrist, being capable of performing this movement when the other flexors are paralysed.

The muscles primarily concerned in extension at the wrist are the **radial extensors of the carpus** (**longus** and **brevis**) and the **extensor carpi ulnaris**. The extensors of the fingers also act at the wrist joint.

Abduction of the hand is produced by the co-operation of the **flexor carpi radialis** with the **radial extensors of the carpus**, assisted by the **long abductor** and the **extensors of the thumb.** Adduction of the hand is similarly produced by the co-operation of the **flexor** and the **extensor carpi ulnaris**.

The flexor and extensor muscles of the carpus have, in addition to the actions just detailed, important synergic actions at the wrist joint. The flexor carpi radialis and flexor carpi ulnaris together steady the wrist during the extension of the fingers, *i.e.*, they are synergic muscles for the extensors of the digits. The flexor carpi ulnaris also steadies the pisiform bone during contractions of the abductor digiti minimi. The radial extensors of the carpus in association with the extensor carpi ulnaris are similarly synergic muscles for flexion of the fingers, as they counteract the effect which the digital flexors would otherwise produce at the wrist (cf. p. 407).

SHORT MUSCLES OF HAND

The short or intrinsic muscles of the hand (in addition to the lumbrical muscles, and a subcutaneous muscle called the palmaris brevis) are the four short muscles of the thumb (three of which form the thenar eminence), the three short muscles of the little finger, which form the hypothenar eminence, and the interosseous muscles, which are placed between the metacarpal bones.

Short Muscles of Thumb

The short muscles of the thumb are the abductor pollicis brevis, the opponens pollicis, and the flexor pollicis brevis, which form the thenar eminence, and the adductor pollicis, which lies deeply in the palm of the hand.

Abductor Pollicis Brevis.—The abductor pollicis brevis **arises**, by fleshy fibres, mainly from the anterior surface of the flexor retinaculum but also from the tubercle of the scaphoid bone, the crest of the trapezium and from tendinous slips derived from the insertions of the palmaris longus and abductor pollicis longus muscles (Fig. 427, p. 499). Strap-like in form and superficial in position, it is **inserted** by a short tendon into the radial side of the proximal phalanx of the

thumb at its upper end, and into the lateral border of the tendon of the extensor pollicis longus muscle.

Opponens Pollicis.—The opponens pollicis is partially concealed by the abductor, and is united with the flexor pollicis brevis, which lies along its medial side. It **arises**, by fleshy and tendinous fibres, from the anterior surface of the flexor retinaculum and from the crest on the trapezium; and it is **inserted** into the whole length of the radial border and the radial half of the anterior surface of the first metacarpal bone.

Flexor Pollicis Brevis.—The flexor pollicis brevis, also partly concealed by the abductor, **arises** by fleshy and tendinous fibres from the distal border of the flexor retinaculum, and sometimes from the crest of the trapezium. It is **inserted** into the radial side of the base of the proximal phalanx of the thumb, medial to and

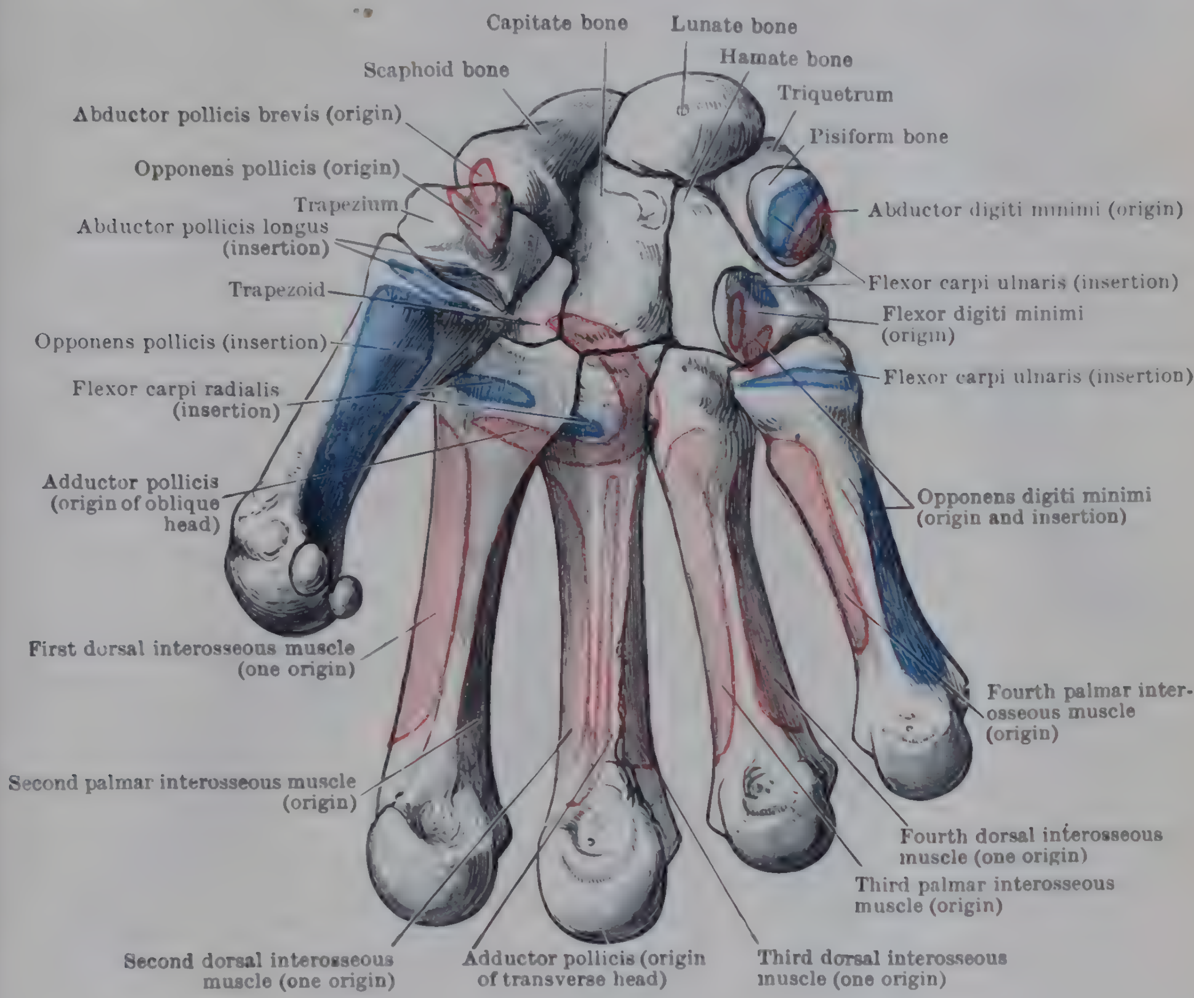


Fig. 431.—Muscle-Attachments to Front of Carpus and Metacarpus.

slightly overlapped by the insertion of abductor pollicis brevis. A *sesamoid bone* is present in the tendon of insertion.

Adductor Pollicis.—The adductor pollicis has two heads—oblique and transverse—separated at their origins by a gap that transmits the radial artery, but **inserted** together by a tendon (in which a sesamoid bone is developed) into the ulnar side of the base of the proximal phalanx of the thumb. Both heads lie deep in the palm behind the long flexor tendons.

The *oblique head* **arises** by fleshy fibres from the sheath of the tendon of the flexor carpi radialis, from the front of the trapezium, trapezoid and capitate bones and the bases of the second, third, and fourth metacarpal bones, and from the palmar ligaments that connect these bones. Usually a slip separates from its upper border, and, passing deep to the tendon of the flexor pollicis longus, is inserted with the flexor brevis into the radial side of the proximal phalanx. The *transverse head* **arises** from the longitudinal ridge on the front of the shaft of the third metacarpal bone, and its fibres converge on the common tendon of insertion.

Short Muscles of Little Finger

The short muscles of the little finger are the abductor, opponens, and flexor digiti minimi.

Abductor Digiti Minimi.—The abductor digiti minimi, the most superficial,

Fig. 432.—Palmar Muscles of Right Hand.

arises from the pisiform bone and from the tendon of the flexor carpi ulnaris and its ligamentous continuations (Figs. 427, 431). It is **inserted** by tendon into the medial side of the base of the proximal phalanx of the little finger—sending a slip to the extensor tendon.

Opponens Digiti Minimi.—The opponens digiti minimi **arises** under cover of the abductor by tendinous fibres from the flexor retinaculum and from the hook

of the hamate bone. It is **inserted** into the medial margin and medial half of the palmar surface of the fifth metacarpal bone in its distal three-fourths (Fig. 431).

Flexor Digiti Minimi. — The flexor digiti minimi may be absent or incorporated with either the opponens or the abductor digiti minimi. It **arises**, by tendinous fibres, from the flexor retinaculum and from the hook of the hamate bone (Figs. 427, 431), and it is **inserted** along with the abductor.

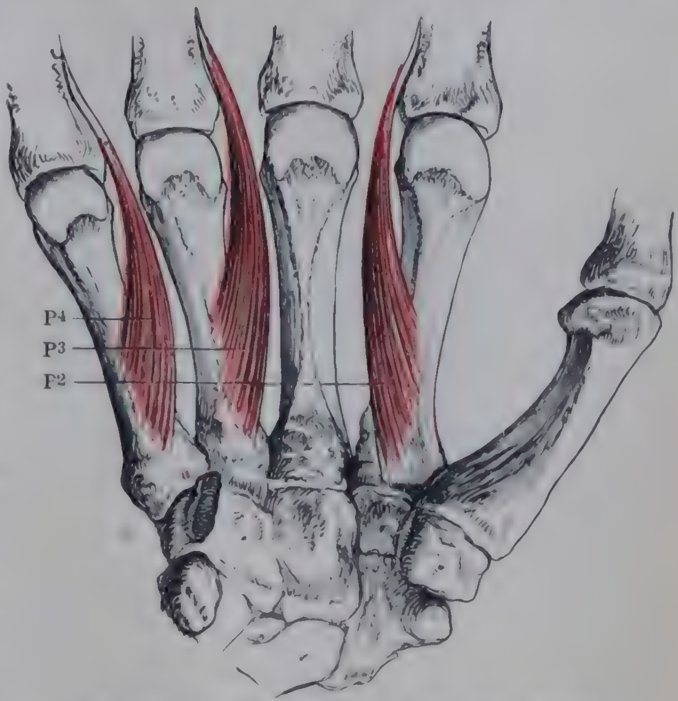


FIG. 433.—THE 2ND, 3RD, AND 4TH PALMAR INTEROSSEOUS MUSCLES (Right Side).

See Fig. 435, p. 509, for 1st palmar interosseous muscle.

Interosseous Muscles

The interosseous muscles of the hand, placed between the metacarpal bones, are arranged in two sets—palmar and dorsal—which are respectively adductors and abductors to or from a line through the middle finger.

Palmar Interossei.—The palmar interossei are four in number. Each **arises** by a single head from the metacarpal bone of the digit which it moves. The muscular fibres of the second, third, and fourth converge on tendons that begin a little proximal to the metacarpo-phalangeal joint. Each tendon passes behind the deep transverse ligament of the palm and is **inserted** partly into the base of the proximal phalanx and partly into the extensor tendon (the continuation of the extensor expansion to the base of the distal phalanx being formed chiefly by the tendons of the interossei and lumbricals, cf. p. 498). The **second** arises from the ulnar side of the shaft of the second metacarpal bone, the **third** and **fourth** from the radial sides of the shafts of the fourth and fifth metacarpal bones respectively, and are inserted into the corresponding sides of the fingers (Figs. 431, 432). Therefore, if the fingers are outspread and the middle finger is held, each muscle adducts its finger to the middle finger. That digit does not require palmar adductors because, when the index and ring fingers are held apart, the middle finger is drawn to one or the other by the alternate action of its two dorsal interossei muscles.

The **first** palmar interosseous muscle ("deep head of flexor pollicis brevis") is a slender slip that springs from the ulnar side of the base of the first metacarpal bone, passes deeply between the first dorsal interosseous muscle and the oblique head of the adductor pollicis to be inserted into the ulnar side of the base of the proximal phalanx of the thumb, in common with the adductor muscle (Fig. 435).

Dorsal Interossei.—The dorsal interossei are larger than the palmar group, and also are four in number. Each **arises** by two heads from the adjacent sides of its two metacarpal bones (Figs. 431, 434, 435). Their heads converge in a bipennate manner on four membranous tendons which descend to the four fingers to be **inserted** in the same way as the tendons of the palmar muscles—the medial three tendons passing behind the deep transverse ligaments of the palm. The insertion of the *first* dorsal interosseous muscle is on the radial side of the index finger; the *second* muscle passes to the radial side of the middle finger; the *third* muscle to the ulnar side of the same finger; and the *fourth* muscle to the ulnar side of the ring finger.

The first dorsal interosseous muscle is larger than the others, and there is a wider interval between its heads, through which the radial artery passes into the palm, while a perforating branch from the deep palmar arch runs between the two heads of each of the other muscles. Between the tendons of the interossei and the joints small *intermetacarpo-phalangeal bursæ* are interposed. The interosseous muscles of the hand are occasionally arranged like those of the foot.

Nerve-Supply.—The intrinsic muscles of the hand, like the muscles on the flexor surface of the forearm, are all supplied by nerves derived from the anterior (*i.e.*, lateral and medial) cords of the brachial plexus through the **median and ulnar nerves**. The ulnar nerve, however, takes a much greater part in the supply of the muscles of the hand—its deep branch extending across the palm to supply all the muscles on the ulnar side of the line of the tendon of the flexor pollicis longus (with the exception of the lateral two lumbricals).

The abductor brevis, the opponens and the flexor brevis of the thumb and the lateral two lumbricals are supplied by the median (C. 6, 7); the medial two lumbricals, the adductor pollicis, the short muscles of the little finger, and all the interossei are supplied by the ulnar (C. 8, T. 1). (Clinical evidence suggests, however, that all the small muscles of the hand may receive their motor supply from T. 1, (Highet, 1943); see also p. 1079.)

Actions of Muscles in Movements of the Fingers.—The movements of the fingers are controlled by the long flexors and extensors, whose tendons pass over the wrist from the forearm, and by the series of short muscles situated in the hand itself, including the interossei, which act on the medial four fingers, and the special muscles of the thumb and little finger. (See Wood Jones, 1941.)

The **flexor digitorum sublimis** is a flexor of the proximal interphalangeal joints and the metacarpo-phalangeal joints of the medial four fingers; the **flexor digitorum profundus**

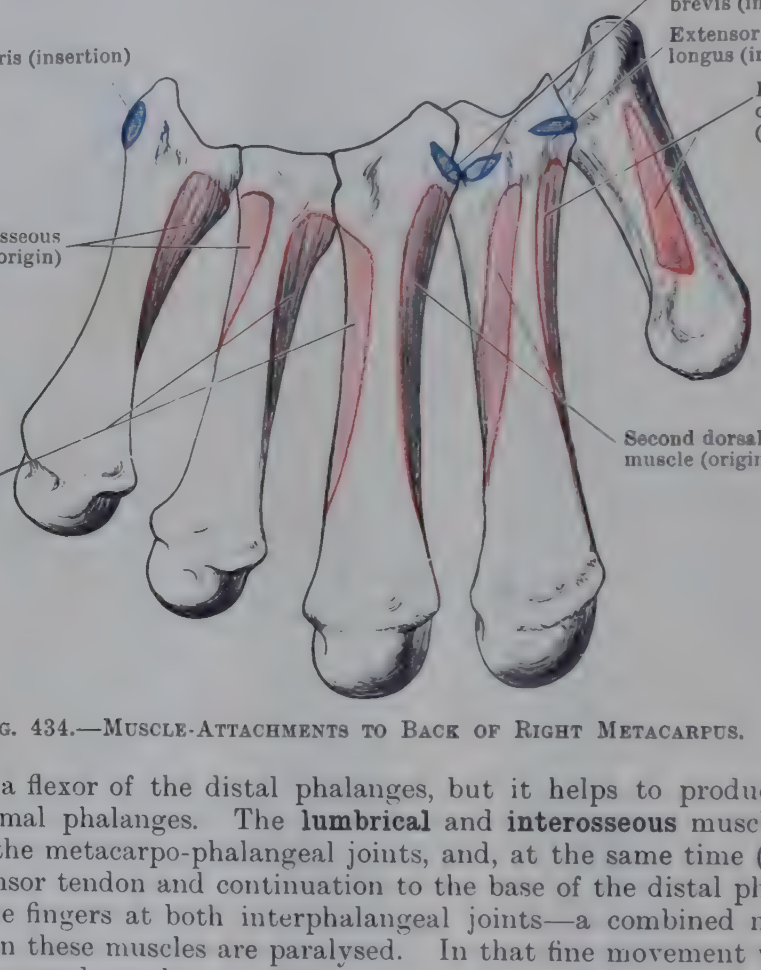


FIG. 434.—MUSCLE-ATTACHMENTS TO BACK OF RIGHT METACARPUS.

acts primarily as a flexor of the distal phalanges, but it helps to produce flexion of the middle and proximal phalanges. The **lumbrical** and **interosseous** muscles act as flexors of the fingers at the metacarpo-phalangeal joints, and, at the same time (by their attachment to the extensor tendon and continuation to the base of the distal phalanx), they act as extensors of the fingers at both interphalangeal joints—a combined movement which is impossible when these muscles are paralysed. In that fine movement which is utilized in making the upward stroke in writing, the interossei participate as well as the lumbricals.

The **extensor digitorum**, assisted by the extensors of the index and the little finger, is the extensor of the fingers. On account of the connexion of the tendons for the third, fourth and fifth digits with one another by means of accessory bands on the back of the hand, these three fingers cannot be fully extended separately, but extension of the index finger can take place independently. In extension of the interphalangeal joints the muscle is aided by the interossei and lumbrical muscles, but in paralysis of the lumbricals and interossei (claw hand), the intact extensor cannot extend the distal phalanges until the metacarpo-phalangeal joints have been passively flexed from the hyperextended position enforced upon them by the extensor, now freed from the antagonism of the lumbricals and interossei in its action on these joints. When the dorsal interossei are paralysed, the fingers can be abducted by the extensor digitorum—a movement always associated with hyperextension at the metacarpo-phalangeal joints.

The free movements of the thumb are of very great importance in the mechanism of

the human hand; they are controlled by special muscles which are quite independent of the common flexors and extensors of the other digits. The **flexor pollicis longus** acts in flexion of the thumb on the metacarpal bone and of both phalanges; the **extensor pollicis longus** acts in a similar way to extend the thumb, while the **extensor pollicis brevis** acts on the metacarpal bone and the proximal phalanx. The **abductor pollicis longus** abducts and extends the metacarpal bone of the thumb; its action in assisting **flexion** of the wrist has already been noted.

The short muscles of the thumb are concerned with the movements of flexion, abduction and adduction, and the characteristic movement of opposition. The **abductor pollicis brevis** acts on all the joints of the thumb. The movement of abduction which it produces occurs at the carpo-metacarpal joint, and the thumb moves in the direction of its radial border. Owing to the fact that the first metacarpal bone is placed with its palmar surface directed medially, abduction of the thumb carries it forwards away from the palm. In addition, the muscle assists in flexion of the metacarpo-phalangeal joint and, through its insertion into the long extensor, in extension of the interphalangeal joint. The **opponens pollicis** acts solely on the metacarpal bone of the thumb, which is drawn medially and forwards and at the same time rotated medially. As a result of the combined movements, in which the long and short flexors and the adductor pollicis participate,

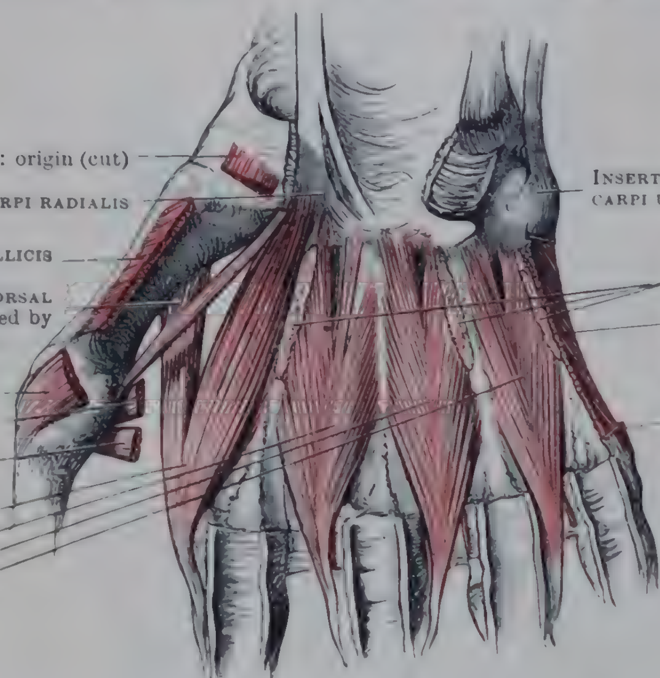


FIG. 435.—DORSAL INTEROSSEOUS MUSCLES OF RIGHT HAND (seen from the Palmar Aspect).

the thumb can be opposed to each of the other digits. The **flexor pollicis brevis** is a flexor of the thumb and assists also in the movement of opposition of the thumb. The **adductor pollicis** adducts and assists in opposition of the thumb.

The short muscles of the little finger are much less important than those of the thumb. The **abductor digiti minimi** abducts the little finger from the ring finger, and assists in flexion at the metacarpo-phalangeal joints. The **opponens** acts only on the metacarpal bone, drawing it forward so as to deepen the hollow of the hand. The **flexor** flexes the little finger at the metacarpo-phalangeal joint.

The interosseous muscles act like the lumbricals and along with them—flexing the fingers at the metacarpo-phalangeal joints and extending them at the interphalangeal joints. In addition, the **dorsal** interossei serve to **abduct** the fingers into which they are inserted from the line through the middle finger; the **palmar** muscles, on the other hand, **adduct** the fingers into which they are inserted towards the middle finger.

Movements of Upper Limb as a Whole.—The characteristic features of the movements of the upper limb are their range and refinement. The hand, in addition to its intrinsic powers, can be moved through a wide range and in several planes by the muscles that act on the wrist and radio-ulnar joints; that range is increased by the fore-and-aft movements at the elbow joint, and the extensive movements of which the shoulder joint and clavicular joints are capable. The result is that the hand can be brought into a position to cover and guard any portion of the body. Precision and refinement of movement are made possible by the co-ordinate actions of the various muscles upon the several joints, so that actions can be performed (as raising the food to the mouth) in which

all the joints of the limb are brought into play; while others (such as writing) are possible by movements at the joints of the wrist and fingers along with fixation of the elbow joint and rotation at the shoulder joint.

The power of the grip, which is such an important feature of the human hand, is due, in no small measure, to the ability to oppose the thumb to the other digits. This movement is possible only (1) because the metacarpal bone of the thumb is set in a plane at right angles to the plane in which the other metacarpals lie, and (2) because the carpo-metacarpal joint of the thumb allows a wide range of movement. As a result of the set of the thumb, flexion carries it medially across the palm, and a very small degree of rotation of its metacarpal bone enables the movement of opposition to be effected. When the fingers encircle a small object, the grip is strengthened by the overlapping thumb, which can then be opposed to the dorsal aspect of the distal phalanges and, if the object is small enough, to the middle phalanges of the index and middle fingers.

FASCIÆ OF FOREARM AND HAND

Superficial Fascia.—In the forearm this layer presents no exceptional features. On the back of the hand it is loose and thin, but in the palm its development into pads to assist the grip and protect underlying structures is characteristic of Man. In reflecting the palmar skin, the knife rasps through tough fibrous strands which enclose the fat in loculi and connect the palmar aponeurosis with the skin, especially along the lines of flexure. Thin and dense in the middle of the palm, and forming thicker and less fibrous pads in the thenar, hypothenar, and metacarpo-phalangeal regions, it plays an important rôle as a cushion readily adaptable to the contour of the various objects grasped. A band of transverse fibres (*superficial transverse ligament of the palm*) crosses the distal part of the palm, enclosed within the skin-folds which form the webs of the fingers and connected to the palmar surfaces of the fibrous flexor sheaths.

FIG. 436.—PALMAR APONEUROSIS.

Palmaris Brevis.—The palmaris brevis is a quadrilateral, subcutaneous muscle which lies in the hypothenar eminence under the superficial fascia. It arises from

the medial border of the palmar aponeurosis and from the palmar surface of the flexor retinaculum, and is **inserted** into the skin of the medial border of the hand for a variable distance. It covers the ulnar artery and nerve, branches of which supply it. Its action is to wrinkle the skin of the medial border of the hand, and, by raising up the skin and superficial fascia, to deepen the hollow of the hand and prevent flattening of the hypothenar eminence by pressure—thus assisting a firm palmar grip (Kirk, 1924).

Deep Fascia.—The deep fascia of the forearm and hand is continuous above with the deep fascia of the upper arm. In the proximal part of the forearm it is strengthened, in front, by fibres from the bicipital aponeurosis; behind, by the fascial insertions of the triceps; and at the sides by fibres derived from the humeral epicondyles in relation to the common tendons of origin of the flexor and extensor muscles of the forearm, which in part take their origin from them. It is attached to the posterior border of the ulna, and affords increased attachment to the flexor and extensor carpi ulnaris and the flexor digitorum profundus. On the back of the wrist, the deep fascia, strengthened by a number of oblique fibres, forms the extensor retinaculum. On the front of the carpus its deep surface blends with a layer that covers the front of the flexor digitorum sublimis, and it also thickens to form the flexor retinaculum; the general fascial sheath of the forearm blends with its superficial surface and covers the tendon of the palmaris longus as the tendon descends in front of the retinaculum to merge with the peak of the palmar aponeurosis.

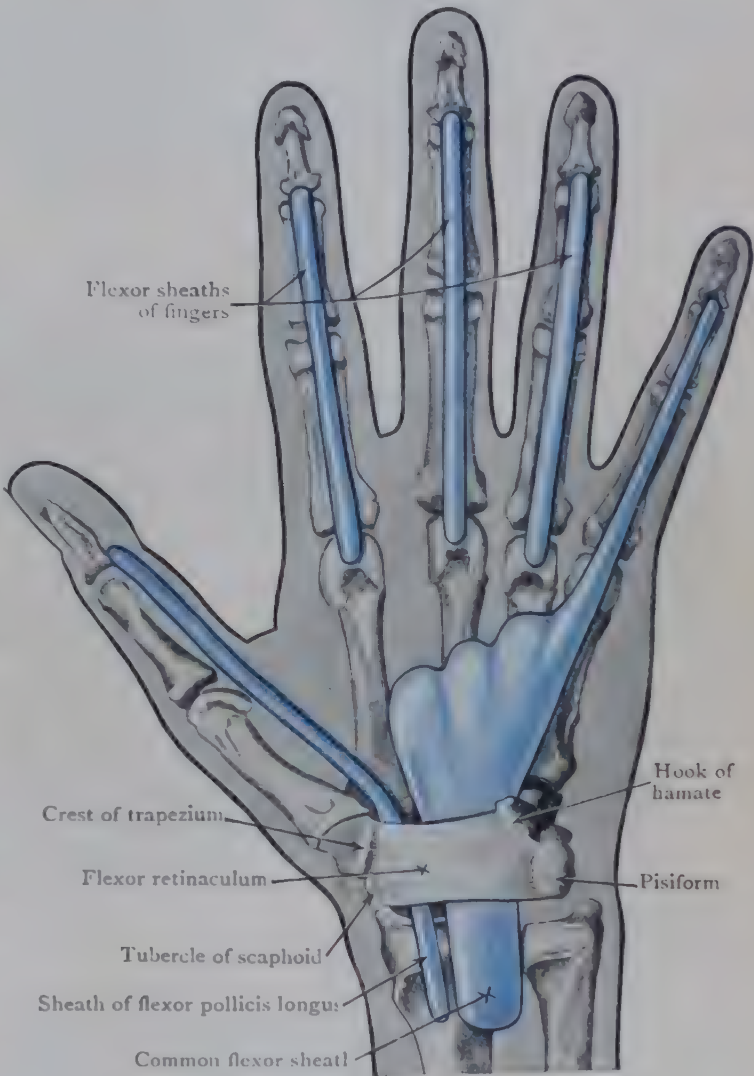


FIG. 437.—SYNOVIAL SHEATHS OF FLEXOR TENDONS OF DIGITS.

Flexor Retinaculum.—The flexor retinaculum is a band about an inch in length and in breadth, continuous with the deep fascia of the forearm and the palm of the hand, but upon a slightly deeper plane; it is attached laterally to the scaphoid and trapezium bones, medially to the pisiform and hamate bones. It is a fibrous restraining arch that binds down, in the hollow of the carpus, the flexor pollicis longus tendon and its synovial sheath, the flexor tendons of the fingers and their synovial sheath, and the median nerve. The attachment to the trapezium is to both lips of the groove on the front of that bone. The fibres attached to the crest cross the groove and convert it into a tunnel which is traversed by the flexor carpi radialis tendon and its synovial sheath. The upper border of the retinaculum is continuous with the deep fascia of the forearm; the distal border is continuous with the palmar aponeurosis in the middle, and at each side it gives origin to some fibres of the muscles of the thenar and hypothenar eminences. The anterior surface of the ligament gives further origin to these muscles, and is largely covered by them. It is also crossed by the palmar branches of the median and ulnar nerves, and by

the tendon of the palmaris longus muscle, which is partly inserted into the surface; the ulnar nerve and vessels descend on to its medial part, and are crossed by the *superficial part of the retinaculum.* This band (not always present) passes to the pisiform bone from the front of the retinaculum and is continuous with the deep fascia that overlies the palmaris longus.

Extensor Retinaculum.—The extensor retinaculum is a thickening of the deep fascia of the back of the limb, partly on the forearm and partly on the wrist, and therefore at a higher level than the flexor retinaculum. It is an oblique band of fibres, about an inch broad, continuous with the deep fasciæ of the forearm and hand. It is attached laterally to the distal part of the anterior border of the radius, and medially to the distal end of the ulna (styloid process), the carpus, and the medial ligament of the wrist. It is crossed by veins, by the radial nerve, and by the dorsal branch of the ulnar nerve. *Six compartments* are formed deep to it by the attachment of septal bands to the distal ends of the radius and ulna. Each compartment is provided with a synovial sheath; and they serve to transmit the

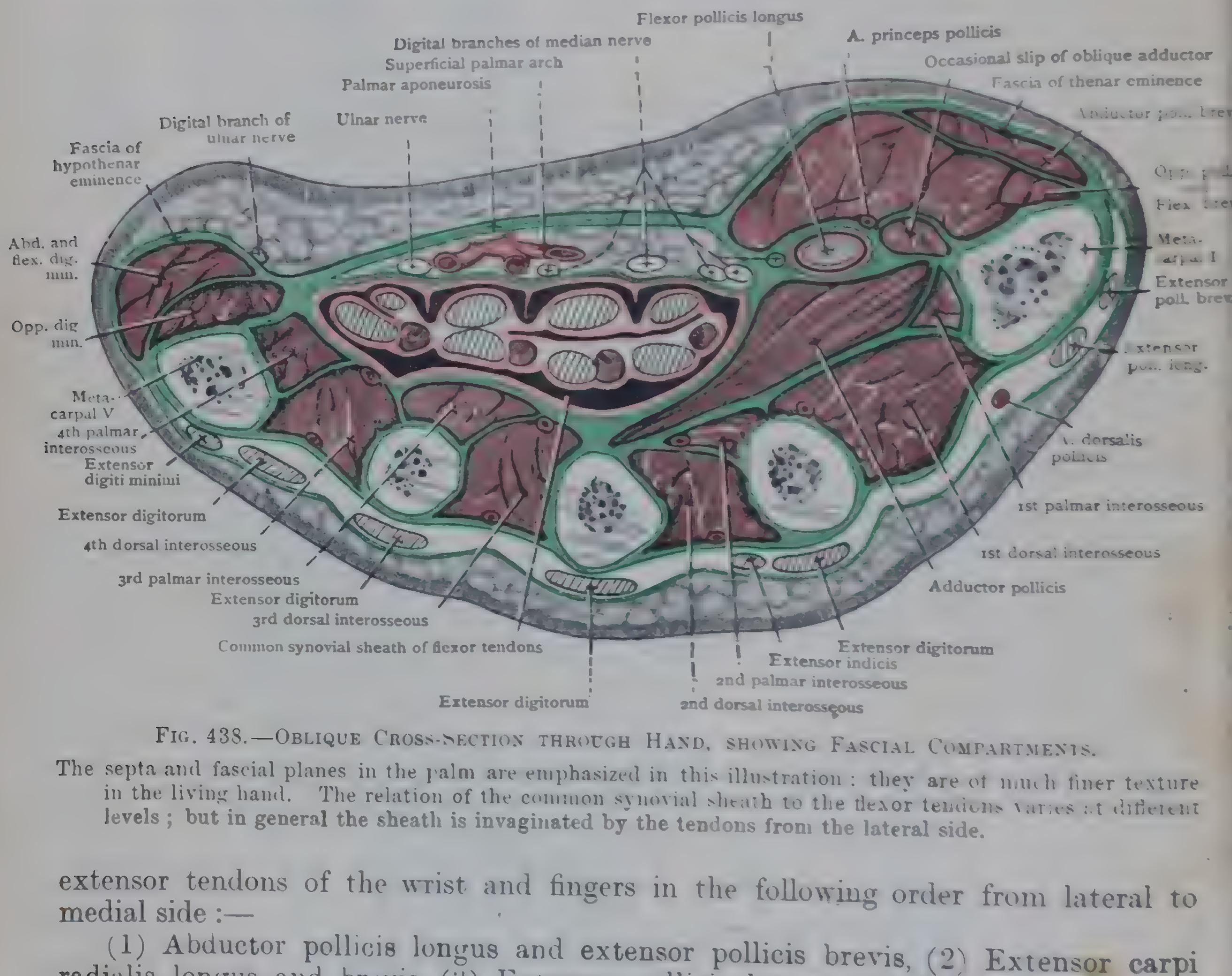


FIG. 438.—OBLIQUE CROSS-SECTION THROUGH HAND, SHOWING FASCIAL COMPARTMENTS.

The septa and fascial planes in the palm are emphasized in this illustration: they are of much finer texture in the living hand. The relation of the common synovial sheath to the flexor tendons varies at different levels; but in general the sheath is invaginated by the tendons from the lateral side.

extensor tendons of the wrist and fingers in the following order from lateral to medial side:—

(1) Abductor pollicis longus and extensor pollicis brevis, (2) Extensor carpi radialis longus and brevis, (3) Extensor pollicis longus, (4) Extensor digitorum and extensor indicis, (5) Extensor digiti minimi, (6) Extensor carpi ulnaris.

The **deep fascia of the dorsum of the hand** is arranged in two layers—superficial and deep—transmitting between them the tendons in their synovial sheaths and the branches of the radial artery. (1) The superficial layer, very thin, and continuous with the distal border of the extensor retinaculum, descends over the tendons to fuse with them upon the fingers; (2) the deep layer is thicker and overlies the interossei—blending with the superficial layer at the clefts between the digits.

The **deep fascia of the palm of the hand** also is in two layers: (1) A superficial layer which displays a central, thick *palmar aponeurosis* (described below), continuous with two thin side-parts on the thenar and hypothenar eminences; (2) a deep layer spread over the interosseous muscles and enclosing the adductor

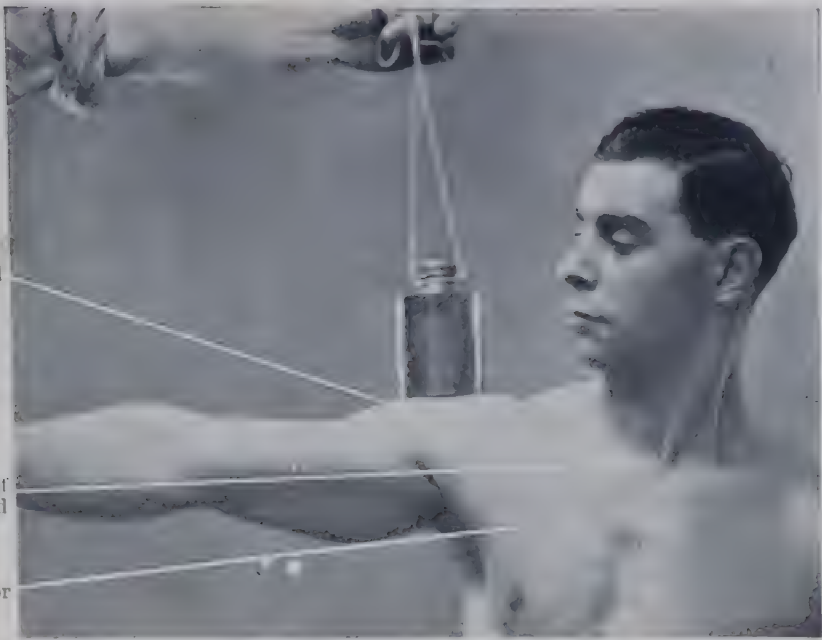


FIG. 1.—ACTIVITY OF DELTOID IN CONTROLLING GRAVITATIONAL DESCENT OF UPPER LIMB, SHOWN BY WEIGHT RIDING UPON THE MUSCLE. Cf. Fig. 2.

FIG. 2.—FLACCIDITY OF DELTOID WHEN ANTAGONISTS PULL ON THE LIMB AGAINST RESISTANCE, SHOWN BY WEIGHT SINKING INTO THE MUSCLE. Note the activity of the pectoralis major in contrast with its passive state in Fig. 1.

FIG. 3.—ACTIVITY OF THE PECTORAL MUSCLES AS ADDUCTORS AGAINST RECIPROCAL RESISTANCE OF HANDS.

PLATE XLI.—PHOTOGRAPHIC ILLUSTRATIONS OF MUSCLES IN ACTION.

[Facing p. 512

PLATE XLII

FIG. 1.—ACTIONS OF THE PECTORALIS MAJOR.

The subject's right arm is being raised and the left arm depressed against resistance. The clavicular part of the muscle is active on the right, inactive on the left; the reverse is the case with the sterno-costal part.

FIG. 2.—FLEXORS OF WRIST AND ELBOW IN ACTION.

In the top left figure the median nerve, escaping from under flexor carpi radialis to lie upon sublimis tendons, is seen well because palmaris longus is absent.

PLATE XLII. PHOTOGRAPHIC ILLUSTRATIONS OF MUSCLES IN ACTION. (From Lockhart's *Living Anatomy*, 1948, by permission of Messrs. Faber & Faber.)

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of the thumb; certain fibres of the two layers blend between the heads of the metacarpal bones.

The flexor retinaculum, the palmar aponeurosis, and the fibrous flexor sheaths form a continuous sheet which serves to increase the efficiency of the flexor muscles of the digits and wrist and to increase the power of prehension. The fascial thickenings retain the tendons in position and provide pulleys over which they act, so that when the flexor muscles of the digits contract, their tendons do not produce ridges of the skin which would interfere with the efficiency of the hand as a gripping instrument; and the extent of the movements of the phalanges is directly proportional to the amount of shortening of the muscles that act upon them.

Palmar Aponeurosis.—The palmar aponeurosis is a dense, strong, triangular membrane that underlies the superficial fascia in the middle of the palm, and consists mainly of longitudinal fibres. Its apex joins the lower edge of the flexor retinaculum, and, more superficially, the tendon of the palmaris longus is inserted into it. The base is scalloped into four slips—one for each finger—and the slips are connected together on their deep surfaces by transverse fibres which cross in front of the lumbrical muscles and the digital nerves and vessels. Beyond the transverse fibres, each slip separates into two parts which pass backwards to be connected to the sides of the metacarpo-phalangeal joint and the proximal phalanx of the finger, their distal edges being continuous with the proximal end of the fibrous flexor sheath. The borders of the aponeurosis are continuous with the thin fascia that covers and ensheaths the thenar and hypothenar muscles; and the proximal part of the medial border gives origin to the palmaris brevis. Further, a septum passes backwards from each border to fuse with the fascia on the interosseous muscles, and the palm is divided by them into three compartments—a *lateral* compartment containing the short muscles of the thumb and its long flexor tendon; a *medial*, with the short muscles of the little finger; and an *intermediate* compartment containing the long flexor tendons.

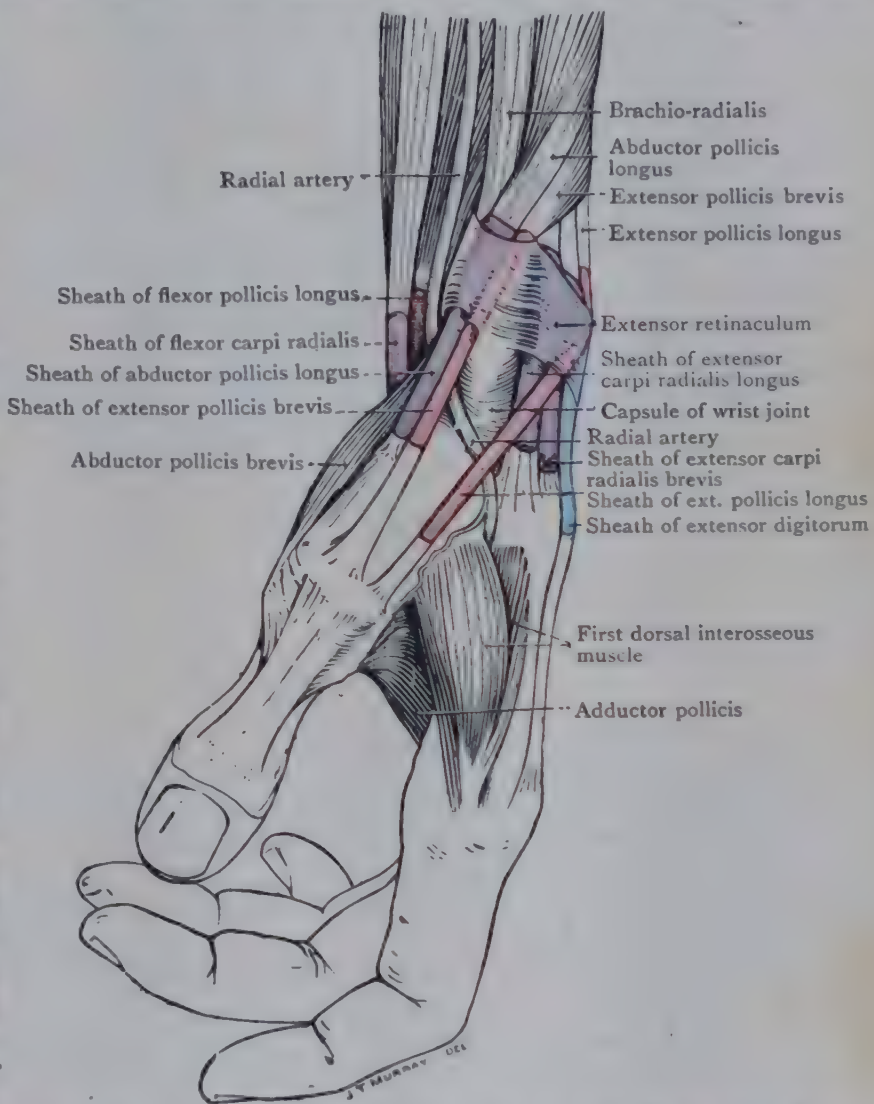

Fig. 439.—Dissection of Lateral Side of Left Wrist and Hand showing Synovial Sheaths of Tendons.

Fascial "Spaces".—The arrangement of the deep fascia in the hand is of great importance in determining the mode of spread of infection and the sites of abscesses. In particular, certain "spaces" may be formed in the fascial plane deep to the flexor tendons. These "spaces" are specially named by the surgeon, and they are not to be confused with the anatomical "compartments" described with the palmar aponeurosis. (See the Section on Surface and Surgical Anatomy and Fig. 1240, p. 1538.).

Fibrous Flexor Sheaths (Fig. 432).—The fibrous sheaths of the long flexors of the digits are arches of dense fibrous tissue that hold the tendons in place on the palmar surfaces of the digits. Each sheath is attached to the margins of the proximal and middle phalanges (in the thumb, proximal only) and interphalangeal joints and to the palmar surface of the distal phalanx; and its proximal end is continuous with a divided slip of the palmar aponeurosis. Opposite the joints it is thin and loose and attached to the skin, but opposite each phalanx it is thick and strong, and serves to keep the tendons closely applied to the bone during flexion of the digit. The canal formed by the phalanges and the fibrous sheath contains not only the tendons but also the synovial sheath that surrounds them.

Synovial Sheaths.—These sheaths have two layers—one around the tendon

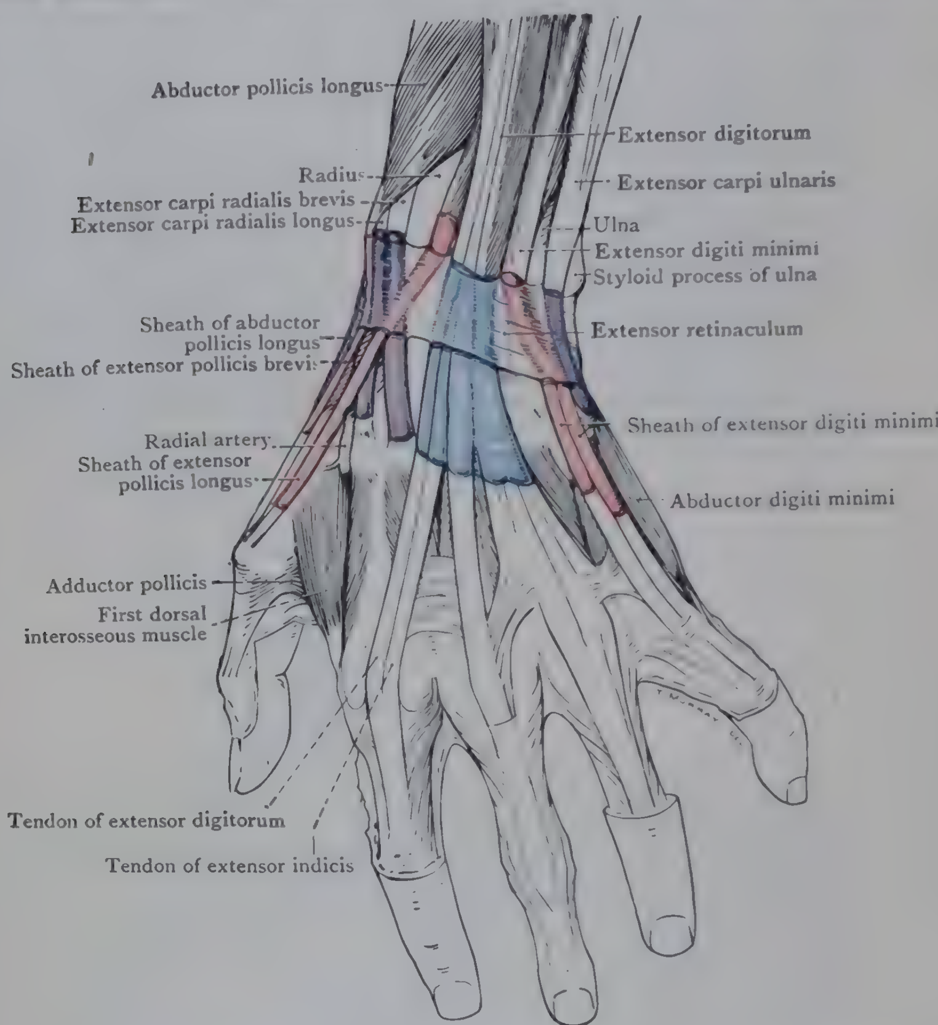

Fig. 440.—Dissection of Back of Forearm, Wrist, and Hand, showing Synovial Sheaths of Tendons.

or tendons, the other applied to the walls of the spaces which the tendons occupy; and the two layers are continuous with each other at the ends of the sheath.

The **common synovial flexor sheath** is by far the largest and envelops the tendons of the flexor sublimis and flexor profundus. It begins about an inch above the flexor retinaculum and passes into the palm—the larger part of it ending at the middle of the palm, but the part related to the tendons of the little finger extends to the base of its distal phalanx. The tendons invaginate the synovial sac from the lateral side to produce the two layers, but the arrangement is complicated by a recess that passes in from the medial side to separate the tendons of the flexor sublimis from those of the profundus.

The **synovial sheaths of the flexor pollicis longus** and the **flexor carpi radialis** begin about an inch above the flexor retinaculum and extend to the insertion of the tendons. The sheath of the flexor pollicis sometimes communicates with the common sheath above the retinaculum.

The **synovial flexor sheaths of the fingers** extend as far as the insertion of the

tendons. The sheath of the little finger is a prolongation from the common sheath. The sheaths of the other fingers begin at the middle of the palm at a variable distance below the common sheath (Fig. 437).

The **synovial extensor sheaths** begin at or a little above the extensor retinaculum and extend downwards for varying distances. The tendons inserted into the metacarpus are usually ensheathed as far as their insertions; the other sheaths extend half-way down the hand.

MUSCLES OF LOWER LIMB

The muscles of the lower limb are divisible (according to their regional arrangement and functional uses) into series and groups corresponding in general to those of the upper limb. In contrast, however, to the freely movable shoulder girdle acted upon by the series of muscles which connect it to the trunk, the pelvic girdle is fixed to the vertebral column, and no corresponding functional series of muscles exists.

Those muscles of the lower limb which pass from the vertebral column (psoas, piriformis, and gluteus maximus) to the femur act upon the hip joint, and are included in the first two of the groups to be described:—1. Muscles of the Groin. 2. Muscles of the Hip and Buttock (Gluteal region). 3. Muscles of the Thigh (Flexor, Extensor, and Adductor Groups). 4. Muscles of the Leg (Flexor and Extensor Groups). 5. Muscles in the Sole of the Foot.

MUSCLES AND FASCIÆ OF THIGH AND GLUTEAL REGION

Muscles of the Groin

The **ilio-psoas** is a compound muscle, consisting of two elements—**psoas (major and minor)**—which connects the femur and pelvic girdle to the axial skeleton; and another element—the **iliacus**—which extends between the hip bone and the femur. The muscles lie chiefly in the posterior wall of the abdomen; only their lower parts appear in the thigh, below the inguinal ligament in the lateral part of the femoral triangle; they are related to a large number of important structures.

Psoas Major.—The psoas major is a long, thick, fusiform muscle with an extensive origin from the lumbar part of the vertebral column. It **arises** by fleshy fibres—(1) from the intervertebral disc above each lumbar vertebra, and the adjacent margins of the vertebræ—from the lower border of the twelfth thoracic to the upper border of the fifth lumbar; (2) from four membranous arches which pass over the sides of the bodies of the upper four lumbar vertebræ; and (3) from the transverse processes of all the lumbar vertebræ (Fig. 385, p. 451). The muscle lies at first on the fronts of the transverse processes closely applied to the side of the vertebral bodies; then, narrowing to pass along the brim of the true pelvis, it enters the thigh behind the inguinal ligament and ends in a tendon which is **inserted** into the lesser trochanter of the femur (Fig. 441). A *bursa*, which may be continuous with the cavity of the hip joint, separates the tendon from the pubis and the capsule of the hip joint.

Psoas Minor.—The psoas minor is an inconstant muscle, being absent in about 40 per cent of bodies. It **arises** from the intervertebral disc between the last thoracic and first lumbar vertebræ and from the contiguous margins of those vertebræ. The muscle is closely applied to the anterior surface of the psoas major. It has a short, slender fleshy belly, and it is **inserted** by a long, narrow tendon into the arcuate line and ilio-pubic eminence, its margins blending with the fascia that covers the psoas major.

Iliacus.—The iliacus is a large fan-shaped muscle that lies along the lateral side of the psoas major. It **arises**, by fleshy fibres, mainly from the floor of the iliac fossa, and it has additional origins from the ala of the sacrum, the anterior sacro-iliac, lumbo-sacral, and ilio-lumbar ligaments, and, outside the pelvis, from the ilio-femoral ligament. Emerging from the abdomen, it descends in front of the hip joint, tapering to be **inserted**, by fleshy fibres—(1) into the lateral side of

the tendon of the psoas major; (2) into the lesser trochanter; (3) into the femur below the lesser trochanter for about an inch; and (4), by its most lateral fibres, into the capsule of the hip joint. These fibres are often separate, forming the iliacus minor or ilio-capsularis.

Nerve-Supply.—The psoas major is supplied directly by branches from the anterior primary rami of the second and third lumbar nerves, with additional branches in some cases from the first and fourth. The psoas minor receives a nerve from the first or the second lumbar nerve. The iliacus is supplied by branches from the femoral nerve (L. 2. 3. 4.) within the abdomen.

Muscles of Gluteal Region

This group comprises the three gluteal muscles, the tensor fasciæ latæ, piriformis, obturator internus and gemelli, and the quadratus femoris.

The gluteus maximus and tensor fasciæ latæ muscles—both ensheathed in deep fascia—are in the same plane. The gluteus medius, partially covered by the gluteus maximus, conceals the gluteus minimus; and the piriformis, obturator internus, gemelli, and quadratus femoris intervene between the gluteus maximus and the posterior surface of the hip joint.

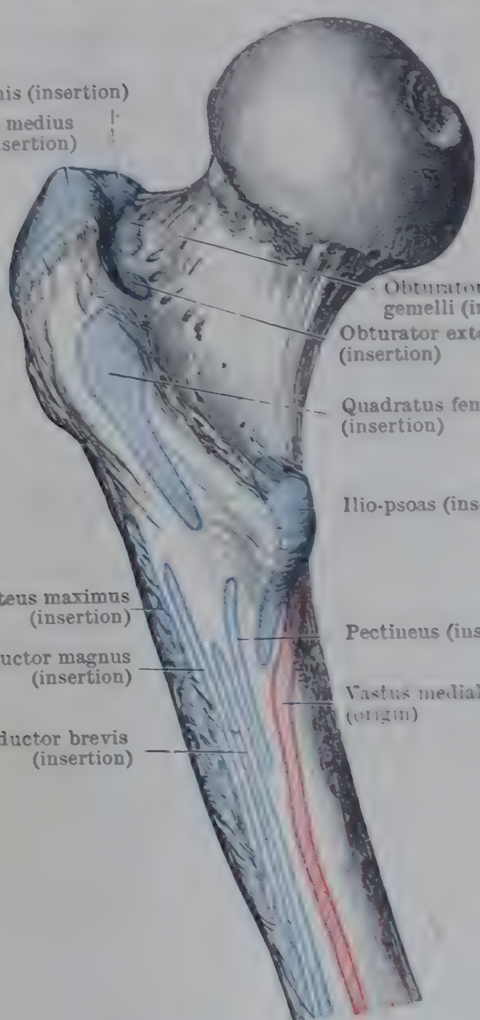

FIG. 441.—MUSCLE-ATTACHMENTS TO BACK OF UPPER PART OF LEFT FEMUR.

Gluteus Maximus.—The gluteus maximus, superficial throughout its extent, and the heaviest and most coarsely fibred muscle of the body, contributing by its weight to form the fold of the buttock, is a peculiarly human muscle, being associated with the adoption of the erect posture. It **arises** from (1) the upper part of the area behind the posterior gluteal line of the ilium; (2) the tendon of the sacrospinalis; (3) the dorsal surface of the sacrum and coccyx; (4) the posterior surface of the sacrotuberous ligament; and (5) the deep fascia ensheathing it.

It extends obliquely downwards and laterally to be **inserted**, by short tendinous fibres, partly into the gluteal tuberosity of the femur (Fig. 441), but mainly, over the greater trochanter, into the ilio-tibial tract. The tract receives the insertion of the whole of the superficial fibres of the muscle and the upper half of the deep fibres, thereby enabling the muscle to obtain a powerful hold over the thigh as a whole, and a virtual insertion into the tibia (Fig. 270, p. 302). The lower half of the deep portion of the muscle is inserted, for the most part, into the gluteal tuberosity; but the lowest fibres of all are inserted into the fascia lata and are thence connected with the lateral intermuscular septum of the thigh and the origin of the short head of the biceps.

A great part of the gluteus medius is visible at its upper border; and at its lower border the hamstring muscles and the sciatic nerve appear as they enter the thigh. This border is crossed by the fold of the buttock. In addition to the muscles already enumerated, it covers the ischial tuberosity, greater trochanter

origins of biceps femoris, semitendinosus, semimembranosus and the adductor magnus. The superficial part of the superior gluteal artery passes between the gluteus medius and the piriformis to reach its deep surface, and, between the piriformis and the superior gemellus, the inferior gluteal and internal pudendal vessels, and the sciatic, pudendal, and posterior cutaneous nerves and muscular branches from the sacral plexus emerge. Three *bursæ* are deep to it: one (not always present) over the ischial tuberosity, a second over the lateral side of the greater trochanter, and a third over the vastus lateralis. The fibres of the gluteus maximus that arise from the coccyx may form a separate muscle (**coccygeo-femoralis** or **agitator caudæ**), and there may be an additional slip from the ischial tuberosity (**ischio-femoralis**).

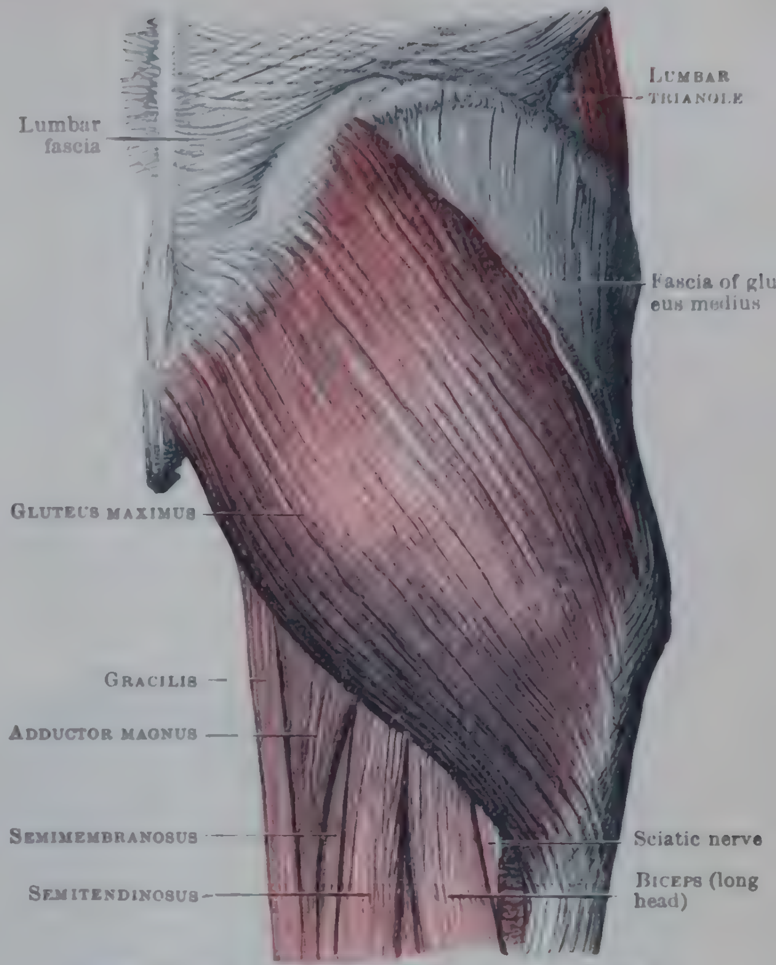

FIG. 442.—RIGHT GLUTEUS MAXIMUS MUSCLE.

Tensor Fasciæ Latæ. — The tensor fasciæ latæ (Pl. XLIV, p. 529, Fig. 3) arises from the outer lip of the fore part of the iliac crest and the anterior border of the ilium, and passes downwards and slightly backwards to be inserted into the ilio-tibial tract (p. 534) a little below the level of the greater trochanter. It is enclosed between two layers of deep fascia, of which the deep layer extends medially to fuse with the heads of the rectus femoris and the capsule of the hip joint; and both layers blend with the ilio-tibial

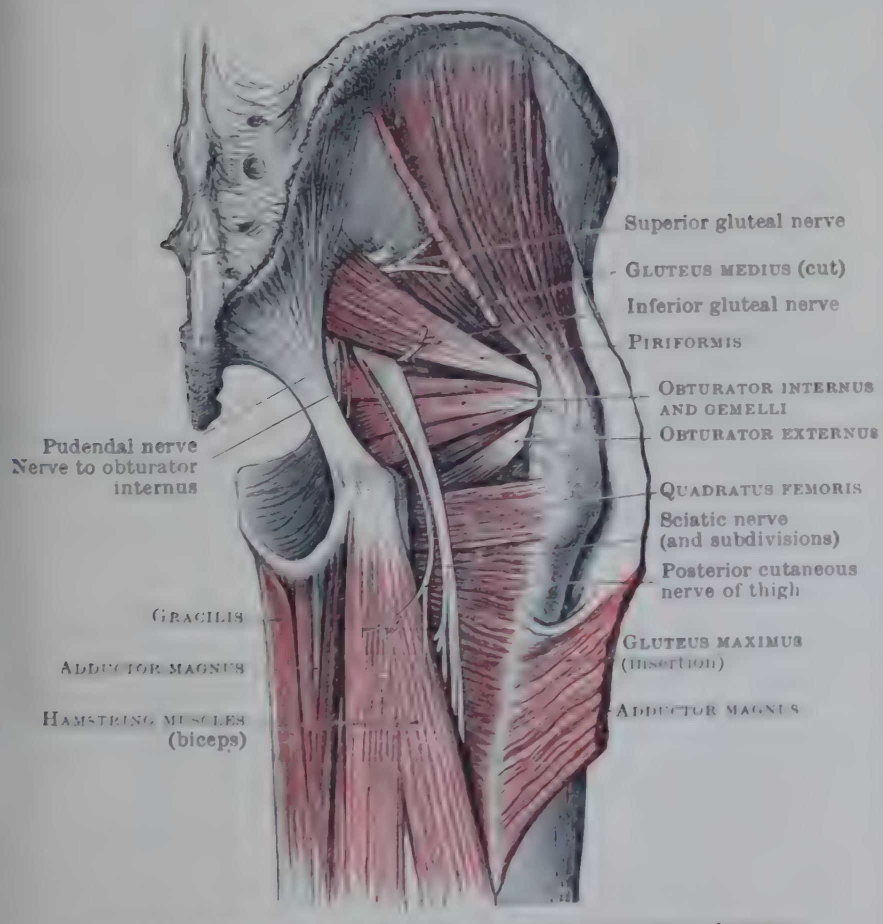

FIG. 443.—MUSCLES AND NERVES OF RIGHT GLUTEAL REGION.
The gluteus maximus is reflected; and the gluteus medius is cut to show a part of the gluteus minimus.

tract along the posterior border of the muscle. Posteriorly the muscle is related to the gluteus medius and minimus, and the vastus lateralis. Anteriorly it is closely related to the sartorius at its origin; but these two muscles diverge from each other as they descend, and the rectus femoris appears in the widening cleft between them (Fig. 448).

Gluteus Medius.—The gluteus medius **arises** from (1) the area of the ilium between the iliac crest and posterior gluteal line above and the middle gluteal line below and (2) the strong fascia that covers its anterior part. It is a fan-shaped muscle whose fibres converge on the greater trochanter to be **inserted** by a strong, short tendon into the postero-superior angle of the greater trochanter and into a well-marked diagonal line on its lateral surface—the most anterior fibres reaching the lowest level (Fig. 443). A *bursa* is placed between the tendon and the trochanter in front of the insertion. The muscle is partly superficial and partly concealed by the gluteus maximus. It covers the gluteus minimus, the superior gluteal nerve and the deep branches of the superior gluteal artery.

Gluteus Minimus.—The gluteus minimus **arises** by fleshy fibres from the gluteal surface of the ilium between the middle and inferior gluteal lines. It is a fan-shaped muscle and its fibres converge on the antero-superior angle of the greater trochanter, covering the upper surface of the capsule of the hip joint. It is **inserted** into the anterior surface of the trochanter (Fig. 450). A *bursa* (trochanteric bursa of gluteus minimus) is placed deep to the tendon in front of the medial part of the anterior surface of the greater trochanter.

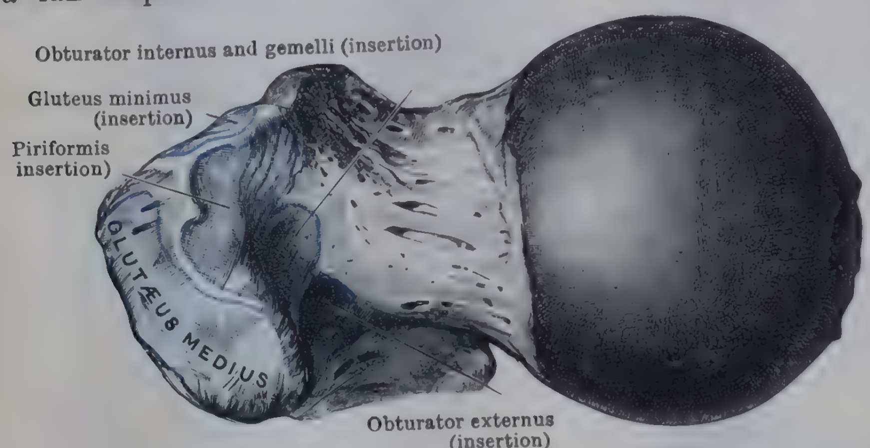

FIG. 444.—FEMUR (LOOKED AT FROM ABOVE) SHOWING MUSCLE-ATTACHMENTS TO GREATER TROCHANTER.

Piriformis.—The piriformis is one of the few muscles that connect the lower limb to the axial skeleton. It **arises** mainly (1) from the pelvic surfaces of the second, third, and fourth sacral vertebræ; but as it passes out through the greater sciatic foramen, it receives additional origins from (2) the upper margin of the greater sciatic notch and (3) the pelvic surface of the sacro-tuberous ligament. In the buttock it forms a rounded tendon which is **inserted**, under cover of the gluteus medius, into the upper border and medial side of the greater trochanter (Fig. 444).

The piriformis, at its origin, covers part of the inner surface of the dorsal wall of the true pelvis, and is related anteriorly to the rectum and the lower part of sacral plexus. In the buttock it is covered by the gluteus maximus and lies between the gluteus medius and superior gemellus on the back of the hip joint. It is frequently pierced by the lateral popliteal nerve when that nerve emerges separately from the pelvis.

Obturator Internus.—The obturator internus **arises** from (1) the whole of the margin of the obturator foramen (except the obturator groove); (2) the inner surface of the obturator membrane; (3) the pelvic surface of the hip bone behind and above the obturator foramen; and (4) the *obturator fascia*, which covers it. It is a fan-shaped muscle whose fibres converge to pass through the lesser sciatic foramen. Its tendon begins on the surface next the bone as four or five separate slips; and as the muscle changes its direction at an acute angle by hooking round the margin of the lesser sciatic notch deep to the sacro-tuberous ligament, these tendinous slips also converge to play over corresponding grooves in the cartilage-covered, pulley-like surface of the bone—a large *bursa*, attached to the margins of the tendon and the cartilage-covered surface of the bone, facilitating this movement. The tendon, after passing over the back of

the hip joint, is **inserted** into the medial surface of the greater trochanter above the trochanteric fossa (Fig. 444).

The fleshy part of the muscle is covered with the obturator fascia, which gives origin to a great part of the levator ani; the part above the levator is related to the cavity of the pelvis and the part below to the ischio-rectal fossa. In the buttock the tendon is embraced by the gemelli muscles which meet deep to it as it emerges from the foramen and more or less conceal its superficial surface as it passes to its insertion.

Gemelli.—The gemelli muscles form accessory portions of the obturator internus, providing it with an additional 'twin' origin from the margins of the lesser sciatic notch. The **superior gemellus arises** from the gluteal surface of the ischial spine and the **inferior gemellus** from the upper part of the ischial tuberosity; each is **inserted** into the corresponding margin and the superficial surface of the tendon of the obturator internus muscle.

Quadratus Femoris.—The quadratus femoris **arises** from the lateral margin of the ischial tuberosity, and is **inserted** into the quadrate tubercle of the femur and into a line leading down from it. The posterior surface is covered by the hamstring muscles, the sciatic nerve, the posterior cutaneous nerve of thigh, the inferior gluteal nerve and artery and the gluteus maximus; the anterior surface is related to the obturator externus muscle and to the lesser trochanter of the femur (a *bursa* intervening); its upper border meets the lower border of the inferior gemellus; and its lower border meets the upper border of the adductor magnus —fusion of these two being not infrequent.

Nerve-Supply.—The **piriformis muscle** is supplied by branches direct from the anterior primary rami of the **first** and **second sacral nerves**; the remaining muscles of the group are supplied by four nerves, two of which arise from the back of the sacral plexus, and the other two have corresponding origins from the front. The **superior gluteal nerve** (L. 4. 5. S. 1.) supplies the **gluteus medius** and **gluteus minimus** and ends in the **tensor fasciæ latæ**; the **inferior gluteal nerve** (L. 5. S. 1. 2.) is concerned solely with the supply of the **gluteus maximus.** Both those nerves arise from the back of the plexus and are associated with the roots of origin of the lateral popliteal nerve. The **quadratus femoris** (with the **inferior gemellus**) and the **obturator internus** (with the **superior gemellus**) are supplied by special nerves which arise respectively from the same nerves of the plexus as the gluteal nerves, but from the front of it, and are associated with the roots of origin of the medial popliteal nerve. The **nerve to the quadratus femoris** (L. 4. 5. S. 1.), after giving a twig to the inferior gemellus, enters the deep (anterior) surface of its muscle; the **nerve to the obturator internus** (L. 5. S. 1. 2.) gives a twig to the superior gemellus and enters its muscle on its perineal surface.

MUSCLES OF THIGH

The muscles of the thigh are divisible into three main groups by their situation, action, and nerve-supply. On the **back** (flexor surface) of the thigh are the hamstring muscles; on the **front** (extensor surface) of the thigh are the quadriceps femoris and the sartorius; on the **medial side** of the thigh are the pectineus and the adductor muscles.

The muscles of the thigh, like the muscles of the upper arm, have a nerve-supply by groups, from the ventral and dorsal offsets of the nerve-plexuses concerned, according to their relation to the flexor and extensor surfaces of the thigh. The flexor and extensor surfaces of the thigh, however, are reversed in position by the developmental rotation of the limb, and become posterior and anterior respectively. There is, moreover, a special adductor group which is represented in the upper arm by the coraco-brachialis only, and is supplied (like that muscle) by ventral branches of the plexus.

The group supply is as follows: *Ventral branches of the plexus*—**Flexors** (hamstrings) by the **sciatic nerve** (medial popliteal division) (L. 4. 5. S. 1. 2. 3.); **Adductors** by the **obturator nerve** (L. 2. 3. 4.). *Dorsal branches of the plexus*—**Extensors** by the **femoral nerve** (L. 2. 3. 4.). In addition to this general statement, the nerve-supply of three muscles is to be specially noted —the adductor magnus, the pectineus, and the short head of the biceps.

Muscles of Back of Thigh

The muscles of this group—the biceps femoris, semitendinosus, and semimembranosus—are known colloquially as the **hamstring muscles.** Morphologically,

the ischio-condylar portion of the adductor magnus, as evidenced by its nerve-supply, also belongs to this group. The origins of the hamstring muscles from the ischial tuberosity are concealed by the gluteus maximus. In the back of the thigh, enveloped by the fascia lata, they are placed behind the adductor magnus—the semitendinosus and semimembranosus medially, the biceps laterally. Towards the knee they diverge to bound the popliteal fossa, the former two muscles on its medial side, the biceps on its lateral side; behind the knee these tendons may be felt as the "hamstrings".

Biceps Femoris.—The biceps femoris has a double **origin**. (1) Its *long head* **arises**, by means of a tendon, in common with the semitendinosus, from the upper medial impression on the ischial tuberosity (Figs. 443, 445) and from

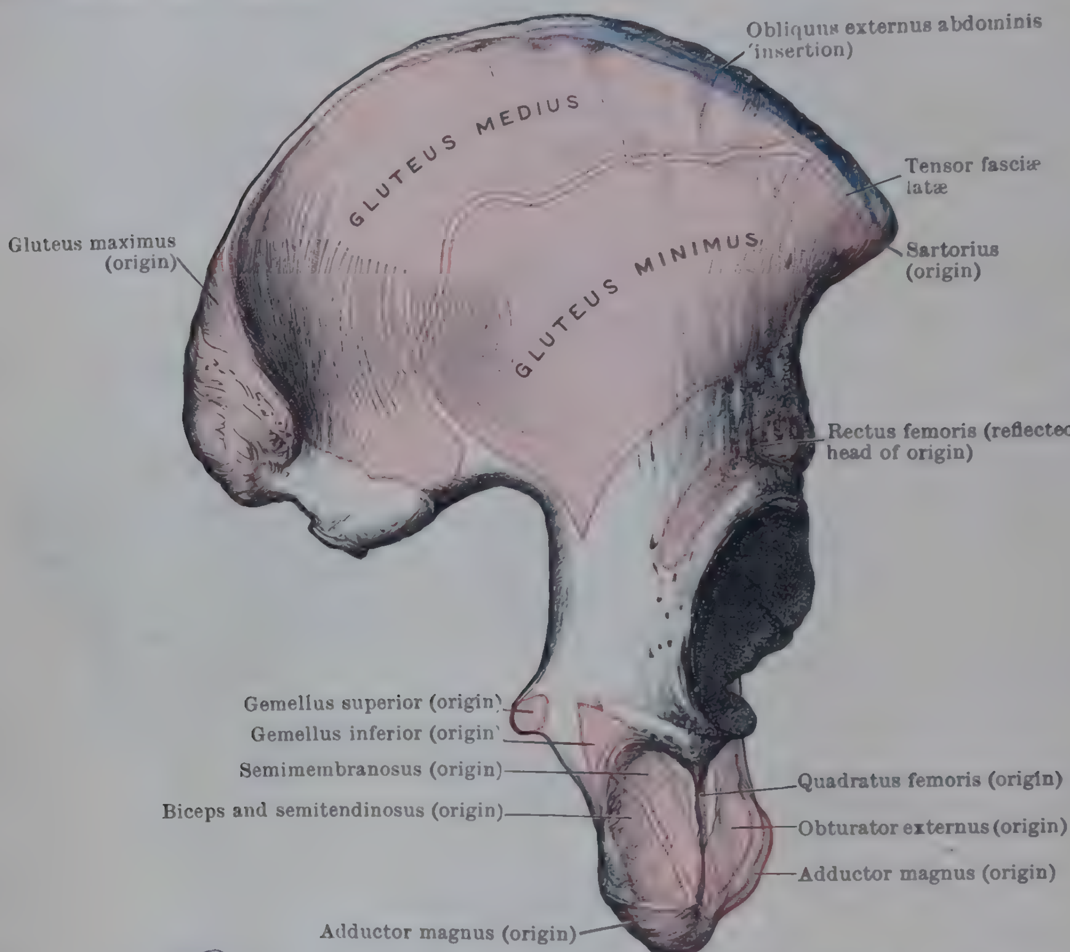

FIG. 445.—MUSCLE-ATTACHMENTS TO OUTER SURFACE OF RIGHT HIP-BONE.

the sacro-tuberous ligament. This head, united for a distance of two or three inches with the semitendinosus, forms a separate fleshy mass which extends to the distal third of the thigh to end in a flattened tendon joined by the short head of the muscle. (2) The *short head* **arises** separately from (i) the whole length of the lateral lip of the linea aspera and the upper half of the lateral supra-condylar line of the femur, and (ii) the lateral intermuscular septum: its upper-most fibres are sometimes blended with the insertion of the lowest fibres of the gluteus maximus. The tendon of the long head, joined by the fibres of the short head, becomes rounded at the knee and is then split into two parts by the lateral ligament of the knee joint as it is **inserted**—(1) into the head of the fibula, and by extensions, (2) forwards to the lateral condyle of the tibia, and (3) to the deep fascia on the lateral side of the leg.

There is a *bursa* between the tendon and the lateral ligament of the knee.

The short head may be absent; there may be an additional origin from the ischium or the femur; and the long head may send a slip to the gastrocnemius or to the tendo calcaneus (**tensor fasciæ suralis**).

Semitendinosus. — The semitendinosus **arises**, in common with the long head of the biceps, from the upper medial impression on the ischial tuberosity

(Fig. 445). Separating from the common tendon of origin, the muscle forms a long band which becomes tendinous in the middle third of the thigh and ends in the distal third in a long, cord-like tendon. Descending over the surface of the semimembranosus and over the medial side of the knee the tendon spreads out to be **inserted** (1) into the upper part of the medial surface of the shaft of the tibia behind the gracilis and sartorius (Fig. 447), and (2) into the deep fascia of the leg. A *bursa* (tibial intertendinous) separates it along with the gracilis from the sartorius superficially, and a *second bursa*, common to it and the gracilis, lies deep to its insertion. The belly of the muscle is marked by an oblique tendinous intersection.

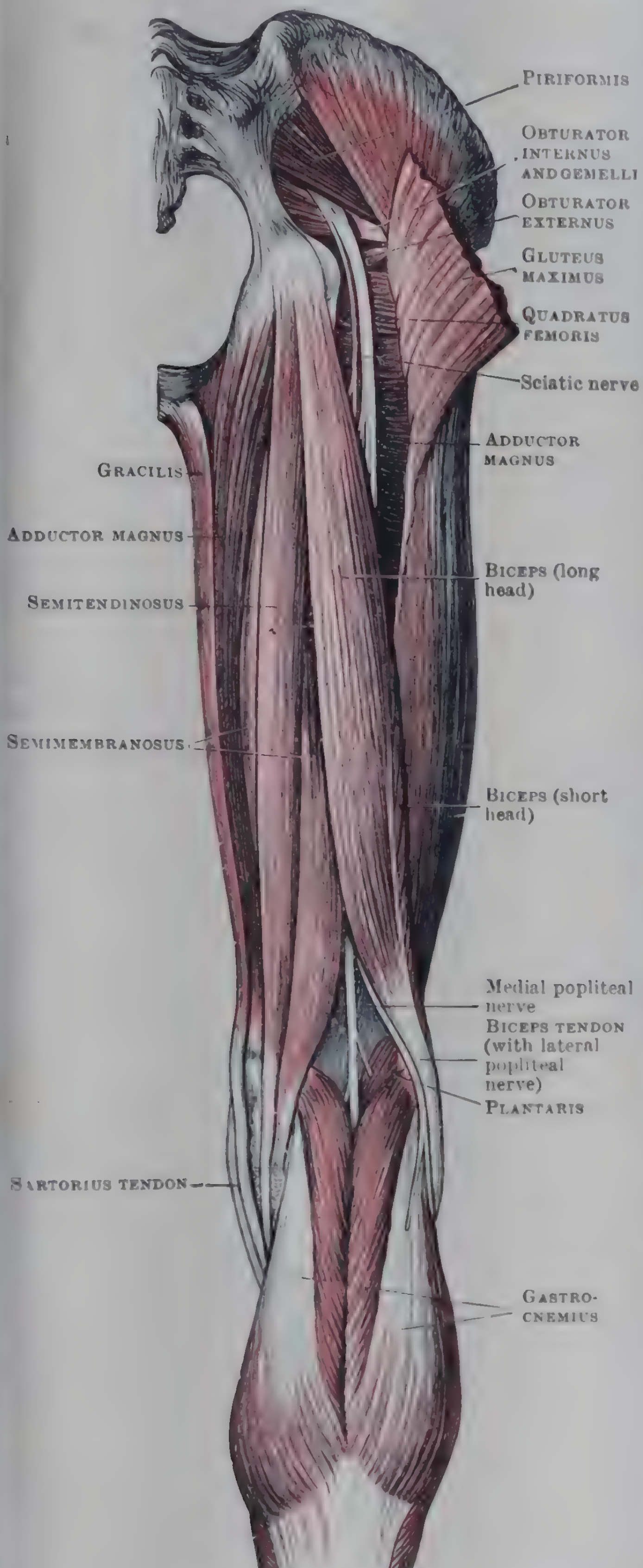

FIG. 446.—MUSCLES OF BACK OF RIGHT THIGH.

Semimembranosus.—The semimembranosus **arises** from the upper lateral facet on the ischial tuberosity (Fig. 445) by a strong membranous tendon from which the muscle

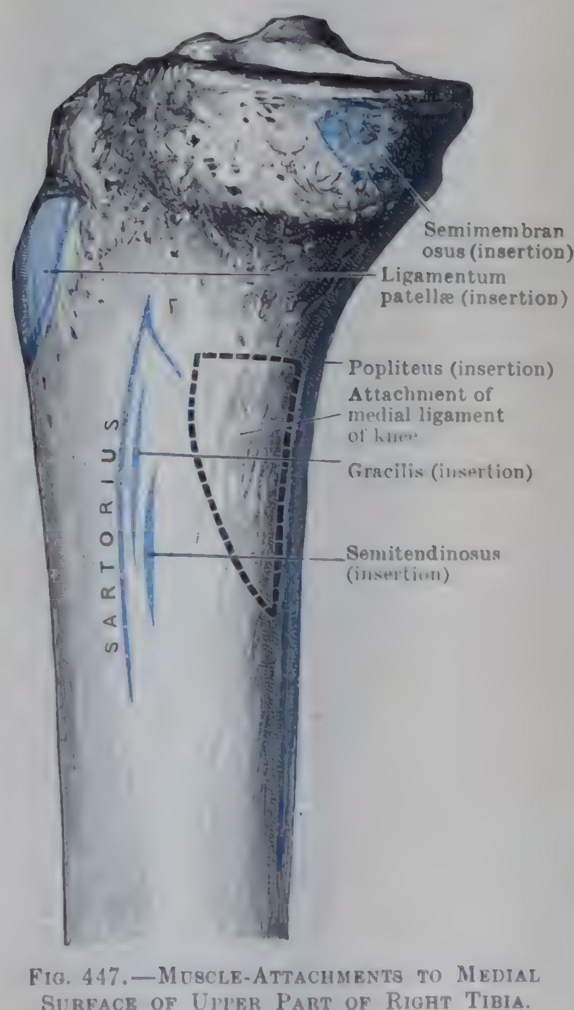

FIG. 447.—MUSCLE-ATTACHMENTS TO MEDIAL SURFACE OF UPPER PART OF RIGHT TIBIA.

derives its name. This membranous sheet is continued downwards along the lateral margin of the muscle, tapering to a point below the middle of the thigh, and giving origin to the rounded fleshy belly which, in the upper third of the thigh, lies in front of the semitendinosus and the long head of the biceps. Inclining medially, with the semitendinosus on its posterior surface, it ends, at the back of

the knee, in a thick, flattened tendon which is separated from the medial head of the gastrocnemius by a *bursa*, and is **inserted** into the horizontal groove on the postero-medial surface of the medial condyle of the tibia (Figs. 340, p. 384, and 447)—another *bursa* lying deep to the tendon near its insertion. It has three *additional membranous insertions*: (1) a fascial band extends downwards and medially to join the posterior border of the *medial ligament* of the knee joint; (2) another fascial band, extending downwards and laterally, forms the fascia on the popliteus muscle, and is attached to the soleal line of the tibia; and (3) a third strong band, extending upwards and laterally to the back of the lateral condyle of the femur, forms the *oblique posterior ligament* of the knee joint (Fig. 339).

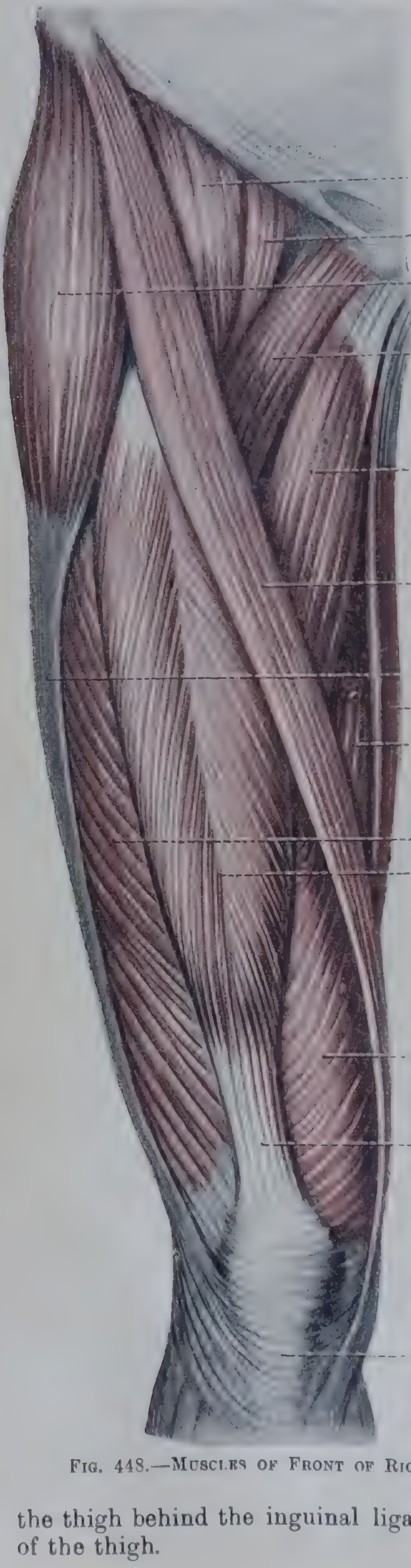

Fig. 448.—Muscles of Front of Right Thigh.

Nerve-Supply.—The hamstring muscles are all supplied by the **sciatic nerve**, by fibres from L. 4, 5, S. 1, 2, 3; when there is a high division of this nerve the fact is disclosed that, with the exception of the nerve to the short head of the biceps, the supply is derived from the part which becomes the medial popliteal nerve. The **semitendinosus** receives two branches—one above and the other below its tendinous intersection.

The **ischio-condylar portion of the adductor magnus** also is supplied from the sciatic nerve by a branch which usually arises in common with the nerve to the **semimembranosus**.

The **short head of the biceps** is separately supplied by a branch from the lateral popliteal part of the sciatic nerve (L. 5, S. 1, 2). (Cf. the supply of a portion of the brachialis in the arm by the radial nerve, p. 492.) The morphological significance of the association of the origin of the short head of the biceps with the insertion of the gluteus maximus is emphasized by the fact that its nerve may arise direct from the sacral plexus in common with the inferior gluteal nerve.

Muscles of Front of Thigh

The chief muscle of the front of the thigh is the quadriceps femoris. The sartorius descends obliquely between the quadriceps femoris and the adductor muscles. The ilio-psoas, after passing into the thigh behind the inguinal ligament, lies in the upper lateral part of the front of the thigh.

Sartorius.—The sartorius, a long strap-like muscle, **arises** from the anterior superior iliac spine and half of the margin of the notch below (Pl. XLIV, p. 529, Fig. 3). It passes obliquely across the front of the thigh, and, reaching its medial side, descends vertically across the medial side of the knee; it then inclines forwards to be **inserted**, by aponeurotic fibres, into the upper part of the medial surface of the shaft of the tibia above and in front of the insertions of the gracilis and the semitendinosus, and by its borders into fascial expansions which join the capsule and the medial ligament of the knee joint and the fascia of the leg.

The sartorius is superficial in its whole extent. Its upper third forms the lateral boundary of the femoral triangle; its middle third lies on the roof of the subsartorial canal which covers the femoral vessels; and its lower third is separated from the tendon of the gracilis muscle by the saphenous nerve and the saphenous branch of the descending genicular artery. The *tibial intertendinous bursa* lies deep to the tendon at its insertion, separating it from the tendons of the gracilis and semitendinosus.

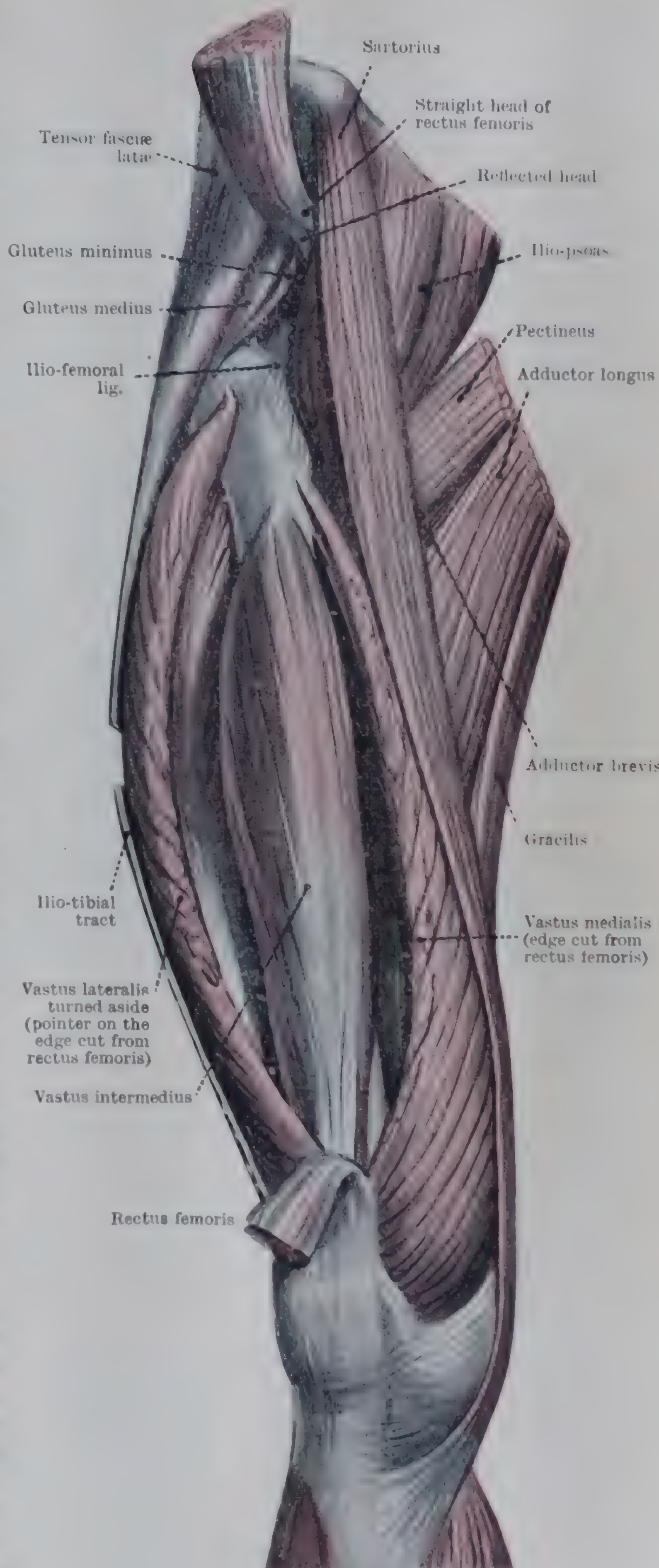

Fig. 449.—Dissection of Muscles of Front of Right Thigh.
The rectus femoris has been removed and the vastus lateralis and vastus medialis pulled apart to show the vastus intermedius.

Quadriceps Femoris.—The quadriceps femoris is composed of four muscles—rectus femoris, vastus lateralis, vastus intermedius, and vastus medialis. The vastus intermedius clothes the shaft of the femur and is overlain by the rectus in front and the other vasti laterally and medially (Fig. 449).

Rectus Femoris.—The rectus femoris, a flattened spindle-shaped muscle, has a double, tendinous **origin** by a *straight head* from the anterior inferior iliac

spine, and a *reflected head* from a rough groove on the ilium immediately above the acetabulum—a *bursa* lying deep to this origin. The two heads are bound together and connected to the capsule of the hip joint by the band of fascia derived from the fascia on the deep surface of the tensor fasciæ latæ, and they give rise to a single tendon. The tendon, at first deeply placed, appears in the cleft between the sartorius and the tensor fasciæ latæ and swells out into the fleshy belly, which descends over the front of the vastus intermedius and the margins of the other two vasti. Becoming a tendon again, it is **inserted** into the upper border of the patella. The tendon of origin spreads for some distance over the front of the muscle and sends a tendinous septum into the middle of its substance as far down as the middle of the thigh. The muscle-fibres arise from the tendon and the septum in a bipenniform fashion, and end chiefly in a prolongation which extends from the tendon of insertion upwards over the lower two-thirds of the back of the muscle. The tendon of insertion gradually narrows as it descends but widens out again near the patella; and it receives parts of the insertion of the vasti on its margins and deep surface.

Vastus Lateralis.—The vastus lateralis—a thick, broad muscle—has an **origin**, partly fleshy, partly membranous, from (1) the capsule of the hip joint, (2) the upper part of the trochanteric line, (3) the lower border of the greater trochanter, (4) the lateral margin of the gluteal tuberosity, (5) the upper half of the linea aspera, and (6) the fascia lata and the lateral intermuscular septum (Figs. 261, 262, pp. 294, 295).

Its fibres are directed downwards and forwards, and are **inserted** by a broad membranous tendon into (1) the tendon of the rectus femoris, (2) the upper and lateral borders of the patella, and (3) the front of the lateral condyle of the tibia—covering, and to a large extent replacing, the antero-lateral part of the capsule of the knee joint.

Vastus Medialis.—The vastus medialis is larger than the vastus lateralis; it has an extensive **origin** from (1) the lower half of the trochanteric line, the spiral line, the linea aspera, and the upper two-thirds of the medial supracondylar line; and (2) the medial intermuscular septum and the tendon of the adductor magnus (Figs. 261, p. 294, and 262, p. 295).

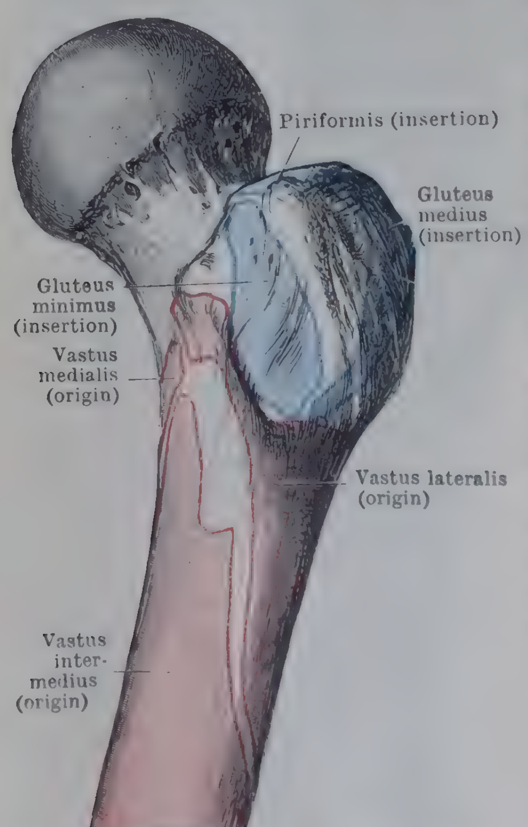

Fig. 450.—Muscle-Attachments to Front of Upper Part of Left Femur.

The muscle is directed downwards and laterally towards the knee, the lowest fibres being nearly horizontal. It is **inserted** by a strong aponeurotic tendon into (1) the rectus tendon, (2) the upper and medial borders of the patella, and (3) the front of the medial condyle of the tibia—covering and replacing the antero-medial part of the capsule of the knee joint. The muscle conceals the medial side of the shaft of the femur and the vastus intermedius, with which it is closely incorporated in its distal two-thirds.

Vastus Intermedius.—The vastus intermedius **arises** by fleshy fibres from—(1) the upper two-thirds of the shaft of the femur on the anterior and lateral surfaces—but not the medial surface; (2) the lower half of the lateral lip of the linea aspera and the upper part of the lateral supracondylar line; and (3) a corresponding portion of the lateral intermuscular septum (Figs. 261 and 262).

For the most part deeply placed, the muscle descends to an **insertion** into the deep surface of the tendons of the rectus and the other vasti muscles by fibres

which join a membranous expansion on its surface. It is closely adherent to the vastus lateralis muscle in the middle third of the thigh, and it is inseparable from the vastus medialis below the upper third. In the lower third it conceals the articularis genu muscle, and the *suprapatellar bursa*—an upward prolongation of the synovial membrane of the knee joint.

Articularis Genu.—This muscle consists merely of a number of small separate bundles that **arise**, deep to the vastus intermedius, from the lower fourth of the front of the femur and are **inserted** into the synovial membrane of the knee joint.

The four parts of the quadriceps femoris muscle have been traced in their convergence to the patella. Their ultimate **insertion** is into the tubercle of the tibia (Fig. 447), by means of the **ligamentum patellæ**; and the vasti muscles are in addition connected with the **retinacula of the patella**. The patella, indeed, is a *sesamoid bone*, playing the part of a lever and roller-bearing, formed in the

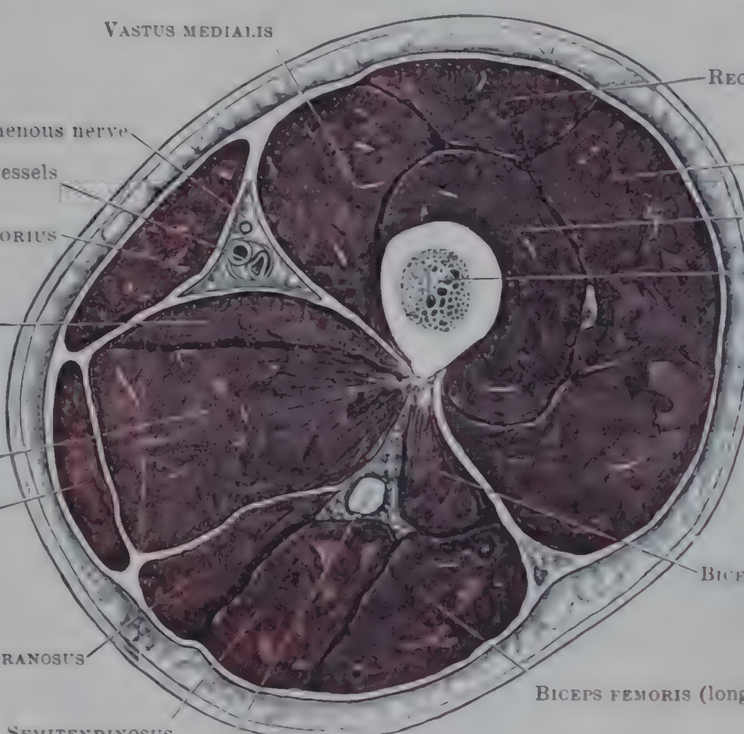

FIG. 451.—TRANSVERSE SECTION OF THIGH THROUGH THE SUBSARTORIAL CANAL.

tendon of the muscle, the ligamentum patellæ being the real tendon of insertion, and the retinacula being membranous expansions from its borders. The ligamentum patellæ replaces the anterior part of the capsule of the knee joint.

Nerve-Supply.—The four parts of the quadriceps femoris are supplied by separate branches of the **femoral nerve** (L. 3, 4); the sartorius receives its supply through two sets of nerves, in association with the lateral and medial parts of the intermediate cutaneous branch of the femoral nerve (L. 2, 3).

Muscles of Medial Side of Thigh

The muscles of the medial side of the thigh are the pectineus, the adductor muscles (longus, brevis, and magnus), the gracilis, and the obturator externus. The pectineus is included because of its situation and action, although it is supplied by the femoral nerve; and the obturator externus because of its situation and its nerve-supply from the obturator nerve.

The gracilis is superficially placed along the medial side of the thigh. The adductor muscles, situated in the medial part of the thigh between the hip bone and the femur, are in different vertical planes. The adductor longus is in the same plane as the pectineus and lies superficially in the femoral triangle; the adductor brevis, on a more posterior plane, is in contact with the obturator externus, and, with it, is largely concealed by the pectineus and adductor longus; the adductor

magnus, the largest and most posterior of these muscles, is in contact with the other adductors and the sartorius anteriorly, while its posterior surface is in relation to the hamstring muscles.

Gracilis.—The gracilis muscle, a long, flat band placed on the medial side of the thigh and knee, and superficial throughout its length, **arises** by a tendon, short, thin, and wide, from the lower half of the edge of the pubic symphysis and for a similar distance along the border of the pubic arch. Its tapering belly descends along the medial side of the thigh to lie between sartorius and semi-membranosus above the knee, and, at the knee, between the sartorius and semi-tendinosus; it ends in a tendon which expands to be **inserted** into the upper part of

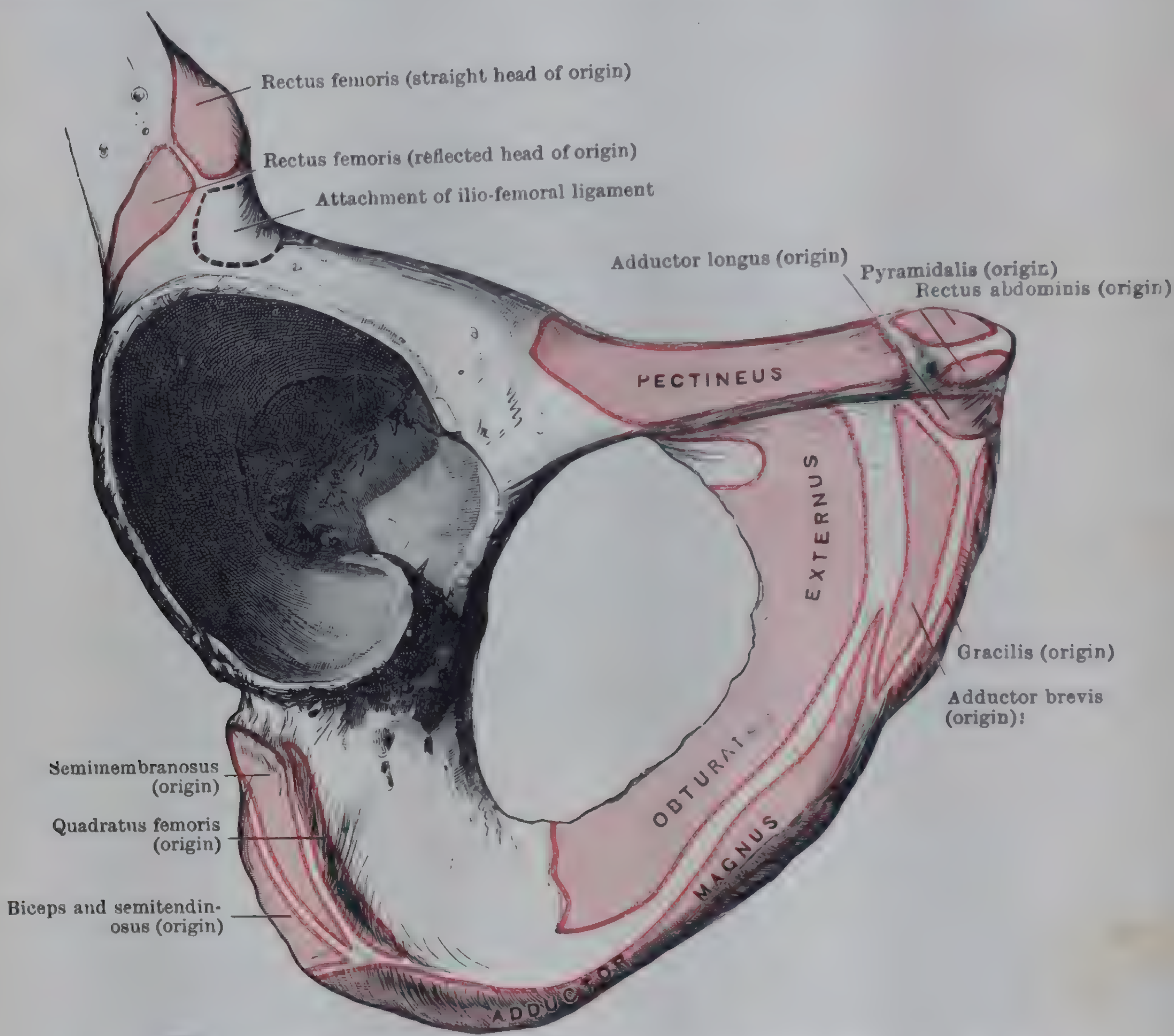

FIG. 452.—MUSCLE-ATTACHMENTS TO OUTER SURFACE OF RIGHT PUBIS AND ISCHIUM.
The actual origin of the pectineus is not so extensive as shown ; it arises from the upper part of the pectineal surface of the pubis and overlies the remainder.

the medial surface of the shaft of the tibia between the sartorius and the semi-tendinosus (Fig. 447). With semitendinosus, it is separated from the sartorius tendon by the *tibial intertendinous bursa*, and deep to its tendon there is a second *bursa* common to it and the semitendinosus.

Pectineus.—The pectineus muscle **arises** by fleshy fibres from the pectineal line and a small area on the medial part of the pectineal surface of the pubis and from the deep fascia which covers it. Forming a broad muscular band which lies in the floor of the femoral triangle between the psoas major and the adductor longus, it is **inserted** by a thin tendon, about two inches in width, into the upper half of a line that leads from the back of the lesser trochanter to the linea aspera (Fig. 441). The muscle is occasionally divided into medial and lateral parts—the medial innervated by the obturator, the lateral by the femoral nerve.

Adductor Longus.—The adductor longus—a triangular muscle, lying in the floors of the femoral triangle and subsartorial canal—**arises** by a strong tendon

from the femoral surface of the body of the pubis in the angle between the crest and symphysis (Fig. 452). Extending downwards and laterally, it spreads out to be **inserted** by a very thin, wide tendon into the medial lip of the linea aspera between the adductor magnus and vastus medialis. It lies between the pectineus and the gracilis, in front of the adductor brevis and magnus and the profunda vessels; superficially, its upper part is covered only with fascia and skin (but is crossed near its origin by the spermatic cord), and its lower part is related to the sartorius, the vastus medialis and the femoral vessels.

Adductor Brevis.—The adductor brevis is a large muscle which **arises** from an elongated area on the femoral surface of the body and inferior ramus of the

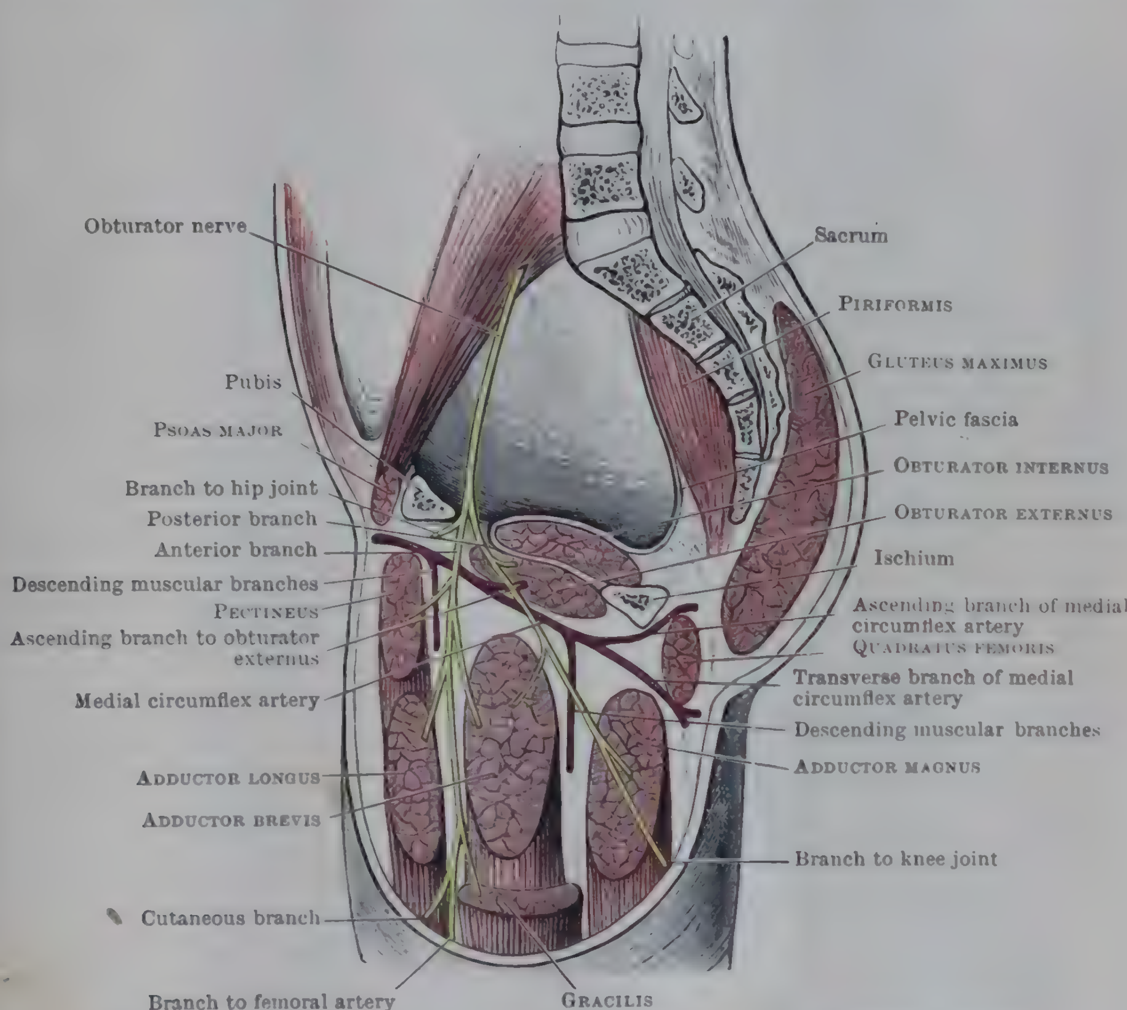

Fig. 453.—Scheme of Adductor Group of Muscles and Obturator Nerve.

pubis, surrounded by the other muscles of this group (Fig. 452). Directed downwards and laterally, the muscle expands to be **inserted**, by a short, aponeurotic tendon, behind the insertions of the pectineus and adductor longus, into the lower two-thirds of the line leading from the lesser trochanter to the linea aspera, and to the upper half of the linea aspera itself (Fig. 441, p. 516). It is in relation anteriorly with the pectineus and adductor longus, posteriorly with the adductor magnus; its upper border is crossed by the obturator externus and the tendon of the ilio-psoas; and its lower border is applied to the gracilis and adductor magnus.

Adductor Magnus.—This is the largest muscle of the adductor group and is triangular in outline. It **arises**, mainly by fleshy fibres, from the lower lateral impression on the ischial tuberosity and from the conjoined rami of the ischium and pubis—its most anterior fibres arising between the obturator externus and adductor brevis (Fig. 452). Its upper fibres are directed horizontally and laterally from the pubic bone towards the upper part of the femur; the lowest fibres descend from the ischial tuberosity to the medial condyle of the femur; and the intervening fibres radiate obliquely laterally and downwards. The muscle is **inserted** into the femur by tendinous fibres—(1) into a line extending from the

insertion of the quadratus femoris, medial to the gluteal tuberosity, to the linea aspera; (2) into the whole length of the linea aspera; (3) into the medial supracondylar line; and (4) into the adductor tubercle by a strong tendon derived from the fibres which arise from the ischial tuberosity. The tendon is bound to the medial supracondylar line by a tendinous sheet, and is partly continuous below with the medial ligament of the knee joint. The attachment to the linea aspera is interrupted by a series of tendinous arches which are thrown over the perforating branches of the profunda femoris artery, and the attachment to the supracondylar line is similarly interrupted by a larger archway—the **opening in the adductor magnus**—for the passage of the femoral vessels into the popliteal fossa.

Fig. 454.—Deep Muscles of Back of Right Thigh.

The part of the muscle attached between the insertion of the quadratus femoris and the linea aspera is often separated from the rest as the **adductor minimus.**

The muscle is covered anteriorly by the other adductors and by the sartorius muscle. The adductor brevis and the profunda femoris vessels lie between it and the adductor longus muscle; and the femoral vessels are in contact with it in the distal part of the subsartorial canal. The posterior surface of the muscle is in relation with the hamstring muscles and the sciatic nerve.

Obturator Externus.—The obturator externus, placed deeply, under cover of the preceding muscles, is a fan-shaped muscle that lies horizontally in the angle between the hip bone and the neck of the femur. It **arises** from the surfaces of the pubis and ischium which form the medial half of the margin of the obturator foramen, and from the corresponding portion of the superficial surface of the obturator membrane (Figs. 452, and 253, p. 287). The fibres of the muscle converge on the wide groove below the acetabulum and end in a stout tendon which passes obliquely across the back of the neck of the femur to be **inserted** into the trochanteric fossa (Fig. 441, p. 516); in its course it overlaps the capsule of the hip joint, from which it is usually separated by the synovial *bursa of the obturator externus.*

Nerve-Supply.—The principal nerve of supply to the adductor group of muscles is the **obturator** (L. 2, 3, 4); the anterior branch (L. 2, 3, (4)) is distributed to the **gracilis**, the **adduct**

PLATE XLIII

PLATE XLIII.—PHOTOGRAPHIC ILLUSTRATION OF MUSCLES IN ACTION. (From Lockhart's *Living Anatomy*, 1948, by permission of Messrs. Faber & Faber.)

The subject is 'setting' the muscles of the leg. Note the concavity of the popliteal fossa behind the flexed knee and the fullness of that region behind the straight knee.

PLATE XLIV

Fig. 1.—Activity of the Calf Muscles in Rising on the Toes.

Fig. 2.—Activity of Muscles in Extension and Resisted Flexion of Leg.

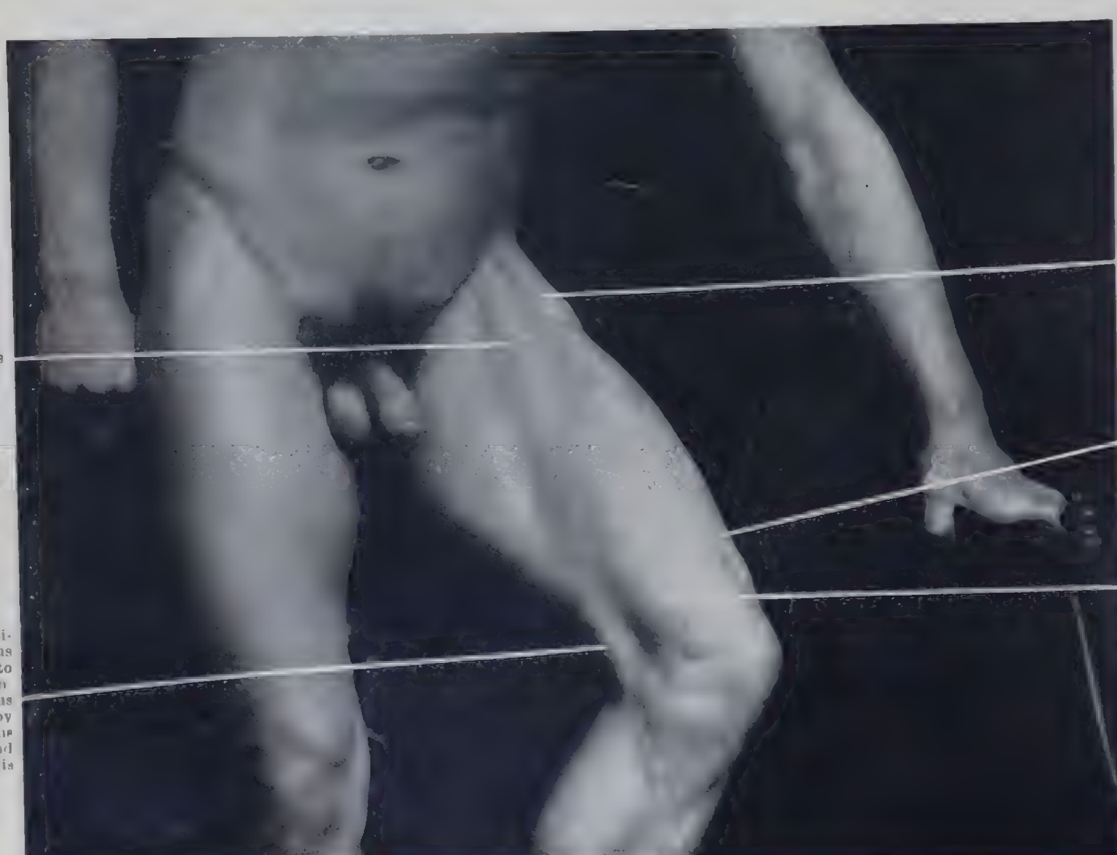

Fig. 3.—The Sartorius in Action.

Plate XLIV.—Photographic Illustrations of Muscles in Action.

[Facing

longus, and the **adductor brevis**; the posterior branch (L. 3, 4) to the **obturator externus** and the **adductor magnus**. The **adductor magnus** is, however, a double muscle and has a double nerve-supply. The *adductor* portion is supplied (on its anterior surface) by the posterior branch of the obturator: the *ischio-condylar* portion, associated with the hamstring group of muscles, is supplied (on its posterior surface) by a branch from the sciatic nerve (L. 4, 5 (S. 1)).

The **pectineus**, although it belongs functionally to the adductor group on account of its situation and action, is always supplied by a branch of the **femoral nerve** (L. 2, 3)—an indication of its morphological association with the ilio-psoas; it occasionally receives an additional nerve from the obturator, or from the accessory obturator nerve, when that nerve is present.

Femoral Triangle.—The femoral triangle is a large triangular space, in the upper third of the front of the thigh, which contains the femoral vessels in the first part of their course and the femoral nerve. It is bounded above by the inguinal ligament, laterally by the sartorius, and medially by the medial border of the adductor longus muscle. Its floor is formed laterally by the ilio-psoas, and medially by the pectineus, adductor longus, and, occasionally, a small part of the adductor brevis.

Subsartorial Canal (Hunter's Canal).—The subsartorial canal is in the middle third of the medial part of the thigh; it contains the femoral vessels (in the distal half of their course) and the saphenous nerve. It is bounded *antero-laterally* by the vastus medialis; *postero-medially* by the adductor longus and magnus; *antero-medially* (or superficially) by the sartorius; deep to the sartorius, a dense membrane, derived from the fascia lata, binds the other two boundaries together and bridges across the femoral vessels.

Action of Muscles in Movements at the Hip Joint.—In considering the muscles that move the joints of the lower limb we have to remember that they act from one end when the trunk is moved upon the limb and from the other when the limb is moved upon the trunk—conditions illustrated respectively in the supporting side and the advancing side during walking. Again, the line of the body-weight transmitted through the supporting limb must be observed, for its position, say, in front of the axis of movement of a joint, will call the antagonists of that movement into action. Though the muscles may be arranged in flexor, extensor, adductor, abductor, and rotator groups, individual muscle action is not always wholly in agreement with these terms, but may merge into the action of other groups. Action of the muscles that move the hip is usually associated with action at the other joints of the limb, for the hip is seldom flexed without accompanying, automatic flexion of the knee: indeed, if the knee is voluntarily kept extended, the flexors of the hip will be limited in their action by the inability of the hamstrings to relax unless trained to do so—as in the high kick. It is, therefore, largely a theoretical practice to consider the action at one joint alone: the muscular activity at all the joints must be reviewed when any one is considered. The extensors of the hip are stronger than the flexors in Man; and the adductors and lateral rotators are far more powerful than the abductors and medial rotators.

The **gluteus maximus** is mainly an extensor of the thigh, and has a powerful action in straightening the lower limb, as in climbing or running. Its lower fibres also adduct the thigh and rotate it laterally. Acting from its insertion the muscle (assisted by the hamstring group) is a powerful extensor of the trunk on the lower limbs and is called into play when the body is being raised from the sitting or stooping position; when these attitudes are being assumed from the erect position, its relaxation under tension is the main factor. The action of this muscle is all the more important in view of the fact that when the body is bent forwards, as in stooping to touch the floor, the vertebral column plays but a small part in the movement, which is mainly secured by relaxation of the gluteus maximus (and **hamstrings**) permitting flexion at the hip joint (Pl. XXXI, p. 346, Fig. 1). The **tensor fasciæ latæ** assists in flexion, abduction and medial rotation of the thigh, but its most important action is exerted in counteracting the backward pull of the gluteus maximus on the ilio-tibial tract; by this action it assists in maintaining extension of the knee, and it has, therefore, been found a suitable muscle to transplant as substitute for a paralysed quadriceps femoris (Dunn & Stuart, 1924). The **gluteus medius** is a powerful abductor of the thigh for all positions of the limb, and a medial rotator of the extended thigh. The **gluteus minimus** is primarily an abductor of the thigh, but its anterior fibres, in addition, produce medial rotation, and its posterior fibres lateral rotation of the extended limb. Both the gluteus medius and gluteus minimus take an active part in the movements of the pelvis associated with walking, and their paralysis (much more serious than that of gluteus maximus) severely alters the gait, causing a peculiar

lurching style of walk. When one limb leaves the ground, the centre of gravity of the body no longer falls within the area of support, but the action of gravity is successfully opposed by the abductors of the opposite side. Further, as one limb advances, the pelvis is rotated to the opposite side by the gluteus medius and minimus of that side (see pp. 408 and 549). In this connection, the muscular control of gravitational movement is highly important. The moment the abductors, acting against gravity, have poised the trunk upon, say, the right limb, any further inclination to the right (which would be assisted by gravity) results in immediate flaccidity of the abductors, and powerful action of the adductors, which permit the desired inclination by relaxing under tension. There is a position of equilibrium in which the two sets of muscles have little action; but the alternate contraction of one or other group is readily seen in varied movements of the trunk poised on one limb.

The lateral rotators of the thigh are the **piriformis**, the **obturator internus** with the **gemelli**, the **quadratus femoris**, and the **obturator externus**. The piriformis and obturator internus act as lateral rotators of the extended thigh, and as abductors when the limb is flexed; the quadratus femoris and obturator externus, in addition to their action as lateral rotators, are adductors. These short muscles probably have more important actions in restraining movements at the hip joint, *i.e.*, ligamentous action, and they act as postural and articular muscles like those of the shoulder (p. 487) in facilitating movement effected by the more powerful muscles.

The chief flexors of the hip joint are the **psoas major** and the **iliacus**; their action is accompanied by a slight degree of medial rotation. (*N.B.*—The axis of rotation does *not* correspond to the shaft of the femur but to a line drawn from the middle of its head to the centre of the intercondylar notch when the limb is extended.) The ilio-psoas advances the limb in walking, and its paralysis interferes with the normal gait. In addition, acting from their insertions, the ilio-psoas muscles can flex the trunk on the lower limbs against resistance, and the psoas major can produce lateral flexion of the vertebral column. The **psoas minor** assists in the latter movement, and in flexing the pelvis on the vertebral column, or the vertebral column on the pelvis. When the knee is extended the **rectus femoris** is a powerful assistant of the ilio-psoas as a flexor of the hip joint; it has indeed been maintained that flexion of the hip joint is the chief action of that part of the quadriceps. The straight head of the rectus is taut when the movement begins, but it becomes a little relaxed and the reflected head is tightened when the thigh becomes flexed. When the body is recumbent, with the knees extended, the two recti assist the ilio-psoas muscles to flex the trunk on the hips.

In addition to their chief action, the muscles of the adductor group assist in other movements at the hip joint. The **pectineus,** while mainly an adductor, is also a flexor of the hip; the **adductors longus** and **brevis** assist in flexion and lateral rotation; the proximal part of the **adductor magnus** has a similar action, while the distal fibres, acting with the hamstrings, take part in extension of the femur and may assist in medial rotation.

The hamstring muscles (**long head of the biceps, semitendinosus,** and **semimembranosus**), in virtue of their attachment to the ischial tuberosity, assist the gluteus maximus in extension of the thigh.

Action of Muscles in Movements at the Knee Joint.—In addition to the flexor and extensor groups of the thigh, the muscles of the leg which take origin from the femur are concerned in movements at the knee joint. The greater power of the flexors compared with the extensors (in contrast with the hip joint) is again a human characteristic.

The **quadriceps femoris** is the great extensor of the limb at the knee joint; it can be felt in action both when one rises from the sitting position and when one assumes that position—taking active part in the first movement and controlling the other. The tendency for the patella to be pulled laterally as well as upwards is counteracted by the distal, horizontal fibres of the vastus medialis. The **articularis genu** draws the synovial membrane of the joint upwards during this movement.

The hamstring muscles are essentially flexors of the leg at the knee joint. When the knee is flexed the **biceps** is, in addition, a lateral rotator of the leg, and the **semitendinosus** and **semimembranosus** are additional medial rotators.

The **sartorius** —"the tailor's muscle"—is a feeble flexor of both the hip joint and the knee joint. It also adducts the thigh and rotates it laterally, and it assists in medial rotation of the tibia. The **gracilis** muscle has a similar flexing and rotating action at the knee joint.

Three muscles of the leg also act upon the knee joint. The **gastrocnemius,** assisted by the feeble action of the **plantaris,** takes part in flexing the leg upon the thigh when resistance is encountered as in Pl. XLIV, p. 529, Fig. 2. The **popliteus**

has a special action as a medial rotator of the tibia and a flexor of the knee. It is believed that the popliteus muscle is responsible for the unlocking movement of medial rotation of the tibia which occurs immediately before, or synchronous with, the initial stage of flexion of the fully extended knee joint. The popliteus and the short head of the biceps are the only two flexors of the knee confined in their action to that joint. As the hip and knee are usually both flexed or both extended together, their flexors and extensors work in unison. Some muscles, *e.g.*, the rectus femoris and the long head of the biceps, act upon both joints, as extensors of one and flexors of the other, and they may be unable, individually, to secure at the same time the maximum movement at both, *e.g.*, the rectus femoris having extended the knee may not be able to secure full flexion of the hip, even if the hamstrings are relaxed as in the high kick. The last stage of flexion of the hip in this exercise may be due to the momentum imparted to the limb in the initial stage of the movement. Again, the long head of the biceps (the muscular fibres of which are shorter than those of the short head), cannot flex the knee so far when the hip is extended. Quite apart from this point, the flexors of the knee do not, in the average person, secure the full flexion at this joint even when the hip is flexed, though the momentum of a slight backward kick can carry the heel into contact with the thigh, and the weight of the body may secure the full movement, as in sitting upon the heels. The main point is that the muscles are efficient for all natural movements, that their abilities are remarkably increased by training, and that contortionist movements are executed either by the aid of gravity or by pulling the limbs into place while appropriate muscles are stretched or relaxed. For postural action, see pp. 409, 543, 549. (See Pl. XLIII, p. 528, and Pl. XLV, Figs. 1 & 2, p. 546.)

FASCIÆ OF THIGH AND GLUTEAL REGION

The **superficial fascia** of the thigh and gluteal region is continuous above with the fascia of the abdomen and back, medially with that of the perineum, and below with that of the leg. It presents noticeable features in the gluteal region and the groin.

In the gluteal region the superficial fascia is of considerable thickness, and is usually loaded with fat, thereby contributing to the contour of the buttock and the formation of the fold of the buttock.

In the groin it is divisible into *two layers*, separated from each other by the superficial inguinal lymph-glands and subcutaneous vessels: a superficial **fatty layer**, continuous with the similar layer on the anterior surface of the abdominal wall and in the perineum, and a deeper **membranous layer**. The deeper layer is attached medially to the pubic arch, where it is continuous with the membranous layer of the superficial fascia of the perineum (p. 468); lateral to the arch it blends with the deep fascia of the thigh a short distance below the inguinal ligament; superiorly, it is continuous with the similar layer in the abdominal wall. Its attachments cut off the more superficial tissues of the thigh from the perineum and the abdominal wall, preventing the passage into the thigh of fluid collected in the perineum or beneath the fascia of the abdominal wall.

The **deep fascia** forms a tubular investment for the muscles and vessels of the thigh and extends upwards over the muscles of the gluteal region. It is firmly attached above to the iliac crest, the sacro-tuberous ligament, the ischium, the pubic arch, the pubic symphysis and crest, and the inguinal ligament. In the distal part of the thigh the intermuscular septa are connected with its deep surface; and, in the region of the knee, it is continuous with the deep fascia of the leg and gains attachment to the condyles of the tibia, the head of the fibula, and the patella—forming the medial and lateral retinacula of the patella. The portion that invests the thigh is called the **fascia lata**.

The immediate relations of the fascia lata in its descent from the inguinal ligament will be appreciated best if we consider first of all the disposition of structures as they cross the inguinal border between abdomen and thigh (Figs. 456, 457).

The **transversalis fascia** and **fascia iliaca** (different names for different parts of the same fascial sheath, p. 465) are prolonged in an oval, funnel-like tube—the **femoral sheath**—upon the front and back respectively of the vessels that pass

behind the inguinal ligament from the abdomen into the thigh. At the lateral side of the lip of the funnel these two layers are confluent; lateral to this point they are blended in their attachment to the inguinal ligament, and therefore are not prolonged into the thigh. At the medial side of the lip the two layers, again confluent, course past the lateral edge of the pectineal part of the inguinal ligament. Behind the inguinal ligament there are, therefore, two large compartments—a medial and a lateral. The medial compartment transmits the femoral sheath (itself divided into three compartments); the lateral transmits the ilio-psoas muscle, the femoral nerve, and the lateral cutaneous nerve of the thigh.

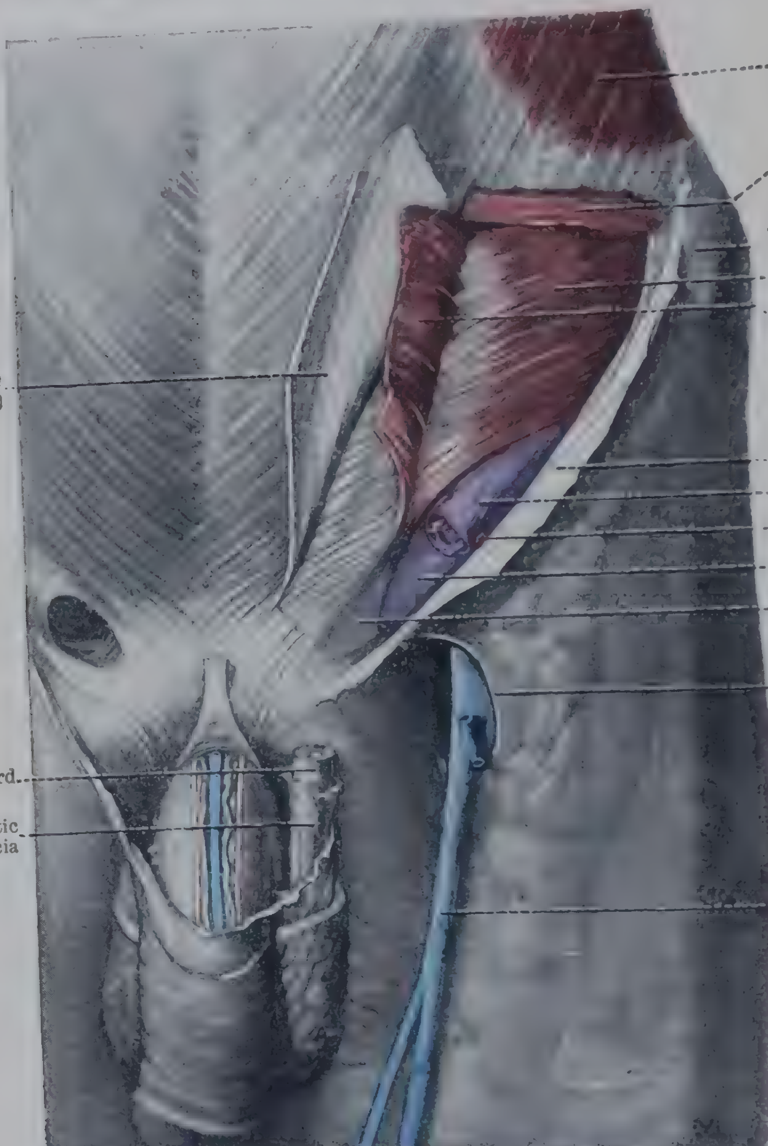

Fig. 455.—Dissection of Left Saphenous Opening.

(Bearing in mind the fact that the fascia iliaca, stretching from the iliac crest to the brim of the pelvis, thus strapping down the ilio-psoas in the iliac fossa, is continued upwards over the surface of the psoas major, it will be readily understood that inflammatory exudates from disease of the 'psoas' vertebræ track down on the surface of the muscle, behind the fascia iliaca and run behind the inguinal ligament in the muscular compartment to enter the thigh behind the fascia lata, lateral to the femoral sheath.) The femoral sheath, then, has a cover of fascia lata in front, while its bed is a muscular furrow formed by the ilio-psoas muscle and the pectineus, both covered with deep fascia—the fascia on the pectineus being tucked in behind the sheath to fuse with the capsule of the hip joint and with the fascia of the ilio-psoas in the thigh. The femoral sheath, itself, is divided by septa into three tubes—a lateral for the artery, an intermediate for the vein, and a medial named the femoral canal. The **femoral canal** contains some fat and a few lymph-vessels; its upper end—named the **femoral ring**—covered with

peritoneum and possibly occupied by a lymph-gland, is situated between the femoral vein and the lateral margin of the pectineal part of the inguinal ligament. The sheath is about an inch and a half long and terminates in the region of the saphenous opening, becoming lost upon the coats of the vessels. Its lateral wall is pierced by the femoral branch of the genito-femoral nerve and its anterior wall by the long saphenous vein.

On the front of the thigh, then, the fascia lata, continued from the inguinal ligament, is immediately applied to the femoral sheath in the intermediate area, to the ilio-psoas and sartorius laterally, and to the pectineus and adductor longus medially. But in this region—opposite the contiguous margins of the pectineus and psoas and the medial part of the femoral sheath—it presents an oval gap, named the saphenous opening. The **saphenous opening** is immediately below the medial part of the inguinal ligament; it is about an inch and a half long and half an inch wide, and its centre is an inch and a half below and lateral to the pubic tubercle. Medially, it is bounded by the sloping, anterior surface of the pectineus, covered with fascia extending laterally posterior to the femoral sheath. Its upper, lateral, and lower boundaries form one sharp, curved edge called the **falciform margin** of the opening, over whose lower part the long saphenous vein dips backwards to pierce the femoral sheath and enter the femoral vein—which is opposite the opening, while the artery is overlapped by the lateral boundary. The opening is closed by a layer of fibrous and fatty tissue which is perforated by the long saphenous vein, small arteries and lymph-vessels, and is therefore termed the **cribriform fascia**.

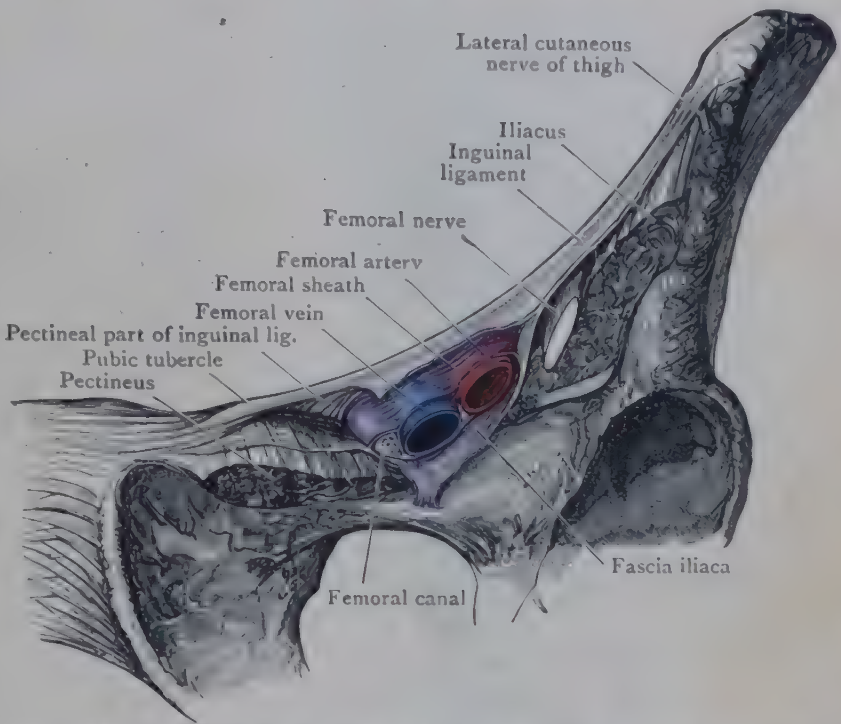

FIG. 456.—DISSECTION TO SHOW FEMORAL SHEATH AND STRUCTURES WHICH PASS BETWEEN INGUINAL LIGAMENT AND HIP-BONE.

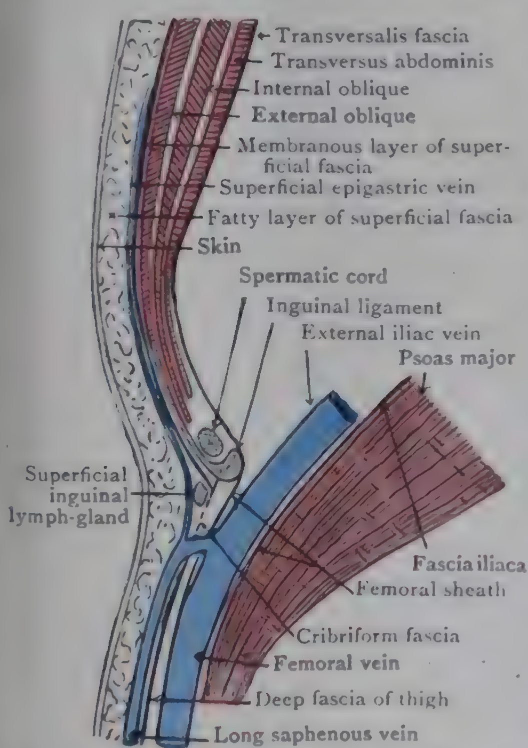

FIG. 457.—DIAGRAM OF FASCIÆ AND MUSCLES OF INGUINAL AND SUBINGUINAL REGIONS IN THE LINE OF THE SAPHENOUS OPENING.

When herniation occurs down through the femoral ring, femoral canal, and saphenous opening, the condition is termed a *femoral hernia*. This, subsequently rising up on to the abdominal wall, may be mistaken for an inguinal hernia; the successful reduction of both types depends upon their being made to retrace their different anatomical routes. The coverings of a femoral hernia, in addition to extra-peritoneal tissue, are the femoral sheath, cribriform fascia, superficial fascia and skin.

The fascia lata is pierced by numerous vessels and nerves, but the largest and most important aperture is the saphenous opening just described (Fig. 455).

On the medial side of the thigh, where it covers the adductor muscles, the fascia lata is thin. At the knee it is associated with the tendons of the vasti muscles, and forms the medial and lateral **retinacula of the patella**, attached to the borders of the patella and to the condyles of the tibia. On the lateral side of the thigh it is thickened by longitudinal fibres to form the **ilio-tibial tract**. This wide, strong band extends from the tubercle of the iliac crest to the lateral condyle of the tibia and the capsule of the knee joint. It receives the insertion of three-quarters of the gluteus maximus and the whole of the tensor fasciæ latæ, and it is continuous with both of the layers of fascia that enclose the tensor.

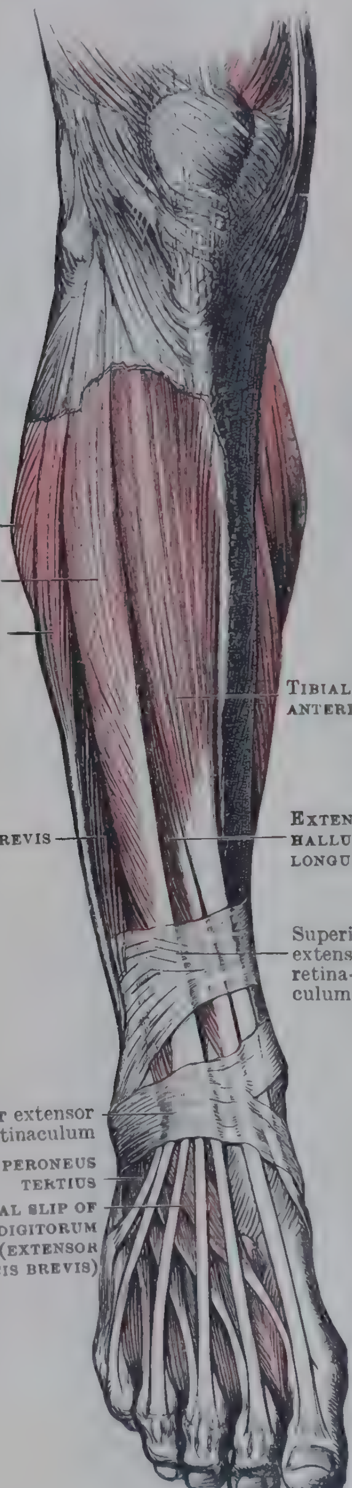

FIG. 458.—MUSCLES OF FRONT OF LEG AND DORSUM OF FOOT OF RIGHT SIDE.

On each side of the thigh above the knee an intermuscular septum is formed. The **lateral intermuscular septum** extends from the ilio-tibial tract to the lateral supracondylar line and the linea aspera of the femur, giving attachment to the vastus lateralis and intermedius anteriorly, and the short head of the biceps posteriorly. The **medial intermuscular septum,** in the distal third of the thigh, is associated with, and to a large extent represented by, the tendon of insertion of the adductor magnus muscle. It is related also to the fascia which envelops the adductor muscles and forms the sheaths of the sartorius and gracilis. In the middle third of the thigh the fascia under the sartorius is greatly thickened by transverse fibres and binds the vastus medialis to the adductor longus and magnus. That layer of fascia roofs over the femoral vessels in their course through the *subsartorial canal.*

On the **back of the thigh** and over the **popliteal fossa** the fascia is strengthened by transverse fibres. The fascia forming the roof of the popliteal fossa is specially thick, and is usually pierced by the short saphenous vein and the posterior cutaneous nerve of the thigh.

The **fascia of the gluteal region** is thick anteriorly, where it covers and gives origin to the gluteus medius, but is much thinner posteriorly, where it splits to enclose the gluteus maximus. Over the greater trochanter it becomes continuous with that part of the ilio-tibial tract into which most of the fibres of the gluteus maximus gain insertion.

MUSCLES AND FASCIÆ OF LEG AND FOOT

The muscles of the leg and foot are divisible into three series: (1) the extensor muscles on the front of the leg and dorsum of the foot; (2) the peroneal muscles on the lateral side of the leg; and (3) the flexor muscles on the back of the leg and in the sole of the foot.

Muscles on Front of Leg and Dorsum of Foot

These muscles are the tibialis anterior, the extensor hallucis longus, the extensor digitorum longus and peroneus tertius, and the extensor digitorum brevs.

On the front of the leg the tibialis anterior, extensor digitorum longus and peroneus tertius are superficially placed, and conceal the extensor hallucis longus muscle. On the dorsum of the foot, the extensor digitorum brevis is deep to the tendons of the extensor digitorum longus and peroneus tertius.

Tibialis Anterior.—The tibialis anterior **arises** from the lateral condyle and the upper two-thirds of the lateral surface of the shaft of the tibia, from the interosseous membrane, from the deep fascia, and from an intermuscular septum laterally. The muscle ends in a strong tendon which becomes free in the lower third of the leg and passes downwards and medially over the front of the distal end of the tibia, the ankle joint, and the dorsum of the foot, to be **inserted** into the medial sides of the medial cuneiform and base of the first metatarsal bone near the sole (Fig. 294, p. 319). Special compartments, lined with a separate synovial sheath, are provided for the tendon in both the superior and inferior extensor retinacula.

The double insertion recalls the double muscle in pronograde apes.

The **tibio-fascialis anterior** is a separated portion of the muscle occasionally present, inserted into the fascia on the dorsum of the foot.

Extensor Digitorum Longus.—This is a pennate muscle which **arises**, by fleshy fibres, from the lateral side of the lateral condyle of the tibia, from the upper two-thirds or more of the anterior surface of the shaft of the fibula, from the deep fascia and intermuscular septa, and from the upper part of the interosseous membrane.

It gives rise to a tendon which passes deep to the superior

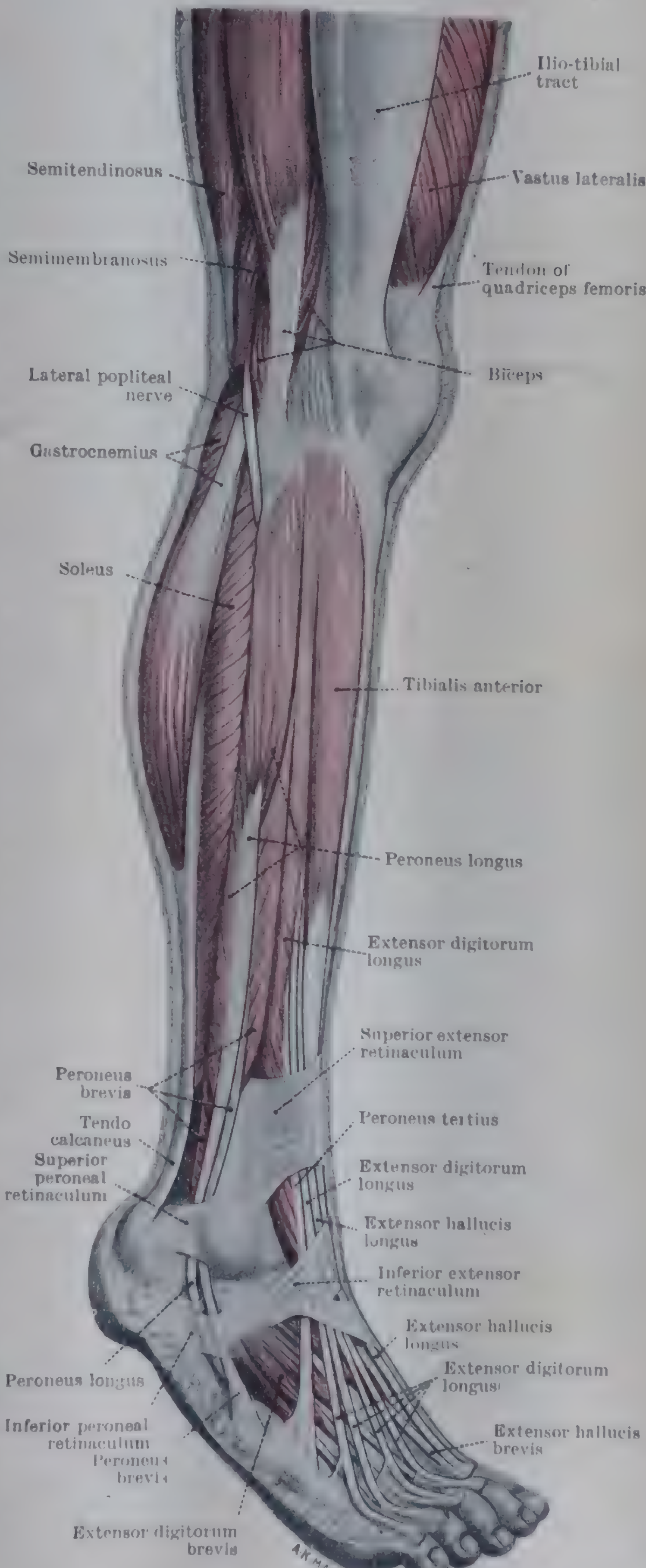

FIG. 459.—MUSCLES OF KNEE, LEG, AND DORSUM OF FOOT SEEN FROM LATERAL SIDE.

extensor retinaculum, and divides into four tendons on the front of the ankle, under cover of the inferior extensor retinaculum; these tendons, together with the tendon of the peroneus tertius, are enclosed in a single synovial sheath as they lie in the most lateral compartment of this retinaculum. They are **inserted** into the lateral four toes, exactly in the same way as the corresponding tendons in the hand (see p. 502), and form membranous expansions on the dorsum of the proximal phalanx, joined by the tendons of the extensor digitorum brevis, lumbricales, and interossei, and each then separates into one middle and two collateral slips, attached respectively to the middle and distal phalanges.

Peroneus Tertius.—The peroneus tertius, very variable in its size and sometimes absent, is a partially separated portion of the extensor digitorum longus. It **arises** (inseparably from the extensor) from the lower part of the anterior surface of the fibula, and from the intermuscular septum on its lateral side. Its tendon is **inserted** into the dorsum of the fifth metatarsal bone near its base.

Extensor Hallucis Longus.—The extensor hallucis longus **arises** from the anterior surface of the fibula in its middle three-fifths, medial to the origin of the extensor digitorum longus, and for a corresponding extent from the interosseous membrane. Its tendon passes over the dorsum of the foot, to be **inserted** into the base of the distal phalanx of the big toe. As the tendon lies under cover of the superior extensor retinaculum, it occupies the same compartment as the extensor digitorum longus and the peroneus tertius, but, in the inferior extensor retinaculum, it is provided with a special compartment, lined with a separate synovial sheath.

It is occasionally inserted also by separate slips into the proximal phalanx and the metatarsal bone.

Extensor Digitorum Brevis.—The extensor digitorum brevis **arises** from the fore part of the upper surface of the calcaneum and from the deep surface of the inferior extensor retinaculum. It usually divides into four fleshy bellies from which narrow tendons are directed forwards and medially to be **inserted** into the medial four toes. The lateral three tendons join those of the long extensor muscle to form the membranous expansions on the dorsum of the toes. The *most medial tendon* (**extensor hallucis brevis**), after crossing the dorsalis pedis artery, is inserted separately into the base of the proximal phalanx of the big toe.

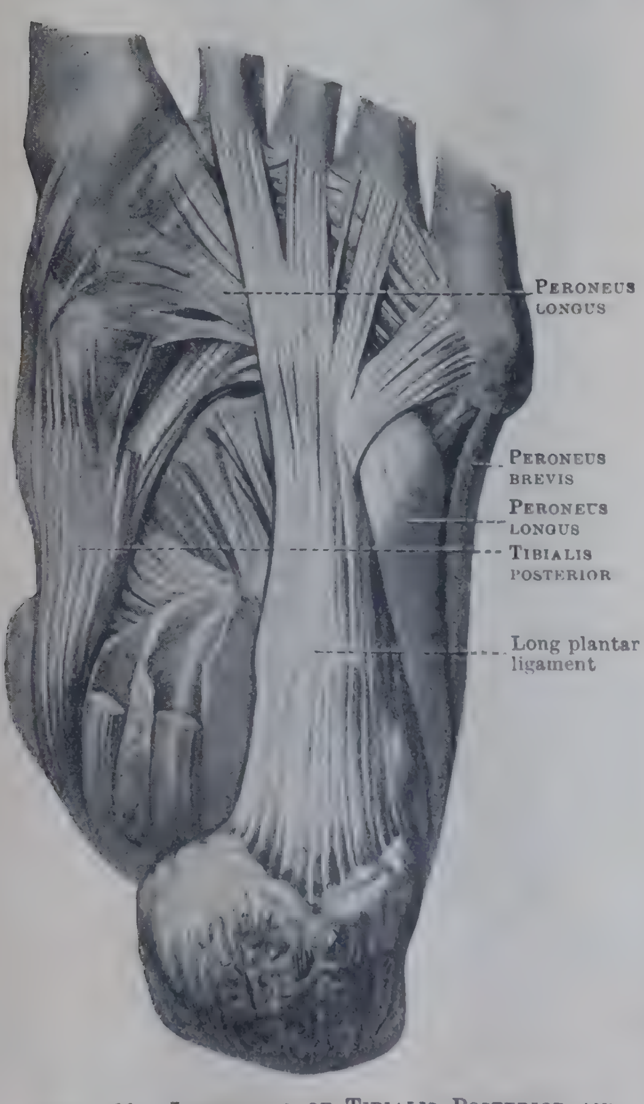

FIG. 460.—INSERTIONS OF TIBIALIS POSTERIOR AND PERONEUS LONGUS IN SOLE OF LEFT FOOT.

Muscles on Lateral Side of Leg

The peroneal muscles—longus and brevis—occupy a special osteo-fascial compartment on the lateral side of the leg where they are placed between the extensor digitorum longus in front and the soleus and flexor hallucis longus behind.

Peroneus Longus.—The peroneus longus **arises** from the lateral condyle of the tibia, from the head and the upper two-thirds of the lateral surface of the shaft of the fibula, from intermuscular septa at its sides, and from the fascia covering the muscle.

It forms a stout tendon, which lies superficial to the peroneus brevis,

and hooks round the lateral malleolus deep to the superior peroneal retinaculum, where it is invested by a synovial sheath common to it and the peroneus brevis (p. 553). Then, crossing the lateral side of the calcaneum under cover of the inferior peroneal retinaculum, it diverges from the peroneus brevis tendon, passes below the peroneal tubercle, and, finally, crosses the sole of the foot obliquely to be **inserted** into the lateral sides of the medial cuneiform and base of the first metatarsal bones (Fig. 294, p. 319). As it enters the sole of the foot a *sesamoid fibro-cartilage* (occasionally a bone) is formed in the tendon where it plays over the smooth surface of the tuberosity of the cuboid bone. In its passage across the foot the tendon traverses the groove on the cuboid and is enclosed in a fibrous sheath derived from the long plantar ligament and the tibialis posterior tendon. A synovial sheath also invests this part of the peroneal tendon.

Peroneus Brevis.—The peroneus brevis **arises** by fleshy fibres from the lower two-thirds of the lateral surface of the shaft of the fibula (its upper half arising anterior to peroneus longus), and from intermuscular septa at its sides. Its tendon grooves the back of the lateral malleolus, invested by the synovial sheath common to it and the peroneus longus (p. 553). Farther forwards it passes above the peroneal tubercle and is **inserted** into the dorsal surface of the base of the fifth metatarsal bone.

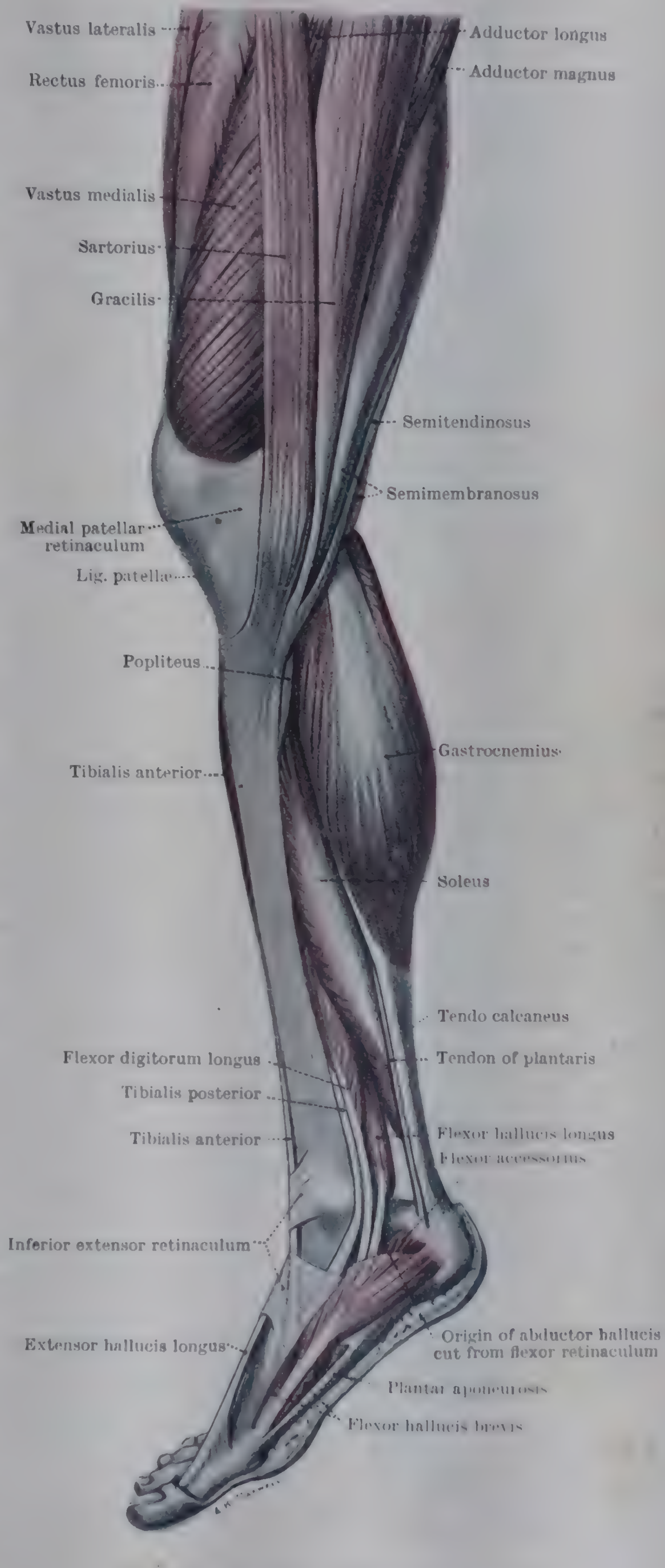

Fig. 461.—Muscles of Knee, Leg, and Foot seen from Medial Side.

The peroneus longus and brevis may be fused together, or additional slips may be present which either join the tendon of the peroneus longus (**peroneus accessorius**) or are inserted into the calcaneum or the cuboid ; an occasional tendinous slip of the peroneus brevis which joins the long extensor tendon of the little toe is known as the **peroneus digiti minimi.**

Muscles on Back of Leg

The muscles on the back of the leg are in two groups—superficial and deep.

The **superficial muscles** are the gastrocnemius, soleus, and the plantaris. The gastrocnemius and the soleus, by their bulk, form the calf of the leg, the massiveness of which is peculiar to Man and is associated with his ability to maintain the erect position while walking and running. The gastrocnemius is superficial except at its origin, where two bellies, forming the boundaries of the popliteal fossa, are overlapped by the tendons of the hamstring muscles. The soleus muscle is partially concealed by the gastrocnemius and plantaris, and becomes superficial in the distal part of the leg on each side of the common tendon (tendo calcaneus).

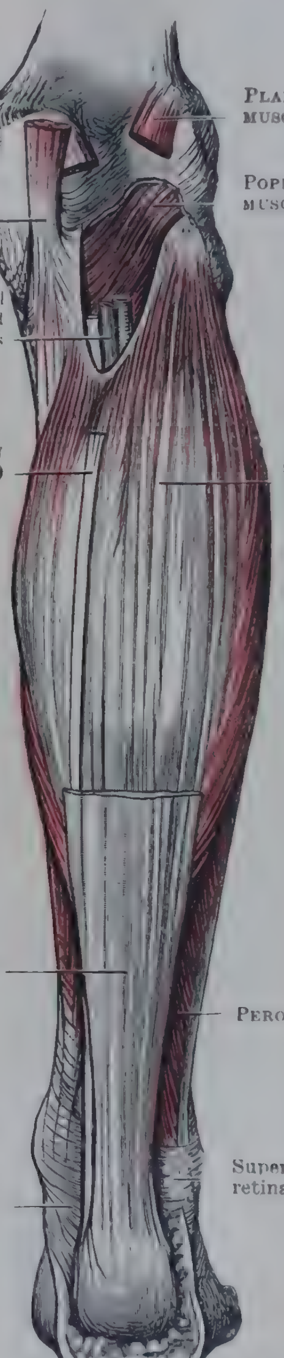

FIG. 462.—RIGHT SOLEUS MUSCLE.

Gastrocnemius [γαστήρ (gaster) = belly ; κνήμη (knēmē) = leg].—The gastrocnemius **arises** by *two heads*, medial and lateral, by strong tendons which are prolonged over the surface of the muscle. The **lateral head** arises from an impression on the upper and posterior part of the lateral surface of the lateral condyle of the femur, and from the distal end of the lateral supracondylar line ; at its origin it may contain a sesamoid bone. The **medial head** arises from a rough mark on the popliteal surface of the femur above the medial condyle. Each head has an additional origin from the back of the capsule of the knee joint. A *bursa* lies deep to each tendon of origin. The bursa of the medial head frequently communicates with the cavity of the knee joint and also with a *bursa* which intervenes between the medial head and the tendon of the semimembranosus. The bursa of the lateral head is smaller, and rarely communicates with the knee joint.

The two fleshy bellies, of which the medial is the larger, remain separate (Pl. XLIV, p. 529, Fig. 1) and are inserted into the posterior surface of a broad, membranous tendon which narrows distally and fuses with the tendon of the soleus to constitute the tendo calcaneus.

The **tendo calcaneus**, about half a foot long, the strongest tendon in the body, narrows and thickens as it descends to the heel, where it again spreads out to be **inserted** into the middle part of the posterior surface of the calcaneum. A bursa intervenes between the tendon and the bone immediately above the insertion.

Plantaris.—The plantaris—a narrow fleshy slip, not more than four inches in

length—**arises** from the lateral supracondylar line of the femur for about an inch at its distal end, from the adjacent part of the popliteal surface of the femur, and from the oblique posterior ligament of the knee joint. It ends in a remarkably long, slender tendon which descends obliquely between the gastrocnemius and soleus, and then along the medial border of the tendo calcaneus to be **inserted** into the medial side of the posterior surface of the calcaneum, or the tendo calcaneus, or the flexor retinaculum. The tendon of the muscle, although apparently a narrow bundle, can be drawn out into a fine, aponeurotic sheet, two or three inches in width.

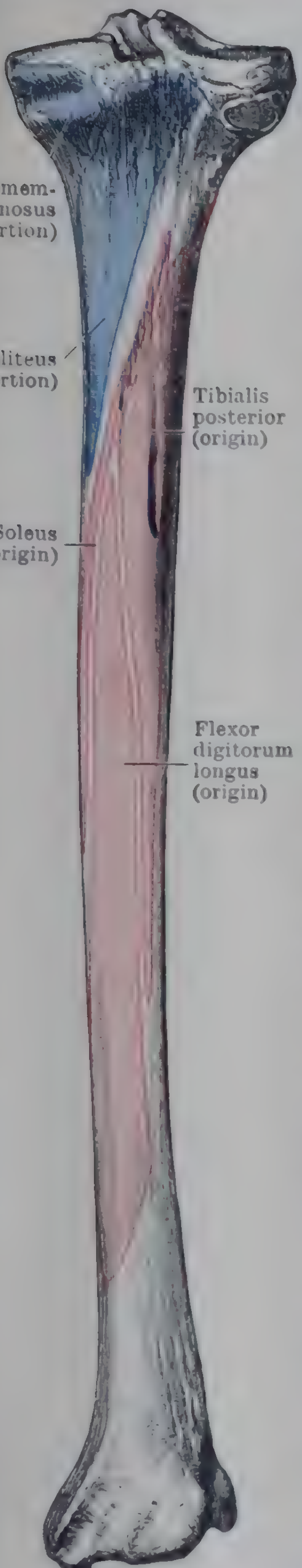

FIG. 463.—MUSCLE-ATTACHMENTS TO POSTERIOR SURFACE OF RIGHT TIBIA.

Like the palmaris longus in the forearm, the plantaris is a variable muscle and may be absent. Each of these muscles is the remains of a superficial layer of the primitive common flexor of the digits; and they are represented in the palm and in the sole by an aponeurosis.

Soleus.—The soleus, as its name implies, is a thick flat plate; it has a triple **origin** from—(1) the posterior surfaces of the head and the upper third of the shaft of the fibula; (2) a fibrous arch (*tendinous arch of soleus*) that stretches between the tibia and fibula across the popliteal vessels and medial popliteal nerve; and (3) the soleal line of the tibia and the middle third of its medial border (Fig. 463).

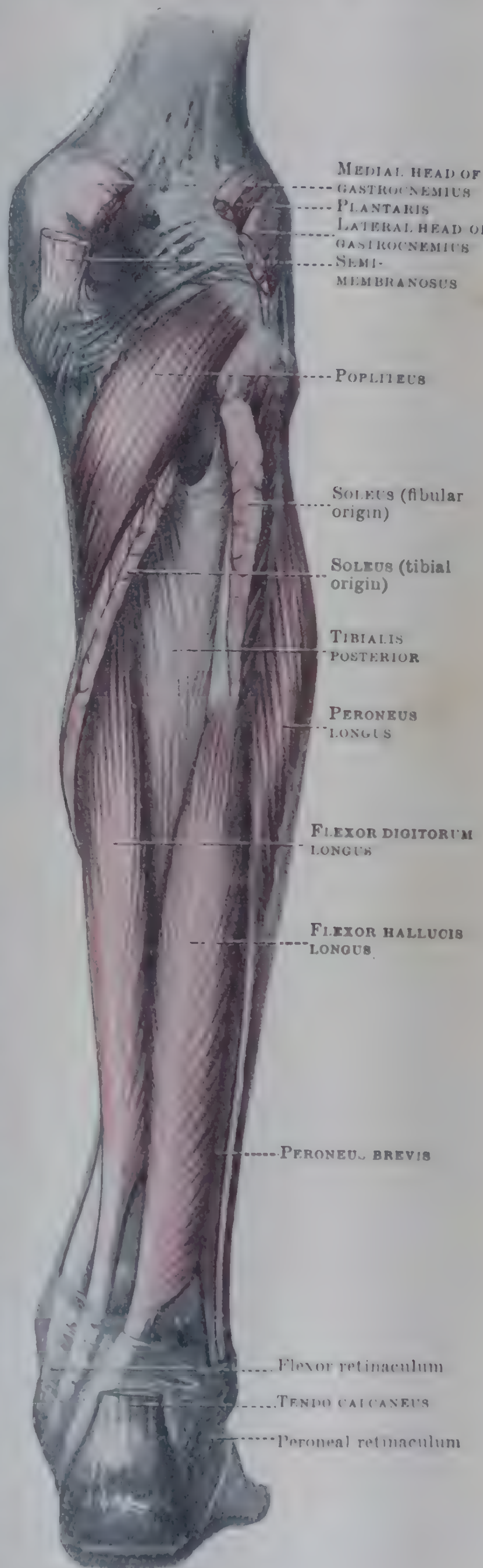

FIG. 464.—DEEP MUSCLES ON BACK OF RIGHT LEG.

From their origin the upper muscular fibres descend to join the deep (anterior) surface of a broad membranous tendon which is applied to the deep surface of the similar tendon of the gastrocnemius—the two gliding upon each other above but fused below to obtain a common

insertion through the tendo calcaneus; the lower fibres are inserted directly into the tendo calcaneus to within one or two inches of the calcaneum. The muscle is related to the lower border of the popliteus above, and is separated anteriorly by a transverse fascial septum from the posterior tibial vessels and nerve and the muscles of the following group.

The **deep muscles** of the back of the leg are the popliteus, flexor digitorum longus, flexor hallucis longus, and tibialis posterior.

The popliteus muscle is deeply placed in the distal part of the floor of the popliteal fossa, and is crossed by the popliteal vessels and medial popliteal nerve. The flexor digitorum longus lies on the tibia, the flexor hallucis longus on the fibula, and the tibialis posterior, lying between them, is related to the interosseous membrane and both bones of the leg. The four muscles are concealed by the superficial group, and are bound down to the bones by layers of the deep fascia.

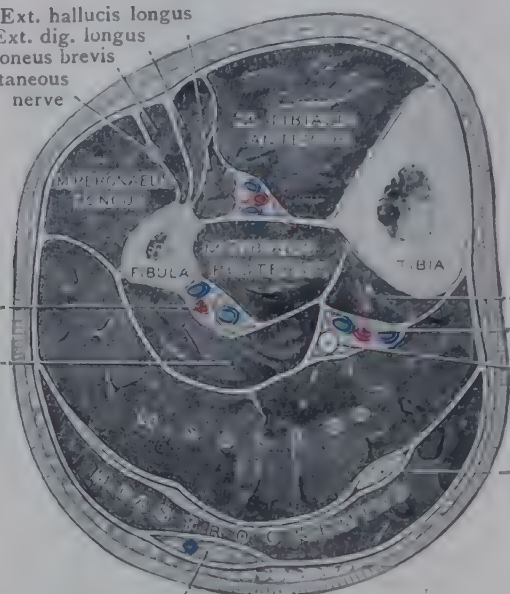

Fig. 465.—Transverse Section through Middle of Leg.

Popliteus.—The popliteus **arises**, by a stout tendon, from a rough pit on the lateral surface of the lateral condyle of the femur, below the attachment of the lateral ligament of the knee and close to the articular margin. The tendon, grooving the lateral semilunar cartilage, passes between it and the capsule of the knee joint and emerges from under the arcuate ligament of the knee, from which it takes an additional fleshy origin (Fig. 339, p. 383). It is **inserted**, by fleshy fibres, (1) into a triangular surface on the back of the tibia above the soleal line (Fig. 463), and (2) into the fascia which covers it.

Intracapsular at its origin, the tendon is partially invested by the synovial membrane, which protrudes along it for a short distance after it has pierced the capsule.

The pit of origin lies at the antero-inferior end of a groove on the lateral surface of the condyle; in that groove the upper margin of the tendon lies when the knee joint is flexed, but in extension the tendon slips over the articular edge of the condyle and rests in a shallow notch on the bone.

Flexor Digitorum Longus.—The flexor digitorum longus takes **origin** by fleshy fibres from the posterior surface of the shaft of the tibia in its middle three-fifths below the soleal line and medial to the vertical line, from the overlying fascia and from an intermuscular septum on each side (Fig. 463).

Its tendon, crossed obliquely in front by the tendon of the tibialis posterior, lies along its lateral side on the back of the lower end of the tibia, and then passes deep to the flexor retinaculum, where it is invested in a special synovial sheath. Escaping from the retinaculum, it passes forward over the medial margin of the sustentaculum tali and enters the sole above the abductor hallucis. As it extends forward in the sole it is above the flexor digitorum brevis and crosses below the tendon of the flexor hallucis longus, which separates it from the plantar calcaneonavicular or "spring" ligament; and, as the tendons cross, the flexor hallucis gives to the flexor digitorum a slip that passes into the medial two of the four subordinate tendons into which the tendon of the flexor digitorum longus finally divides. These four tendons are **inserted** into the lateral four toes in precisely the same manner as the flexor digitorum profundus is inserted in the hand (p. 497). Each

tendon enters the fibrous flexor sheath of the toe, perforates the tendon of the flexor digitorum brevis, and is inserted into the base of the distal phalanx. **Vincula tendinum (longa and brevia)** are present as in the hand.

Associated with the tendons of the flexor digitorum longus in the sole of the foot are the lumbrical muscles and the flexor digitorum accessorius.

Lumbricals. — The lumbricals are four slender muscles which are inserted into the lateral four toes; they **arise** from the tendons of the flexor digitorum longus—the *first muscle* by a single origin from the tibial side of the tendon for the second toe, and each of the *other three* by two heads from the adjacent sides of two tendons. Each passes forwards on to the tibial side of its toe, below a deep transverse ligament of the sole, to be **inserted** by tendinous fibres into the dorsal expansion of the extensor tendon; it is also bound to the metatarso-phalangeal capsule and the base of the proximal phalanx.

Flexor Digitorum Accessorius. —The flexor digitorum accessorius **arises** by two heads (Fig. 294, p. 319): (1) the lateral, tendinous head, sometimes absent, springs from the lateral border of the plantar surface of the calcaneum and from the lateral border of the long plantar ligament; (2) the medial head, which is fleshy, arises from the medial surface of the calcaneum in its whole extent, and from the medial border of the long plantar ligament — a portion of the long plantar ligament being exposed between the two origins. The two heads unite to form a flattened band which is **inserted** into the tendons of the flexor digitorum longus—usually into those destined for the second, third, and fourth toes.

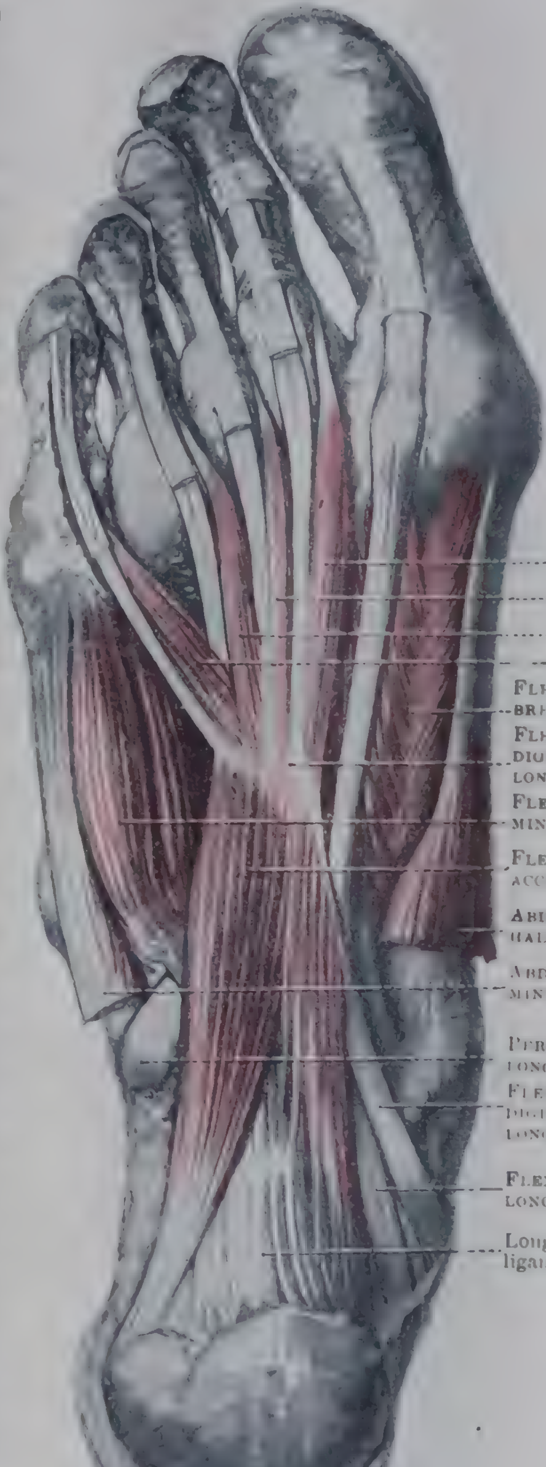

FIG. 466.—MUSCLES OF RIGHT FOOT (Second Layer).

In the sole of the foot the tendons of the flexor digitorum longus, along with the lumbricals and flexor accessorius and the flexor hallucis longus tendon, constitute the second layer of muscles, which lies between the abductors of the big and little toes and the flexor digitorum brevis superficially and the flexor brevis and adductor of the big toe more deeply.

Flexor Hallucis Longus.—The flexor hallucis longus **arises** from the lower two-thirds of the posterior surface of the shaft of the fibula, from the covering fascia and from intermuscular septa at its sides, overlapping the tibialis posterior considerably. Its tendon, passing deep to the flexor retinaculum, enclosed in a

special synovial sheath, grooves the posterior surface of the distal end of the tibia, the talus, and the plantar surface of the sustentaculum tali (to which it is strapped by a fibrous sheath lined with the synovial sheath), and is directed forwards in the sole of the foot, passing above the tendon of flexor digitorum longus, to be **inserted** into the base of the distal phalanx of the big toe after traversing a fibrous sheath under the proximal phalanx.

Tibialis Posterior.—The tibialis posterior, the deepest muscle on the back of the leg, has a fourfold fleshy origin. It **arises**—(1) from the posterior surface of the shaft of the fibula between the medial crest and the interosseous border; (2) from the lower part of the lateral condyle of the tibia, and from the upper two-thirds of its shaft below the soleal line and between the vertical line and the interosseous border; (3) from the interosseous membrane; and (4) from the covering fascia and the septum on each side. The muscle ends in a strong tendon which is invested with a special synovial sheath. The tendon grooves the back of the medial malleolus, and then, turning forwards below the malleolus between the flexor retinaculum and the deltoid ligament, it passes below the plantar calcaneo-navicular ("spring") ligament and spreads out to be **inserted** by three bands into (1) the tuberosity of the navicular bone and the plantar surface of the medial cuneiform bone, (2) the plantar surfaces of the bases of the second, third, fourth (and sometimes fifth) metatarsal bones, the intermediate and lateral cuneiform bones and the floor of the groove on the cuboid, and (3) into the medial border of the sustentaculum tali of the calcaneum (Fig. 294, p. 319). As it crosses the spring ligament, a sesamoid cartilage or bone is developed in its substance.

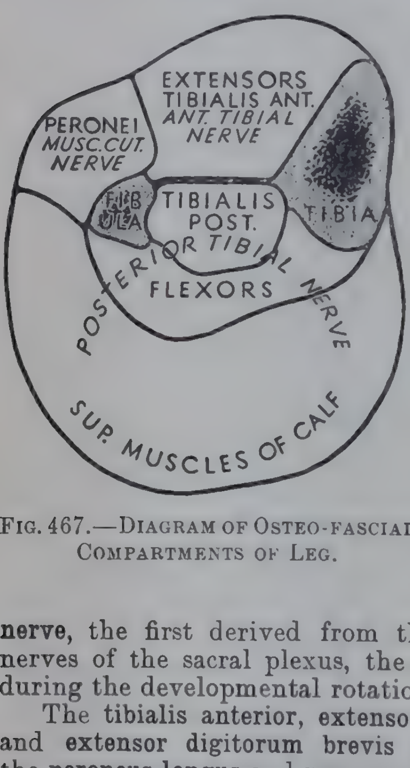

Fig. 467.—Diagram of Osteo-fascial Compartments of Leg.

An occasional separate slip (**peroneo-calcaneus**) **arises** from the lower end of the fibula, and is **inserted** into the calcaneum, or may join the tendon of the flexor hallucis longus.

Nerve-Supply.—The muscles of the front and lateral side of the leg and those on the back of the leg are all supplied by nerves derived respectively from the lateral popliteal and medial popliteal divisions of the **sciatic nerve**, the first derived from the dorsal offsets, the second from the ventral offsets of the nerves of the sacral plexus, the extensor and flexor aspects of the leg having been reversed during the developmental rotation of the limb.

The **tibialis anterior, extensor digitorum longus, peroneus tertius, extensor hallucis longus,** and **extensor digitorum brevis** are all supplied by the *anterior tibial nerve* (L. 4, 5, S. 1); the **peroneus longus** and **peroneus brevis** by the *musculo-cutaneous nerve* (L. 4, 5, S. 1).

The following muscles are all supplied by branches of the *medial popliteal* or its continuation—the *posterior tibial nerve*:—**Gastrocnemius**, by two branches, one to each head (S. 1, 2); **plantaris** (L. 4, 5, S. 1); **soleus**, by two branches, one arising in the popliteal fossa and entering its superficial surface (S. 1, 2), the other in the back of the leg and entering its deep surface (L. 5, S. 1, 2); **popliteus** (L. 4, 5, S. 1), by a branch which winds round the lower border of the muscle and enters its deep surface; **flexor digitorum longus** (L. 5, S. 1); **flexor hallucis longus** (L. 5, S. 1, 2); and **tibialis posterior** (L. 5, S. 1). The *posterior tibial nerve*, through its plantar branches, supplies also the muscles associated with the tendons of the flexor digitorum longus in the sole of the foot; the **first lumbrical** is supplied by the *medial plantar nerve* (L. (4), 5, S. 1), the **other three** by the *lateral plantar nerve* (S. 1, 2), which supplies the **flexor digitorum accessorius** also.

Action of Muscles in Movements at Ankle and Intertarsal Joints.—

The terms which are least liable to be misunderstood in the description of movements at the ankle joint are **dorsi-flexion** (produced by muscles on the anterior (extensor) aspect of the leg), and **plantar-flexion** (produced by muscles on the posterior (flexor) aspect of the leg). In addition, important movements of **inversion** and **eversion** of the foot take place at the subtalar joints (p. 398). (See Pl. XLV, Figs. 2 and 3, p. 546.)

The dorsi-flexors of the ankle are: the **tibialis anterior, extensor digitorum longus, peroneus tertius,** and **extensor hallucis longus**. The plantar-flexors of the ankle are: the **gastrocnemius** and **soleus** with the feeble **plantaris**; the **flexor digitorum longus, flexor hallucis longus** and **tibialis posterior**; and the **peroneus longus** and **brevis**.

Most of these muscles have some action also at the intertarsal joints; but the

invertors of the foot, in the order of their strength, are first the tibialis posterior and then the tibialis anterior, acting together (Pl. XXXVI, p. 383, Fig. 1), while the chief **evertors** are the two **peroneal** muscles, **longus** and **brevis**. The **peroneus tertius** also is associated with the movement of eversion, which is a characteristic movement of the human foot (it raises the lateral border of the foot, for example, in the action of skating or dancing).

It is to be noted that the muscles whose tendons pass into the sole have the additional, important postural function of maintaining the arches of the foot. The tibialis posterior is perhaps the most important muscle in that respect because of the direct relation of its tendon to the plantar calcaneo-navicular ("spring") ligament and of its numerous secondary insertions. The flexor hallucis longus also has an important share in this function because of its position in relation to the tarsus and the spring ligament. The peroneus longus, by its passage across the sole, keeps the transverse arch of the foot up, as a taut string maintains the bend of a bow. The arches of the foot are girders constructed of mobile segments which interplay as the muscles lever them into position (Pl. XLVI, p. 547; Fig. 468); and the phrase "supporting the arch" may refer to a direct pull upon its segments, such as is exerted by the tibialis anterior, or an indirect effect upon these segments by the approximation of the pliable pillars as in the action of the flexor hallucis longus.

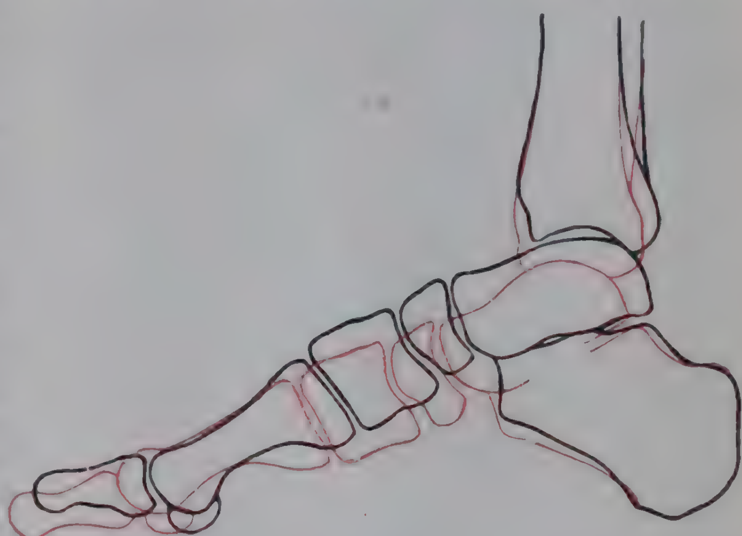

FIG. 468.—TRACINGS OF RADIOGRAPHS (Pl. XLVI, p. 547, Figs. 2 and 3), superimposed to show the position of the Longitudinal Arch of the Foot during Relaxation (red), and Contraction (black) of the Muscles. (See also Fig. 472, footprints 2 and 3.)

As the line of the body-weight in the erect attitude lies in front of the axis of the ankle joint, the plantar flexors are required to be far more powerful than the dorsi-flexors—again, a feature distinctive of Man.

As the function of the limb is to support and propel the body in movement, it is essential to consider the **reversed action** of the muscles in pulling from the foot firmly applied to the ground as well as in pulling upon the free foot from the leg. In the **standing position** the muscles of the tendo calcaneus pull from the heel, but **in walking** they pull up the heel. Again, in standing on one foot the **tibialis anterior** and **posterior** pull the leg medially while the **peroneal** muscles pull it laterally to secure a balance. Now, the movement induced by any one muscle at the joints is never pure flexion, extension or version, and accordingly the synergic action of all groups is necessary. One can readily feel this in all the muscles of the leg in poising the body on the toes of one foot, when the tibialis anterior, though a dorsi-flexor, must act as an invertor to counteract the everting pull of the peroneal muscles. The student will appreciate that such direct antagonists as the tibialis posterior (flexor) and the tibialis anterior (extensor) nevertheless co-operate in producing inversion.

The **gastrocnemius** requires special consideration, not only because it is a powerful plantar-flexor, but also because of the necessity for its relaxation during dorsi-flexion of the ankle in walking. The condition of this muscle varies considerably, and a slight shortening is so common that it can hardly be considered abnormal. Its "ligamentous action" (see p. 408) thus hampers dorsi-flexion at the ankle joint, and an endeavour is made to supplement the ankle joint in that movement during walking by the use of the "transverse tarsal joint" (p. 397). Now, at this joint, dorsi-flexion does not take place in the sagittal plane: the fore part of the foot is moved laterally as well as upwards; the walk becomes "out-toed" and the medial longitudinal arch is depressed—predisposing to flat foot. The muscles of the calf are concerned also in keeping the posture erect, the slowly acting soleus being more important in this respect than the quickly acting gastrocnemius, which is used in more active movements. (See also Cyriax, 1917; Haines, 1934.)

The power of the flexor muscles in their tie-beam action on the foot is well illustrated when the tibialis anterior is paralysed and the gastrocnemius and soleus are weak. In using the flexors powerfully to overcome the drooping of the heel caused by the weakness of their companions, the fore part of the foot is gradually pulled towards the heel, until a marked concavity is produced.

Muscles in Sole of Foot

The muscles in the sole of the foot are arranged in four layers:—
First layer: the abductor hallucis, flexor digitorum brevis, and abductor digiti minimi. *Second layer*: the lumbricals and flexor digitorum accessorius, together with the tendons of the flexor hallucis longus and flexor digitorum longus. *Third layer*: the flexor hallucis brevis, adductor hallucis, and flexor digiti minimi brevis. *Fourth layer*: the interossei (plantar and dorsal), placed between the metatarsal bones; and the tendons of insertion of the tibialis posterior and peroneus longus.

Fig. 469.—Superficial Muscles of Sole of Foot.

FIRST LAYER

Abductor Hallucis.—The abductor hallucis **arises** by a short tendon from the medial side of the medial tubercle of the calcaneum and by fleshy fibres from the flexor retinaculum, the plantar aponeurosis and the intermuscular septum between it and the flexor digitorum brevis. The muscle lies superficially along the medial border of the sole, and its tendon is **inserted** into the medial side of the base of the proximal phalanx of the big toe and partly with the medial head of flexor hallucis brevis into the medial sesamoid bone.

Flexor Digitorum Brevis.—The flexor digitorum brevis is situated above (deep to) the plantar aponeurosis, between the two abductors, and is separated from the second layer of muscles by their fascia and the lateral plantar vessels and nerve. It **arises** from the medial tubercle of the calcaneum, the plantar aponeurosis, and the intermuscular septa at its sides. Passing forwards, it gives rise to four slender tendons which are **inserted** into the middle phalanges of the lateral four toes, after having been perforated by the long flexor tendons, just as in the case of the tendons of the flexor digitorum sublimis of the hand (p. 496).

Abductor Digiti Minimi.—The abductor digiti minimi **arises** by fleshy and tendinous fibres from both tubercles of the calcaneum (partly concealed by the flexor digitorum brevis) and by fleshy fibres from the fascia on its surface and the intermuscular septum between it and the flexor digitorum brevis. Its tendon

glides over a smooth depression on the inferior surface of the base of the fifth metatarsal bone and runs along the bone to be **inserted** into the lateral side of the base of the proximal phalanx of the little toe. The most lateral fibres usually obtain an additional insertion into the lateral part of the plantar surface of the fifth metatarsal bone and may constitute a small separate muscle called the **abductor ossis metatarsi quinti.**

SECOND LAYER

The muscles and tendons of this layer have been described already (pp. 540, 541).

THIRD LAYER

Flexor Hallucis Brevis.—The flexor hallucis brevis **arises** by tendinous fibres from (1) the medial part of the plantar surface of the cuboid bone (behind the groove for the peroneus longus), and from the adjacent part of the lateral cuneiform bone and (2) from the expansions of the tendon of the tibialis posterior in this area. Directed forwards over the first metatarsal bone, the muscle separates into two parts which escort the tendon of the flexor hallucis longus. Each portion gives rise to a tendon which is **inserted** into the corresponding side of the base of the proximal phalanx of the big toe; in each tendon, under the metatarso-phalangeal joint, a *sesamoid bone* is developed to play the part of a roller-bearing (Fig. 468 and Pl. XLVI, p. 547). The tibial tendon is united with the insertion of the abductor muscle of the big toe, the fibular tendon with the insertion of the adductor.

An occasional insertion of some fibres into the shaft of the metatarsal bone represents an **opponens hallucis.**

FIG. 470.—DEEP MUSCLES OF SOLE OF FOOT.

Adductor Hallucis.—The adductor hallucis has two heads. The *oblique head* **arises** (1) from the sheath of the peroneus longus, and (2) from the plantar surfaces of the bases of the second, third, and fourth metatarsal bones (Fig. 294, p. 319). It lies in the hollow of the foot, on a deeper plane than the long flexor tendons and lumbricals, and on the fibular side of the flexor hallucis brevis, with which it is frequently fused; and it runs obliquely, medially and forwards, to be **inserted** on the fibular side of the base of the proximal phalanx of the big toe along with the transverse head and the flexor brevis.

The *transverse head* **arises** from the capsules of the lateral four metatarso-phalangeal joints and the deep transverse ligaments of the sole. Running transversely medially under cover of the flexor tendons and lumbricals and crossed by

the digital nerves, it is **inserted**, along with the oblique head, into the fibular side of the base of the proximal phalanx of the big toe.

Flexor Digiti Minimi Brevis.—The flexor digiti minimi brevis **arises** from the sheath of the peroneus longus and the base of the fifth metatarsal bone. Partially concealed by the abductor digiti minimi, the muscle passes along the fifth metatarsal bone to be **inserted**, in common with that muscle, into the fibular side of the base of the proximal phalanx of the little toe.

A frequent insertion of some fibres into the metatarsal bone represents an **opponens digiti minimi.**

FOURTH LAYER

Interosseous Muscles.—The interosseous muscles of the foot resemble those of the hand except in one respect. In the hand the line from and to which they

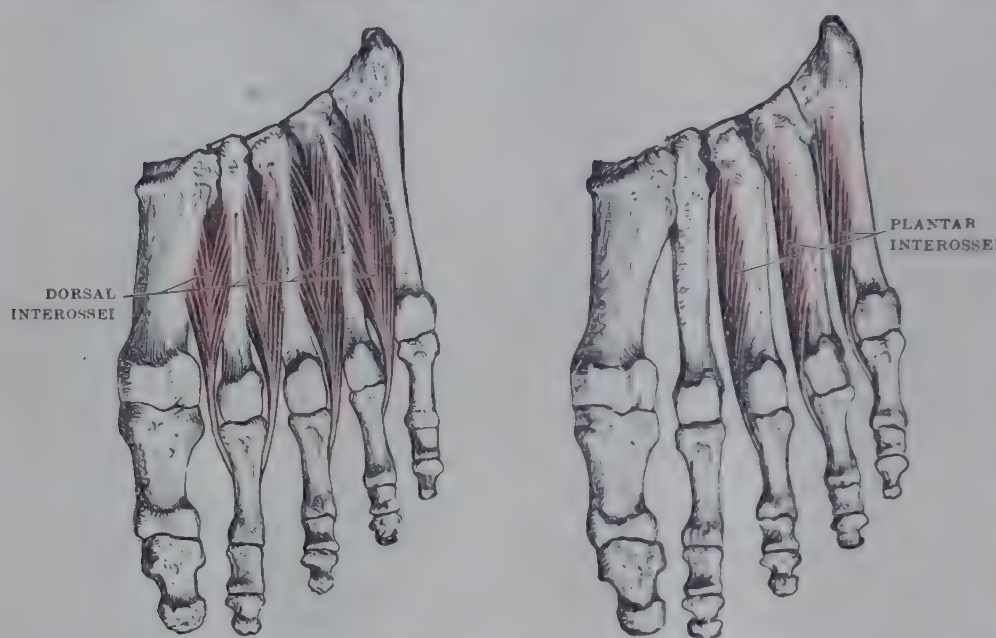

FIG. 471.—INTEROSSEOUS MUSCLES OF RIGHT FOOT.

move the digits is the middle line of the middle digit, whereas, in the foot, it is the middle line of the second digit.

There are four dorsal and three plantar muscles; they occupy the four interosseous spaces, and bulge into the hollow of the foot.

The **four dorsal muscles** lie in the intermetatarsal spaces, and as each **arises** by two heads from the adjacent bones their fibres have a bipennate arrangement. Their tendons pass forwards above the deep transverse ligaments of the sole, and each is **inserted**, on the dorsum of the foot, into the side of the proximal phalanx, the metatarso-phalangeal capsule, and the dorsal expansion of the extensor tendon. The *first* and *second muscles* are inserted respectively into the tibial and fibular sides of the proximal end of the proximal phalanx of the second toe. The *third* and *fourth muscles* are inserted into the fibular sides of the third and fourth toes. The dorsalis pedis artery enters the sole of the foot through the cleft between the heads of the first muscle; the perforating arteries gain the dorsum of the foot through the corresponding intervals in the other three muscles.

The **three plantar muscles** lie in the lateral three interosseous spaces. They **arise**, each by a single head, from the medial side of the third, fourth, and fifth metatarsal bones respectively. Their tendons pass forwards above the deep transverse ligaments, and each is **inserted**, in the same manner as the dorsal muscles, into the tibial sides of the third. fourth, and fifth toes.

Nerve-Supply.—The muscles of the sole of the foot are supplied by the two *plantar nerves*; the **abductor hallucis, flexor hallucis brevis, flexor digitorum brevis,** and the **first lumbrical** by the *medial plantar nerve* (L. (4.) 5. S. 1.); the **adductor hallucis,** the **abductor digiti minimi,** the **flexor digiti minimi brevis,** the **lateral three lumbricals,** the **flexor digitorum accessorius,** and *all* **interossei** by the *lateral plantar nerve* (S. 1. 2.). (Branches from the anterior tibial nerve to the **drosal interossei are probably afferent.**)

PLATE XLV

FIG. 1.—MEDIAL ROTATION OF LEG UPON THIGH.

Contrast the position of the tendon of biceps femoris and ilio-tibial tract in Fig. 2.

FIG. 2.—LATERAL ROTATION OF LEG UPON THIGH.

Note the increased interval between the tendon of biceps femoris and the ilio-tibial tract covering vastus lateralis.

FIG. 3.—EVERSION WITH PLANTAR FLEXION OF FOOT.

The peronei and the muscles of the calf are active. Cf. Fig. 4.

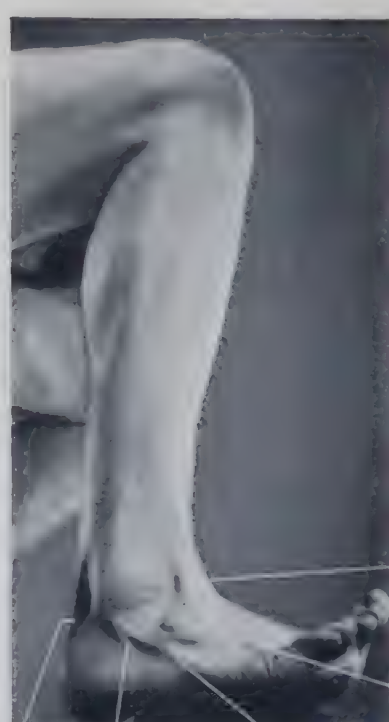

FIG. 4.—EVERSION WITH DORSIFLEXION OF FOOT.

The tendons of the peronei and extensor digitorum longus stand out actively. Cf. Fig. 3.

PLATE XLV.—PHOTOGRAPHIC ILLUSTRATIONS OF MUSCLES IN ACTION. (From Lockhart's *Living Anatomy*, 1948, by permission of Messrs. Faber & Faber.)

PLATE XLVI

Fig. 1.—Radiograph of Right Foot of Subject standing on Toes (see inset).

Fig. 2.—Radiograph of Right Foot of Subject standing with Muscles Contracted. (See Fig. 472, footprint 2 and contrast with footprints 1 and 3.)

Fig. 3.—Radiograph of Right Foot of Subject standing with Muscles relaxed as fully as possible. (For footprint see Fig. 472, 3.)

Plate XLIV.—Photographic and Radiographic Illustrations of the Weight-Bearing Areas of the Foot

Action of Muscles in Movements of the Toes.—The **extensor hallucis longus** extends the big toe, the **extensor digitorum brevis** extends the medial four toes, and the **extensor digitorum longus** the lateral four toes. The **flexor digitorum longus** flexes the lateral four toes: the **lumbrical muscles** have a similar action to those of the hand; they flex the metatarso-phalangeal joints of the lateral four toes and extend their interphalangeal joints. The muscles are capable of performing these actions when the foot is off the ground; but it is more important to consider the action in walking, when the long flexors and the lumbricals act together and the lumbricals, by endeavouring to keep the interphalangeal joints extended, enable the long flexors to "push off" more effectively. The chief action of the flexors and lumbricals in the "push off" is, however, an endeavour to bend the dorsi-flexed metatarso-phalangeal joints while extension of the interphalangeal joints is maintained; and it should be noted that the muscles, though exerted powerfully in this action, do not in fact shorten (cf. Pl. XLVI, Fig. 1 and p. 548.

The attitude of the toes in the "push off" varies even in the same foot according to the balance and the pressure exerted. When all the toes and metatarsal pads are firmly pressed to the ground, there is extension at the metatarso-phalangeal and distal interphalangeal joints, while the interphalangeal joint of the great toe and the proximal interphalangeal joints of the other toes are flexed. If the inner toes are exerting the greater pressure, then both interphalangeal joints of the outer toes tend to flex. By altering his balance and the pressure on his own feet, the student will quickly acquire the best appreciation of the slight differences produced by various attitudes. When the lumbricals are weak, they allow the long flexors to bend the interphalangeal joints; but, when the foot is on the ground, the toes cannot be depressed, and accordingly dorsi-flexion occurs at the metatarso-phalangeal joints and the toes become "clawed". The backs of the toes then press on the shoe, and to mitigate that the flexors curl the toes still more. The surgeon corrects this by straightening the toes and fixing the proximal interphalangeal joints in the extended position so that the long flexors cannot act on these joints and must attempt to flex at the metatarso-phalangeal joints just as normal lumbricals do.

The **flexor digitorum accessorius**, as its name implies, is an accessory flexor of the toes, assisting the long flexor, and tending to draw the tendons into which it is inserted into the middle of the sole of the foot. The **flexor digitorum brevis**, corresponding to

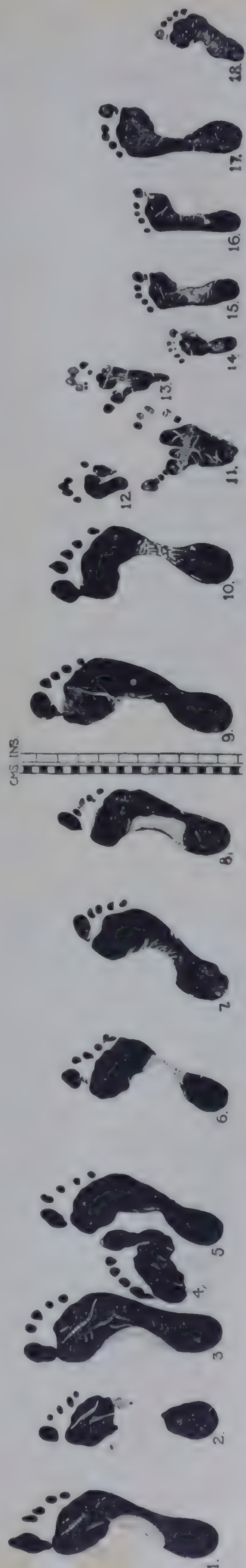

FIG. 472.—COMPARATIVE SERIES OF FOOTPRINTS. 1, 2, 3, 4. Footprints of a Man: (1) Walking-print; (2) Stationary, foot highly arched; (3) With the Muscles relaxed as much as possible (see Pl. XLVI, Figs. 2 and 3); (4) Walking on the Toes. Note the prominence of the bar between the ball and phalangeal pad of the big toe. 5. Footprint of Male Athlete. 6. Athletic Girl. 7. Ballet Dancer in Attention Attitude. 8. The same showing the difference between the arched and relaxed state of the foot, the increased area of contact indicated by the dotted area. 9. Negro, Male. 10. Australian Aboriginal Woman. 11. Chimpanzee, Female, 3½ years of age, walking-print. 12. Hamadryas Baboon, Female. 13. Rhesus Macacus Monkey. (Observe the narrow heel, 11, 12, and 13.) 14. Infant before walking, at 3 months old. 15. The same child after walking at 2 years, 9 months old. 16. The same child at 3 years, 7 months old. 17. The same child at 7¼ years old. 18. This infant, after beginning to walk, was confined to bed through illness, and lost the art. The footprint is taken from a series while the art of walking is being learned anew. The eminence in front of the heel on the medial side is caused by the impression of the area under the head of the navicular bone.

the flexor sublimis of the fingers, acts on the metatarso-phalangeal and proximal interphalangeal joints of the lateral four toes.

The **abductor** and **adductor hallucis** abduct and adduct the big toe, and both assist the **flexor hallucis brevis** and the **flexor hallucis longus** (at the metatarso-phalangeal joint) in flexion of the big toe. The importance of the big toe in walking may be estimated from the fact that the flexor hallucis longus exerts three times more force upon it than is exerted upon any other toe (cf. weight-bearing areas of foot and Fig. 472). The **abductor digiti minimi** abducts, and assists the **flexor digiti minimi brevis** (at the metatarso-phalangeal joint) in flexion of the little toe.

The **interossei** are flexors of the metatarso-phalangeal joints and extensors of the interphalangeal joints of the lateral four toes (but the opinion is also held that they do not extend these joints). The dorsal interossei **abduct** the toes into which they are inserted from the middle line of the *second toe*; the plantar interossei **adduct** the lateral three toes towards the *second toe*. The small muscles of the foot also have an important tie-beam action in maintaining the arches of the foot. (For further discussion of the actions of the muscles of the foot, see Wood Jones, 1944.)

Weight-Bearing Areas of the Foot.—The function of the arches of the foot and the activity of the muscles of the leg and foot in maintaining these arches (pp. 543 and 549) are indicated in some measure by the footprints, which vary considerably in different people and alter remarkably in the early years of life. In the average person (Fig. 472, **1**), the weight of the posterior pillar is taken by the heel pad, that of the anterior pillar by the metatarsal pad—particularly in the region of the ball of the big toe—while under the lateral longitudinal arch there is an area of contact (very frequently absent, Fig. 472, **6**, **10**), and not usually a weight-bearing area. (It has been said that the feet of primitive races are broad and flat, but this is not borne out in Fig. 472, **10**, which shows the foot of an Australian aboriginal woman). The weight-bearing areas are merely roughly and not adequately represented by footprints; a well-worn shoe is one of the best and readiest sources of information. **In the usual method of walking,** as (say) the left heel comes down, pressure is light, for the weight is still borne mainly by the right foot; but pressure on the left heel increases as the weight is transferred, and the left heel rolls forward until the ball of the foot now makes contact. In the forward movement, the heel-pressure decreases as the ball-pressure increases; then the ball-pressure decreases as the toe-pressure increases, and this diminishes as the right foot comes forward—the left toes alone exerting pressure as the weight is being transferred to the right foot. In the last part of the movement it will be noted that there is metatarso-phalangeal dorsi-flexion (Pl. XLVI, p. 547, Fig. **1**) and it should be appreciated that while the toes are thus extended their flexors are exerting their full power of propulsion. The bar between the metatarsal pad and the phalangeal pad is evident in the case of the big toe (Fig. 472, **1**, **4**), but is prevented by the metatarsal pad from appearing, though the toes are extended, in the case of the others. **Most people walk slightly "toeing-out"**—the pressure being marked on the lateral side of the heel, and then transferred to the medial side of the ball of the foot. In those who walk "**toeing-in**", the medial side of the heel bears the greater pressure, and this is transferred to the lateral side of the ball. The net result in both cases is that the line between the areas of pressure is parallel to the line of progress (Elftman, 1934). The angle of gait, usually about 15 degrees between the two feet, varies individually and becomes less the quicker the walk (Morton, 1935). The footprint at birth is flat and the heel narrow (Fig. 472, **14**) (cf. Fig. 472, **17**), and is very variable as the child begins to learn to walk, as is seen by the impression in front of the heel caused by the area under the navicular bone in Fig. 472, **18**. As the child grows the heel broadens out and the raising of the longitudinal arch begins (see pp. 393 and 400).

Movements of Lower Limb as a Whole

The characteristic features of the lower limb are stability and strength, and its muscles and joints are subservient to the functions both of transmission of weight and of locomotion. In the standing position the centre of gravity of the trunk falls between the heads of the femora, and is located about the middle of the body of the last lumbar vertebra. The weight of the body is transmitted from the sacrum through the sacro-iliac joints to the hip bone, and through the femur and tibia to the arch of the foot, where the talus distributes it backwards through the calcaneum to the heel, and forwards through the tarsus and metatarsus to the ball of the foot.

Locomotion.—The three chief means of progression are walking, running, and leaping.

In **walking**, the body and its centre of gravity are inclined forwards, and the trunk oscillates from side to side as it is supported alternately by each foot. As one foot leaves the ground the sacro-spinalis of that side and the gluteus medius and minimus of the opposite side can be felt contracting to maintain the balance of the body. The upper limb swings alternately with the corresponding lower limb, and one foot or the other is always on the ground. The act of progression is performed by the lower limb aided by gravity. The movements of the lower limb occur in the following way. At the beginning of a step, one lower limb, so to speak, " shoves off " ; the heel is raised and the limb is extended. The limb passes forwards by the action of gravity aided by the impetus from the extensor muscles, and it is raised sufficiently to clear the ground by the action of the muscles that flex the hip and knee joints and dorsi-flex the ankle joint and toes. After passing the line of the centre of gravity the flexion of the joints ceases, the muscles relax, and the limb gradually returns to the ground. The other limb then passes through the same cycle, the weight of the body now resting on the limb which is in contact with the ground.

In **running**, the movements are all exaggerated. The time of each movement is diminished, and the force and distance are increased. Both feet are off the ground at one time ; the action of flexors and extensors alternately is much more powerful, so that, on the one hand, the knees are drawn upwards to a greater extent in the forward movement, and not the whole foot but only the toes reach the ground in the extension of the limb. The attempt is made to bring the foot to the ground in front of the line of the centre of gravity. At the same time the trunk is sloped forwards much more than in walking.

In **leaping**, the actions of the limbs are still more exaggerated. The movements of flexion of the limb are still more marked, and the foot reaches the ground still farther in front of the line of the centre of gravity.

The importance of postural action in the muscles of the lower limb in maintaining the posture erect must again be emphasized : and it is an interesting exercise, as the subject leans slightly forwards, to feel the flexor groups of the hip, knee and ankle joints contract to retain the balance, while their opponents relax, and then feel the reverse effects as the model inclines backwards. The muscles and tendons traversing the sole of the foot have a highly important postural function in safeguarding the arches during standing and also during vigorous movement. (For further discussion of the mechanics of locomotion, see Steindler, 1935.)

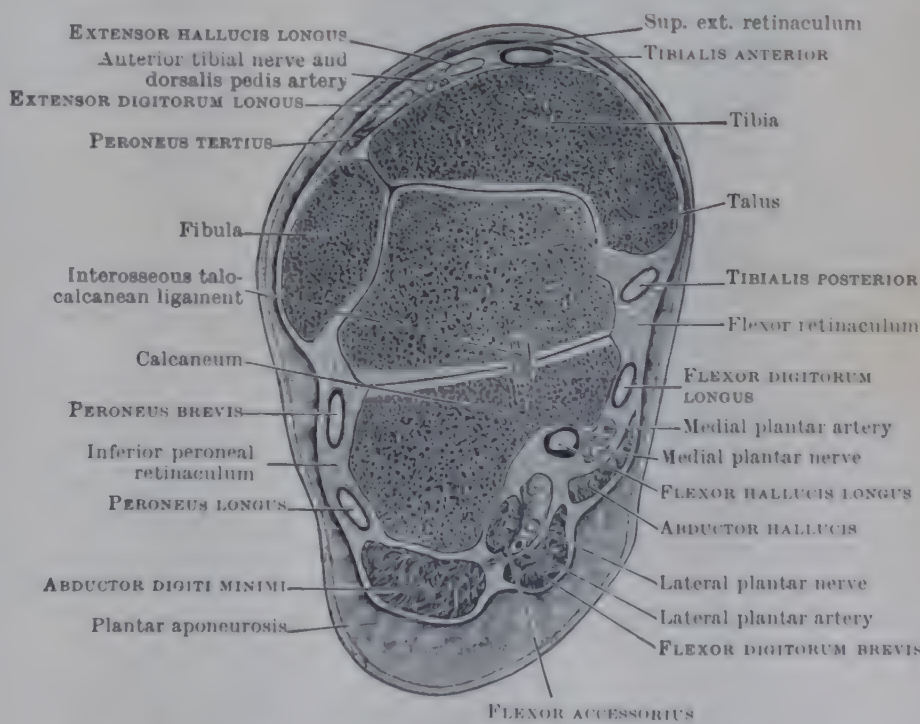

Fig. 473.—Frontal Section through Left Ankle Joint, Talus, and Calcaneum.

FASCIÆ OF LEG AND FOOT

The **superficial fascia** of the leg and foot presents no special features except in the sole, where it is greatly thickened by pads of fat, particularly at the heel and in the ball of the foot and the pads of the toes. These pads are important in weight - bearing, and they protect deeper structures. Their distribution and the flexure-lines of the sole show characteristic changes during the evolution of the arches of the foot (cf. p. 548 and Fig. 472, 3, 9, 11, 15). In the webs of the toes it contains some

transverse fibres that form a weak band called the *superficial transverse ligament of the sole.*

The **deep fascia** is continuous with the fascia lata and is strengthened around the knee by expansions from the tendons of the sartorius, gracilis, semitendinosus, and biceps femoris. Anteriorly, it is attached to the patella, the ligamentum patellæ, and the tubercle of the tibia; medially and laterally, it is connected to the condyles of the tibia and the head of the fibula, and helps to form the **patellar retinacula**—broad membranous bands which pass obliquely from the sides of the patella to the condyles of the tibia and are joined by fibres of the vasti muscles.

In the leg, the fascia blends with the periosteum of the medial surface of the tibia, and extends round the lateral side of the leg from the anterior border of the tibia to its medial border, binding the muscles together and giving origin to them, and gaining an attachment to the lower part of the shaft of the fibula. Two septa pass from its deep surface—anterior and posterior. The **anterior intermuscular septum** is attached to the anterior border of the fibula; it encloses the musculocutaneous nerve, and separates the peroneal muscles from the extensors; the **posterior intermuscular septum** is attached to the posterior border of the fibula, and separates the peroneal muscles from the flexors. The muscles are thus partitioned into three functional groups—extensors anteriorly, flexors posteriorly, and evertors laterally. From the posterior septum another septum extends across the back of the leg, forming a partition between the superficial and deep flexor muscles, and enclosing the posterior tibial vessels and nerve. This septum gives rise to subordinate septa which are attached to the vertical line of the tibia and the medial crest of the fibula, and separate the tibialis posterior from the flexors of the toes. It is attached above to the soleal line, whence a strong fascia is prolonged over the popliteus muscle, reinforced by an expansion from the semimembranosus.

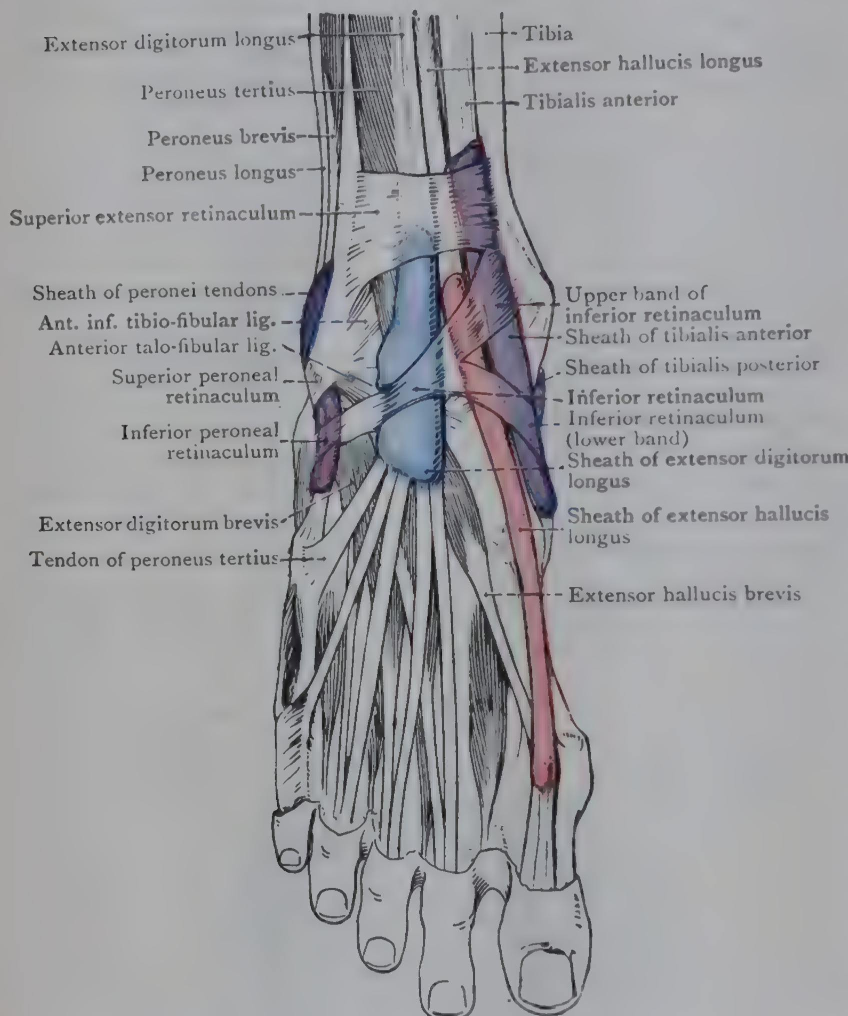

FIG. 474.—SYNOVIAL SHEATHS OF DORSUM OF FOOT.

At the ankle the deep fascia is strengthened by additional transverse fibres, and forms thickened bands named the flexor retinaculum, extensor retinacula, and peroneal retinacula.

The **flexor retinaculum** stretches between the medial malleolus and the medial tubercle of the calcaneum. The space which it bridges is divided into four tunnels by fibrous septa that pass from its deep surface to the back of the lower end of the tibia and to the capsule of the ankle joint. Its upper border is continuous partly with the investing deep fascia of the leg, but chiefly with the septum that covers

the deep muscles of the calf. Its lower border is continuous with the deep fascia of the sole and gives origin to the abductor hallucis muscle. It is pierced by the calcanean vessels and nerve. The four tunnels, enumerated from the medial malleolus laterally, contain (1) the tendon of the tibialis posterior, (2) the flexor digitorum longus, (3) the posterior tibial vessels and nerve, and (4) the flexor hallucis longus; and each of the tendons is enclosed in a separate synovial sheath.

The **superior peroneal retinaculum**, binds down the tendons of the peroneus longus and brevis as they pass together, invested by a single synovial sheath, behind the malleolus; the **inferior peroneal retinaculum**, attached by a septum to the peroneal tubercle, holds them separately to the lateral surface of the calcaneum, each with its own prolongation from their common synovial sheath.

The **superior extensor retinaculum**, broad and undefined at its proximal and distal borders, stretches across between the shafts of the tibia and fibula just above the ankle. It binds down the tendons of the tibialis anterior and the extensor muscles—of which only the tibialis has a synovial sheath at that level.

The **inferior extensor retinaculum** is a better-defined, thickened band of deep fascia that binds down the tendons as they enter the dorsum of the foot. In shape it resembles the letter Y laid on its side. The stem is attached to the anterior part of the upper surface of the calcaneum and to the floor of the tarsal canal (Fig. 347, p. 394); extending medially, it forks into two bands, the upper of which is attached to the medial malleolus, while the lower arches over the medial side of the foot and is lost in the deep fascia near the sole.

Deep to the stem of the Y, the peroneus tertius and extensor digitorum longus occupy one compartment, in a common synovial sheath. The upper limb runs superficial to the anterior tibial vessels and nerve, splits to enclose the tendon of the extensor hallucis longus, and then runs deep to the tibialis anterior, though it may sometimes split to enclose that tendon; the lower limb crosses superficial to the tendons of the extensor hallucis longus and tibialis anterior, the dorsalis pedis artery, and the terminal branches of the anterior tibial nerve. There are three synovial sheaths related to the retinaculum—one for the peroneus tertius and extensor digitorum longus, and one each for the extensor hallucis longus and tibialis anterior. A band of fibres from the deep surface of the stem loops the extensor digitorum longus to become attached to

FIG. 475.—LEFT PLANTAR FASCIA.

adjoining parts of the calcaneum and the neck of the talus; occasionally an additional band connects the upper border of the stem with the lateral malleolus.

In the sole the deep fascia is an unbroken layer which joins the fascia of the dorsum at the borders of the foot; it is greatly thickened in the middle part

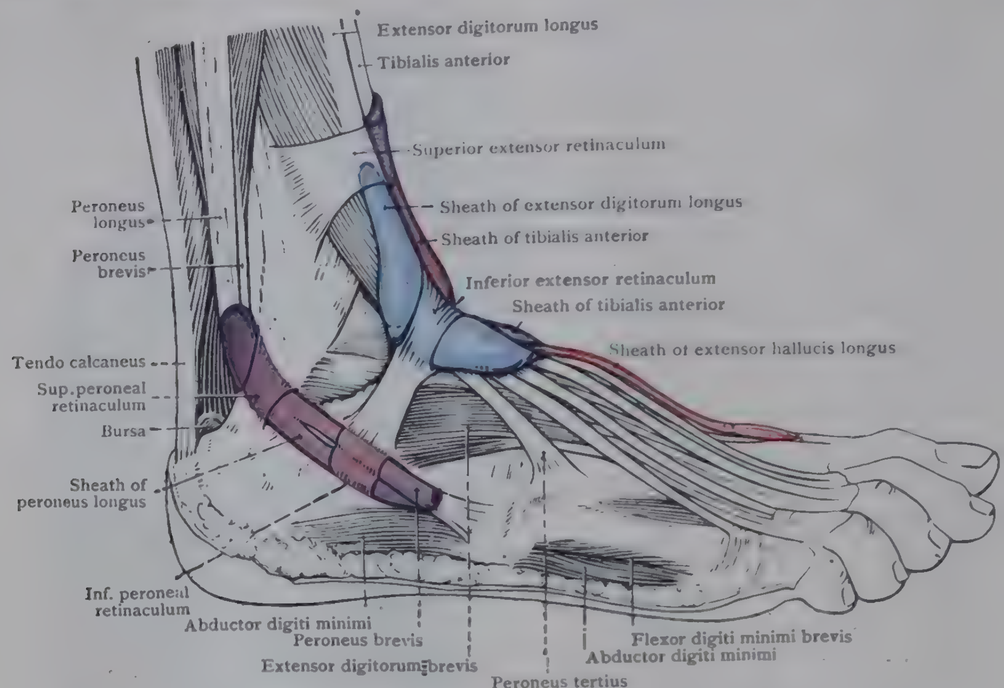

FIG. 476.—DISSECTION SHOWING SYNOVIAL SHEATHS OF TENDONS OF FOOT.

and also on the surface of the abductor digiti minimi between the lateral tubercle of the calcaneum and the base of the fifth metatarsal bone. The thick portion in the middle is called the **plantar aponeurosis**, whose thickness and strength is due chiefly to densely arranged longitudinal fibres.

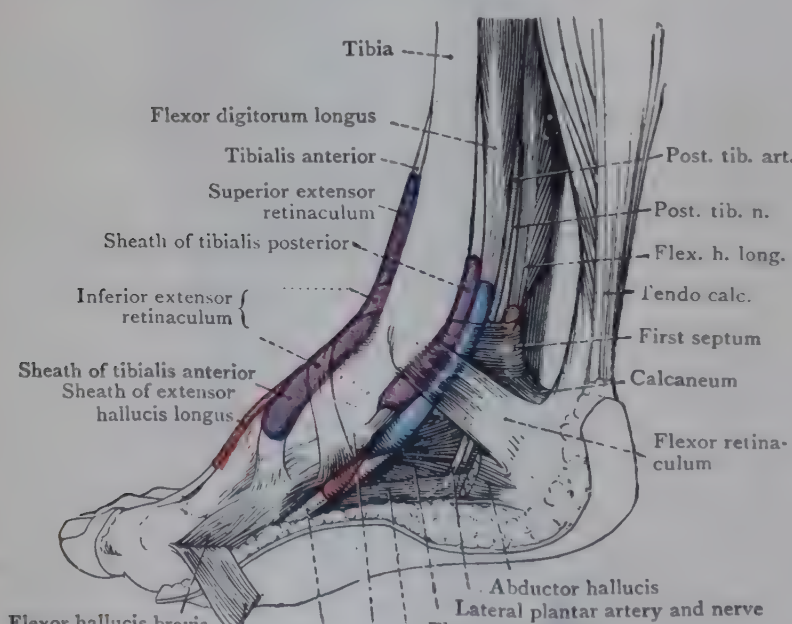

FIG. 477.—DISSECTION OF LEG AND FOOT SHOWING SYNOVIAL SHEATHS.

It is attached to the medial tubercle of the calcaneum and spreads out anteriorly to separate into *five slips* which are directed forwards to the bases of the toes and are united at their origin by ill-defined bands of transverse fibres. The slip for each toe straddles the flexor tendons and is attached on each side to the deep transverse ligaments of the sole and the base of the proximal phalanx. Distally it is continuous with the fibrous flexor sheath. Superficial fibres from the slips are inserted into the skin of the furrow between the toes and the sole. From the margins of the plantar aponeurosis strong septa are sent upwards between the flexor digitorum brevis and the two abductors; they give origin to the muscles between which they lie, and they fuse with the fascia on the deep surface of the flexor brevis, thus enclosing it in a separate sheath.

On the toes, the deep fascia is thickened to form the **fibrous flexor sheaths**, which, though smaller, are similar to those of the fingers (p. 514).

Synovial Sheaths.—The synovial sheaths facilitate the play of the tendons upon the ankle and tarsal regions. They are not so numerous as those at the wrist and in the hand, nor are they so liable to injury; and they do not communicate with the synovial sheaths in the fibrous flexor sheaths, as do those of the thumb and little finger. **On the front of the ankle and dorsum of the foot** there are three separate sheaths: one for the tendon of the tibialis anterior, one for that of the extensor hallucis longus, and a third which is common to the tendons of the extensor digitorum longus and peroneus tertius.

1. The sheath of the **tibialis anterior** begins near the upper border of the superior retinaculum and reaches almost to the insertion of the tendon.

2. The sheath of the **extensor hallucis** begins between the extensor retinacula and extends to the proximal phalanx of the big toe.

3. The sheath of the **extensor digitorum longus and peroneus tertius**, narrow above and wider below, begins at the lower border of the superior retinaculum and ends about the middle of the dorsum of the foot.

On the lateral side of the ankle and foot, the common sheath of the **peroneus longus and brevis** begins at the back of the lateral malleolus and bifurcates as it approaches the peroneal tubercle; one part is prolonged on the peroneus brevis almost to its insertion; the other ensheaths the peroneus longus (with or without interruption at the lateral side of the foot) across the sole to its attachment.

On the medial side of the ankle and foot there are three synovial sheaths.

1. The sheath of the **tibialis posterior** begins about 2 inches (50 mm.) above the tip of the medial malleolus, and ends at the insertion into the navicular bone.

2. The sheath of the **flexor digitorum longus** begins immediately below the previous one, but extends farther forwards—reaching the middle of the foot.

3. The sheath of the **flexor hallucis longus** begins immediately below the last one, and may extend to the middle of the first metatarsal bone.

Within the fibrous flexor sheaths the tendons, as in the fingers, are accompanied by short synovial sheaths—that of the big toe running backwards as far as the shaft of its metatarsal bone, while the others do not extend backwards farther than the heads of the metatarsal bones.

DEVELOPMENT AND MORPHOLOGY OF SKELETAL MUSCLES

The mesoderm on each side of the neural tube separates primarily into mesodermal somites, intermediate cell-mass (nephrotome), and the lateral plate. Afterwards each mesodermal somite divides into two parts—a medial portion called the **scleratogenous segment**, and a lateral portion called the **muscle-plate** (myotome). The lateral plate divides into an outer layer called the **somatic mesoderm** and an inner layer called the **splanchnic mesoderm** (p. 50).

The skeletal muscles are derived from the muscle-plates of the mesodermal somites. The limb-muscles, however, appear to be formed in the mesenchymal core of the limb-bud, probably from cells that have migrated from the muscle-plates into the core; and the visceral muscles of the head and neck are derived from the mesoderm of the pharyngeal arches. Each **mesodermal somite** is at first a quadrilateral mass which rests against the neural tube and notochord. Its cavity represents a diverticulum of the cœlomic cavity. In the early stages of embryonic life the growth of the mesodermal somite is rapid. From its scleratogenous segment, masses of cells arise which grow medially and surround the neural tube and notochord to form the rudiment of the vertebral column. On its lateral side, cells appear to be given off which participate in the formation of the corium of the skin. At the same time the dorsal and ventral borders of the muscle-plate continue to extend, and present extremities (growing points) which have an epithelial structure for a considerable period. *On the dorsal side*, it overlies the neural tube as the "dorso-lateral sheet", which gives rise to the muscles of the back; its *ventral extension* traverses the somatic mesoderm in the body-wall, and produces the "ventro-lateral sheet", which gives rise to the lateral and ventral muscles of the body-wall and, by a medial prolongation, the prevertebral muscles of the neck. The cells of the medial layer of the muscle-plates are responsible for the formation of the muscle-fibres. The innervation of a muscle-plate or of a pre-muscle mass is determined at a very early stage of development, and the nerve-supply of a muscle is consequently the best guide to its morphology. The dorso-lateral sheet is innervated by the posterior primary rami of the spinal nerves, the ventro-lateral by the anterior primary rami.

Portions of two or more neighbouring muscle-plates may fuse to form a skeletal muscle, and that is the common mode of origin, as it is only in a few groups that the individual muscles can be referred to single muscle-plates.

In the course of growth and development a muscle may become widely separated from the skeletal elements which are derived from the same somites as its myotomic constituents. The diaphragm (C. 3, 4, and 5) is an excellent example of "muscle migration". In the same way muscles derived from the mesodermal core of the limb-buds may spread to the trunk and there obtain attachments to skeletal elements at a considerable distance. The latissimus dorsi is an outstanding example of such "migration".

Musculature of the Trunk.—The **dorsal portion** of each muscle-plate becomes separated off and becomes continuous with the corresponding portions of neighbouring myotomes; a longitudinal pre-muscle column is thus formed, to which the posterior primary rami of the spinal nerves are distributed. That column gives rise to the muscles of the back of the neck and the

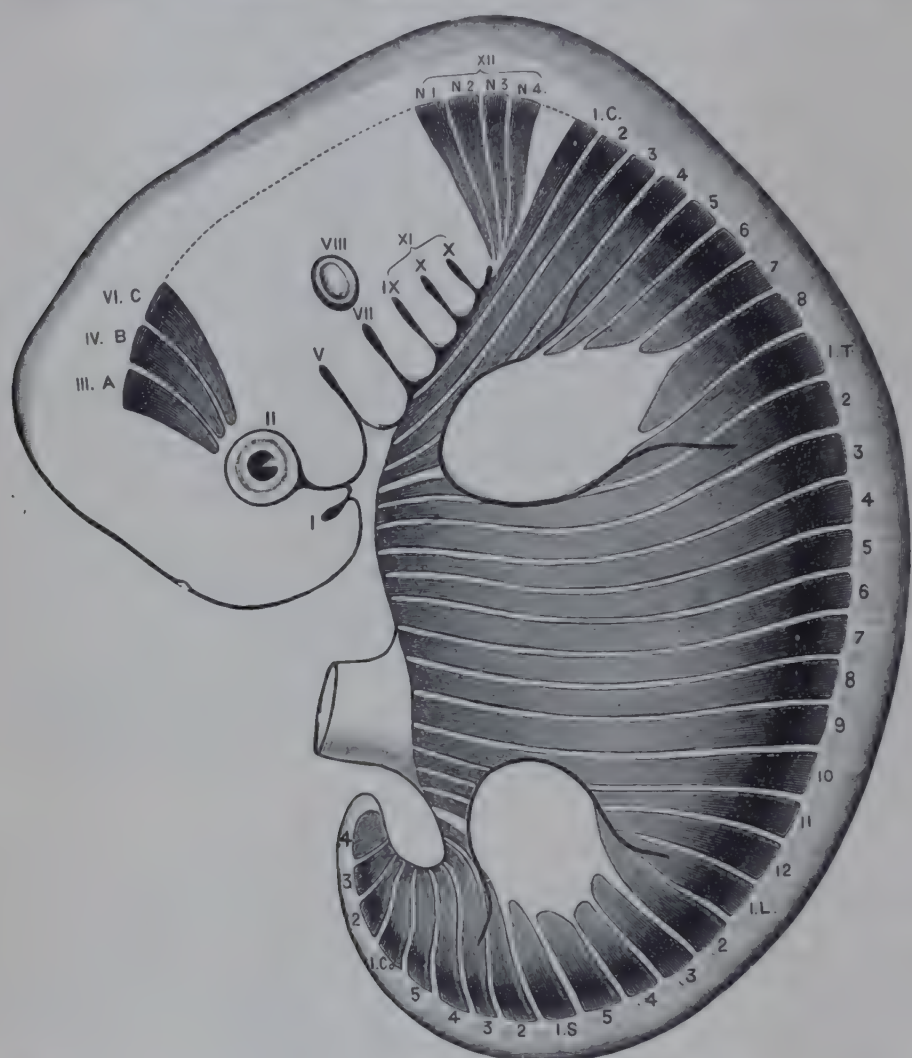

FIG. 478.—SCHEME TO ILLUSTRATE THE DISPOSITION OF THE MYOTOMES IN THE EMBRYO IN RELATION TO THE HEAD, TRUNK, AND LIMBS.

A, B, C, First three cephalic myotomes; N, 1, 2, 3, Occipital myotomes (it is probable that three only are represented in the human embryo); C., T., L., S., Co., The myotomes of the cervical, thoracic, lumbar, sacral, and caudal regions; I, II, III, IV, V, VI, VII, VIII, IX, X, XI, XII, refer to the cranial nerves and the structures with which they may be embryologically associated.

back of the trunk, and they become differentiated from one another by the formation of longitudinal fibrous septa. The deeper parts of the dorsal portions of the muscle-plates remain separate in certain regions and constitute the rotatores and interspinales.

The **ventral portion** of each muscle-plate carries off the anterior primary ramus of the corresponding nerve and spreads ventrally into the somatic mesoderm dorso-lateral to the derivatives of the intermediate cell-mass. (*a*) The dorsal portion of this strip separates off from the rest and fuses with the corresponding portions of neighbouring segments. In the human embryo the column so formed persists only in the cervical region, where it gives rise to the longus cervicis, longus capitis, and the crura of the diaphragm. (*b*) The ventral ends of this extension into the somatic mesoderm behave in a similar way—giving rise, in Man, to the rectus abdominis, the pyramidalis, the sterno-costal portions of the diaphragm, and, probably, the infra-hyoid group of muscles. (*c*) The intermediate portions of these strip-like extensions into the somatic mesoderm become fused and then, in some vertebrates, are delaminated into as many as five layers. In Man, only three such layers are formed, viz., the obliquus externus, the obliquus internus, and the transversus abdominis. Dorsally, the quadratus lumborum, with its enclosing layers of the lumbar fascia, is derived from the same source. In the thoracic region, however, the fusion of the individual myotomic derivatives is carried out only in the case of the transversus thoracis.

The more superficial derivatives constitute the external and internal intercostal muscles, which retain their segmental characters. It appears probable that in the cervical region the corresponding myotomic derivatives in part disappear and in part form the scalene muscles and the remaining portion of the diaphragm.

The ventral portions of the lumbar myotomes (with the exception of the first) and the upper sacral myotomes disappear in Man; but they persist in the third and fourth sacral somites and give rise to the levator ani and the coccygeus.

The occipital myotomes form the muscles of the tongue.

The diaphragm, which may justly be termed the most essential of all the skeletal muscles in Man, is derived to a very large extent, if not entirely, from the ventral portion of the fourth cervical muscle-plate. The crura are on the same morphological plane as the longus cervicis, the sterno-costal portions as the rectus and transversus abdominis. The phylogenetic history of the diaphragm shows that it represents the detached cervical portion of the transversus sheet. In Amphibia and Reptilia there is no separation of the pleural and peritoneal cavities, and the whole transversus sheet functions as a compressor of the cœlom and so as a muscle of expiration. In Mammalia, on the other hand, the diaphragm intervenes between the pleural and the peritoneal cavities, and its action as a cœlomic compressor is restricted to the latter. At the same time, its new position makes it a powerful inspiratory muscle, and in Man it is of very much greater importance than all the other muscles which, primarily or secondarily, help to increase the capacity of the thorax. In pronograde mammals, on the other hand, inspiration depends much more on elevation of the ribs by the external respiratory muscles, and the principal action of the diaphragm in those animals would seem to be its primitive action as a compressor of the cœlom.

The **branchial musculature** is formed in the mesoderm of the pharyngeal arches and is quite distinct from the musculature derived from the occipital and cervical myotomes, not only in its source but also in its innervation, which is obtained from certain of the cranial nerves. Although laid down in the substance of the arches, the branchial muscles may undergo extensive "migration". This change of position is best exemplified by the muscles of the second arch (*vide infra*).

The sterno-mastoid and trapezius have a special morphological history, as is clearly indicated by the peculiarity of their supply from the accessory nerve. They arise from a special common rudiment, believed to be branchial in origin, situated in the embryo over the hinder part of the branchial region ventral to the last two occipital myotomes and first two cervical myotomes, from which situation they spread to their attachments to the head and shoulder-girdle. The accessory part of the vagal complex which supplies these muscles extends into the cervical part of the spinal cord, and this extension is perhaps to be associated with their afferent supply from that region (C. 2, 3, 4); if any motor fibres reach the muscles through these cervical nerves, this is to be looked upon as a secondary supply from the same source by an alternative route and not as an indication of myotomic origin.

The accompanying table indicates the muscles derived from the individual pharyngeal arches with their nerves of supply :—

Arch	Nerve	Muscles
First (mandibular)	Trigeminal (mandibular division)	Muscles of mastication Tensor tympani Tensor palati
Second (hyoid)	Facial	Muscles of facial expression (including muscles of scalp and platysma) Stylo-hyoid Posterior belly of digastric Stapedius
Third	Glosso-pharyngeal	Stylo-pharyngeus (Constrictors of pharynx ?)
Fourth Fifth ? Sixth	Vagus-Accessory	Constrictors of pharynx Muscles of soft palate Muscles of larynx Sterno-mastoid and trapezius

Muscles of the Orbit.—It has not been possible to identify cephalic muscle-plates in the human embryo. The muscles of the orbit can be distinguished in the embryo as a single pre-muscle mass, closely related to the optic vesicle, and receiving the terminations of the third, fourth, and sixth cranial nerves. Muscle-plates have been demonstrated in the head-region of elasmobranch fishes: the precise number is uncertain, but probably there are at least nine, of which the last four are occipital. The first three cephalic muscle-plates form the muscles of the orbit—the first giving rise to the group supplied by the oculomotor nerve, the second to the superior oblique, and the third to the lateral rectus muscle. The fourth and subsequent myotomes disappear, but three occipital muscle-plates persist to form the muscles of the tongue.

Musculature of the Limbs.—The developing limb-bud consists of an ectodermal envelope enclosing a mass of mesoderm from which both the skeletal elements and the musculature of the limb are derived. Ventral and dorsal sheets of muscle are laid down, and they are at first continuous with each other along the pre-axial and post-axial borders of the bud. The anterior primary rami of the spinal nerves which eventually enter into the formation of the limb-plexus are at first arranged segmentally in the developing limb, and each gives ventral and dorsal branches to exactly corresponding portions of the muscle-sheets. It will therefore be found that the muscles which develop along the pre-axial border, whether ventral or dorsal, are innervated by the highest nerve of the plexus, while those which develop along the post-axial border are innervated by the lowest nerve of the plexus. The early subdivision of the limb-musculature into ventral and dorsal sheets, and the innervation of portions of both sheets by every nerve of the limb-plexus, are indicated in the fully formed upper limb by the division of the trunks of the brachial plexus into anterior and posterior divisions before the formation of the cords; and, in the case of the lower limb, by the similar division of the nerves that enter the lumbar and sacral plexuses.

The proximal portions of the two muscle-sheets extend towards the trunk and eventually constitute the muscles which connect the limb or its girdle to the trunk (with the exception of the trapezius). Those muscles are much more numerous in the upper limb than they are in the lower limb, where their chief representative is the psoas major.

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FIG. 1.—LATERAL RADIOGRAPH OF LEFT HALF OF JAWS OF MALE SKULL WITH COMPLETE SET OF TEETH.

Note the details of the Tooth Cavities and Root Canals, and of the structure of the bone around the Tooth Sockets (for periodontal membrane and lamina dura, see p. 574). The usual relation of the Roots of the Upper Teeth to the Maxillary Sinus (see p. 197) is well shown; see also Plate VII, p. 154.

FIG. 2.—RADIOGRAPH OF RIGHT HALF OF MANDIBLE OF CHILD AGED TWO YEARS, SHOWING THE STATE OF ERUPTION OF THE TEETH.

Note the situation of the developing first permanent molar behind the full set of deciduous teeth. In Figs. 2 and 3, the deciduous teeth are indicated by small letters, the permanent teeth by capitals.

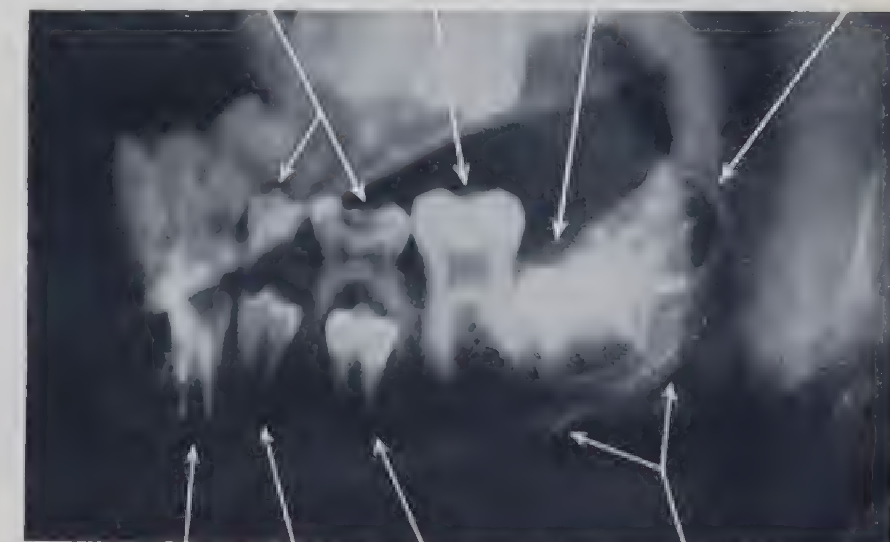

FIG. 3.—RADIOGRAPH OF MANDIBLE OF CHILD AGED NINE YEARS, SHOWING THE STATE OF ERUPTION OF THE TEETH.

Note the situation of the second and third permanent molars, behind the fully-erupted first permanent molar, and the stage of their development. The roots of the permanent canine and premolars are not fully calcified at their apices.

PLATE XLVIII

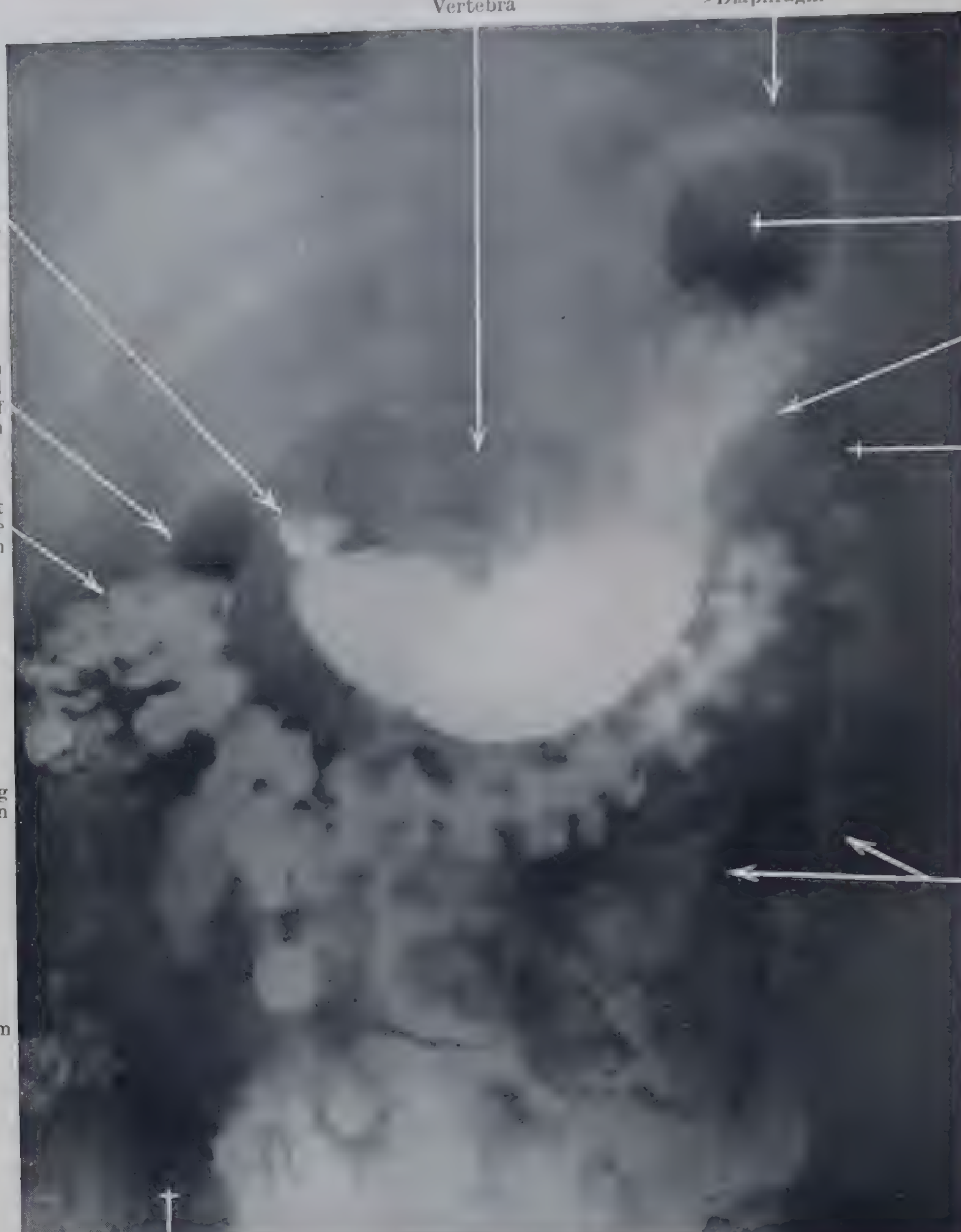

PLATE XLVIII.—RADIOGRAPH OF ABDOMEN OF MAN AGED 28 IN THE ERECT POSTURE, SHOWING THE APPEARANCE OF THE ALIMENTARY CANAL AFTER ADMINISTRATION OF OPAQUE MEALS AT INTERVALS.

The contents of the Stomach and Duodenum and of the Ileum seen in Plate LIII, p. 612 (given respectively 45 and 48 hours previously) are now in the Large Intestine. The first half of a third opaque meal (given one hour before the radiograph was taken) is in the Jejunum and Ileum, and the Stomach is half-filled by the second half. Note the Duodenal Cap (see p. 621) and the residue of radio-opaque material in the Cæcum and Ascending Colon. For further stage in the filling of the Large Intestine, see Plate LVII, p. 648.

DIGESTIVE SYSTEM

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The physical characters and chemical composition of food taken into the body are such that much of it cannot be utilized at once by the organism. Before it is absorbed and used in nutrition, it is acted upon both chemically and mechanically. The process of performing these mechanical and chemical changes is called *digestion*.

The term **Digestive System** is applied collectively to the organs which are concerned in this process, in the reception of food into the body, and in the excretion of the unabsorbed residue.

A simple form of digestive system, found in many of the lower animals, consists of a tube that passes through the interior of the body from an anterior aperture or mouth to a posterior aperture or anus.

In Man, a tube of that kind forms the basis of the digestive system. It extends from the mouth, through the neck, thorax, abdomen, and pelvis, to the anal orifice. The wall and lining membrane act mechanically and chemically upon the food in its interior, absorb products of digestion and transmit them into the adjacent blood-vessels and lymph-vessels.

The successive parts of this tube are the *mouth, pharynx, œsophagus, stomach, small intestine,* and *large intestine.* The mouth and pharynx are used for respiration as well as for digestion, and the **alimentary canal** proper begins at the upper end of the œsophagus. In addition, there are several glandular organs whose ducts open into the mouth—the *salivary glands*—and into the small intestine—*liver* and *pancreas.* These also are included in the digestive system. The general arrangement, position, and size of these various parts are shown in Fig. 479.

MOUTH

The **mouth**, the first part of the digestive system, is bounded externally by the lips and cheeks, and is roofed in by the palate. Within it lie the teeth and greater part of the tongue; and the ducts of the salivary glands open into it.

The aperture of the mouth or **oral fissure** is the interval between the lips, which meet at the *angles of the mouth.* In a state of rest, with the lips in apposition, the aperture forms a slightly curved line which extends transversely between the first premolar teeth at a level immediately below the middle of the upper incisor crowns. The shape of the aperture varies with every movement of the lips, from the resting linear form, curved like the conventional bow, to a circular or oval shape when the mouth is widely open, or the "pursed-up" condition produced by the contraction of the orbicularis oris muscle.

The **cavity of the mouth** is divisible into two portions—the *vestibule* and the *cavity proper.*

The **vestibule of the mouth** is the interval between the lips and cheeks externally and the teeth and gums of the upper and lower jaws internally.

When the oral fissure is closed and the lips and the teeth are in contact, the vestibule is merely a slit whose roof and floor are formed by the reflexion of the mucous membrane from the lips and cheeks to the maxillæ and mandible.

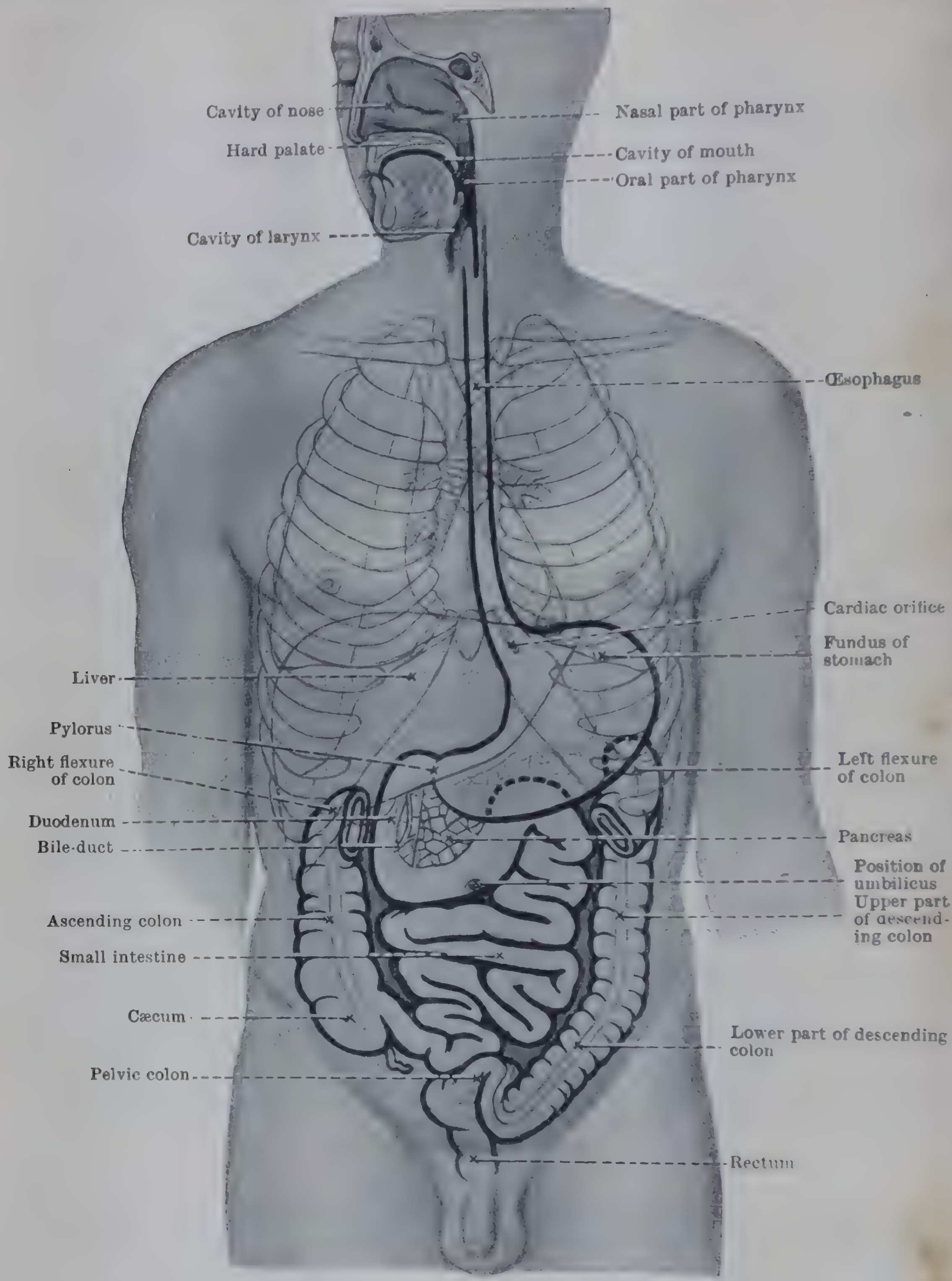

FIG. 479.—DIAGRAM OF GENERAL ARRANGEMENT OF DIGESTIVE SYSTEM.

The transverse colon is not represented, in order that the duodenum and pancreas, which lie behind it, may be seen.

From the back of each lip in the median plane projects a small vertical fold of mucous membrane—the **frenulum**—which connects the lip to the front of the corresponding gum. The *frenulum of the upper lip* is the larger, and is brought into view when the lip is everted. The *frenulum of the lower lip* is not always obvious.

On the outer wall of the vestibule, opposite the crown of the second upper molar tooth, there is a slight eminence, and on its summit is the small opening of the duct of the parotid salivary gland.

When the upper and lower teeth are in contact the vestibule communicates with the cavity of the mouth only through small and irregular spaces between opposing teeth, and, behind, by the wider but variable aperture between the last molars and the ramus of the mandible.

Advantage may be taken of that aperture for the introduction into the mouth of liquid food in certain cases—trismus, anchylosis, etc.—in which the jaws are rigidly closed.

If the finger is passed backwards in the vestibule, the anterior border of the masseter can be distinctly felt on the outer wall when the muscle is thrown into a state of contraction. Still farther back, the front of the coronoid process, bearing the insertion of the temporal muscle, can also be made out. The pterygo-mandibular ligament, which is felt along with the anterior border of the medial pterygoid muscle, is distinguishable as a pliant ridge when the finger is carried from the front of the coronoid process behind the last molar tooth into the cavity of the mouth.

In addition to the ducts of the parotid glands, those of numerous small glands, which are embedded in the lips and cheeks, open into the vestibule.

Under normal conditions the lips and cheeks lie against the teeth and gums, obliterating the cavity of the vestibule; and they help, with the aid of the tongue, to keep the food between the grinding surfaces of the molar teeth during mastication. In facial palsy, however, the lips and cheeks fall away from the dental arches, owing to the paralysis of their muscles, and particularly of the buccinator muscle, and food accumulates in the vestibule.

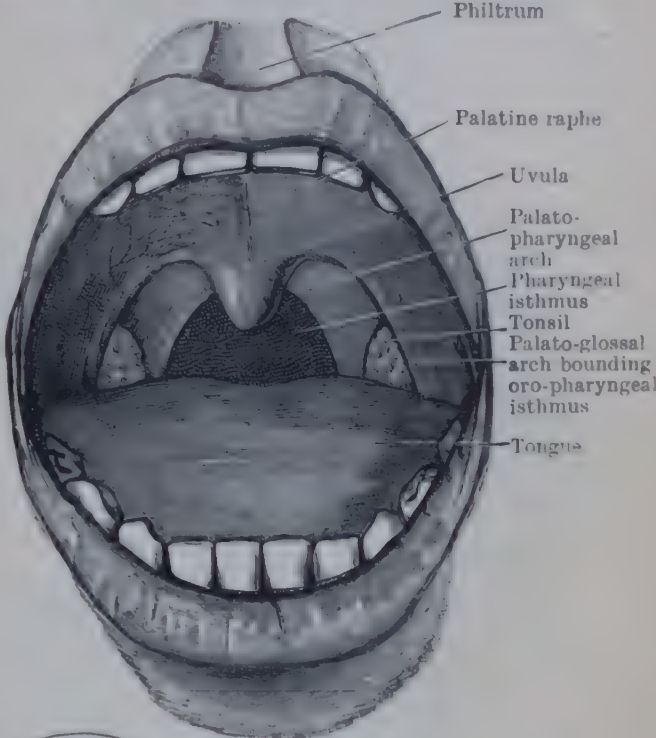

FIG. 480.—OPEN MOUTH SHOWING PALATE AND TONSILS.

It shows also the two palatine arches, the oro-pharyngeal isthmus, through which the mouth communicates with the oral part of the pharynx, and the pharyngeal isthmus or communication of the oral part of the pharynx with the nasal part.

The **cavity proper of the mouth** is within the arches of the teeth and gums and extends back to the palato-glossal arches. The *roof* is formed by the **hard palate** and the anterior portion of the **soft palate**, the *floor* by the anterior part of the tongue in the middle, and on each side by the reflexion of the mucous membrane from the side of the tongue to the mandible.

The term "floor of the mouth" indicates the muscular and other structures, especially the mylo-hyoid muscles, which fill in the interval between the two halves of the body of the mandible (from the symphysis menti to the body of the hyoid bone) and form the basis upon which the tongue and the mucous membrane of the sublingual space are supported.

When the tip of the tongue is raised the mucous membrane in the median plane forms a prominent fold, called the **frenulum of the tongue**, which stretches from the floor of the mouth to the inferior surface of the tongue. On each side of the frenulum, near its junction with the floor, there is a prominent soft projection, called the **sublingual papilla**, on which the **duct of the submandibular gland** opens (Fig. 481). Running laterally and backwards, on each side, from the frenulum, there is a well-marked ridge, called the **sublingual fold**, which is due to the bulging of the underlying sublingual gland. Most of the ducts of the gland open near the crest of this ridge. Another fold, called the **fimbriated fold**, lies lateral to the frenulum, on each side, on the inferior surface of the tongue (Fig. 481).

This fold represents the "sublingua" of Lemurs, a highly developed fringe situated under the tongue which functions as a cleanser of the incisor teeth (Wood Jones, 1918).

Lips.—The lips are the two mobile folds, covered externally with skin, and internally with mucous membrane, which surround the oral fissure and contain the orbicularis oris muscle. Laterally they are prolonged into the cheeks, and below into the chin. The junction of the lips and cheek is marked on the

surface by the **naso-labial sulcus**—a slight groove which passes downwards and laterally from the margin of the nose towards the angle of the mouth—and the **mento-labial sulcus** separates the lower lip from the chin. At the middle of the upper lip there is a shallow vertical groove—the **philtrum**—bounded by two distinct ridges that descend from the nasal septum (Fig. 481); inferiorly the groove widens out and ends opposite a slight projection on the free edge—the *labial tubercle*. This tubercle is particularly well developed in children and is chiefly responsible for the characteristic curve of the oral fissure. The lower lip is usually longer and more movable than the upper lip.

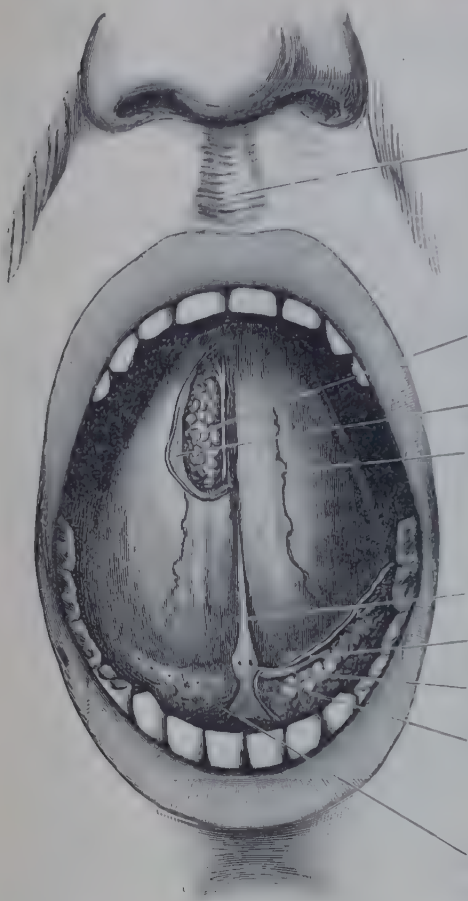

Fig. 481.—Open Mouth with Tongue raised, and the Sublingual and Anterior Lingual Glands exposed.

The sublingual gland of the left side has been laid bare by the removal of the mucous membrane; to expose the anterior lingual gland of the right side a thin layer of muscle, in addition to the mucous membrane, has been removed. A branch of the lingual nerve is seen running on the medial side of the gland. The profunda vein also is faintly indicated on this side.

Between the inner and outer surface of each lip there is an intermediate area—the free margin—which bounds the oral fissure. It is covered with a modified mucous membrane similar to that of the mouth but devoid of mucous glands and dry. It is translucent and transmits the colour of the blood in the underlying capillaries, and hence in health it is reddish-pink in colour. Its size and shape vary greatly; it may be narrow and thin, occupying only a small area on the external surface of the lip, or it may be wide and pouting and, as in the negro, may occupy a wide surface externally. The surface is richly vascular and numerous nerve-terminals are present in it. It is limited externally by a sharply defined line where the skin and mucous membrane meet, but the internal boundary merges into the mucous membrane of the mouth. In the upper lip, the external bounding line follows a curve from near the angle of the mouth to the root of the labial tubercle and there turns sharply downwards, forming with its fellow a bow-shaped figure. In the lower lip the line runs in a more uniform curve from one angle of the mouth to the other. In the child the free margin is transversely grooved and is also divided by a longitudinal groove into two zones—the outer villous, the inner smooth.

In each lip the following structures are present from the external to the internal surface:—(1) **Skin**, closely studded with hairs, small and fine in children and women, long and stout in men. (2) A layer of fatty **superficial fascia** continuous with the fascia of the face. (3) The **orbicularis oris muscle**, a number of whose fibres, or those of the muscles which join it, pass through the superficial fascia and are attached to the skin. (4) **Submucous tissue**, which is occupied by an almost continuous layer of glands—the **labial glands**; they are small, nodular glands, each about the size of a grape-seed, closely packed together, and lie immediately external to the mucous membrane of the upper and lower lips; each nodule is a small, racemose gland lined with mucous secretory cells, with a short duct which pierces the mucous membrane. (5) **Mucous membrane** of the mouth, covered with stratified squamous epithelium.

For the various muscles which enter into the formation of the lip, see the Section on Myology (pp. 424-426).

Vessels and Nerves.—The lips receive a free **arterial** supply from the labial branches of the *facial artery*.

The sensory **nerve-supply** of the lips is derived from the *trigeminal nerve*—that of the upper through the *infra-orbital branch* of the maxillary nerve, and that of the lower from the

mental branch of the inferior dental branch of the mandibular nerve, while the *buccal* branch of the mandibular nerve supplies the region of the angle. The **lymph-vessels** of the upper lip pass with the facial artery to the *submandibular lymph-glands*, while those from the lower lip pass in part to the same glands, and in part to the *submental glands.*

Movements of Lips.—Opening and closing of the oral fissure are usually associated with elevation and depression of the mandible. Finer movements are effected by contraction of the orbicularis oris muscle as a whole or of its parts, and by those muscles of expression which are inserted into the upper and lower lips.

Ability to perform finer movements of the lips in speech or in whistling constitutes a test of the integrity of the nerve-supply of these muscles.

Cheeks.—The cheeks resemble the lips in structure, and have corresponding layers, but the buccinator muscle takes the place of the orbicularis oris. Under the skin lies the fatty superficial fascia of the face, through which the **parotid duct** runs inwards to pierce the buccinator; it is much looser in texture than in the lips. Near the end of the duct are found four or five mucous glands, as large as hemp-seeds, known as the **molar glands**; their ducts pierce the cheek and open into the vestibule. Beneath the superficial fascia lies the *buccinator muscle,* covered by the bucco-pharyngeal fascia. Deeper still is the submucosa, which, like that of the lips, contains numerous mucous glands—the **buccal glands**—and finally the mucous membrane.

The **buccal pad of fat** is an encapsuled mass of fat which lies on the outer side of the buccinator, and in the recess between that muscle and the overlying part of the masseter and ramus of the mandible. It gives to the cheeks their rounded contour. It is relatively larger in the child than in the adult, and it strengthens the cheek to resist the effects of atmospheric pressure during the act of sucking.

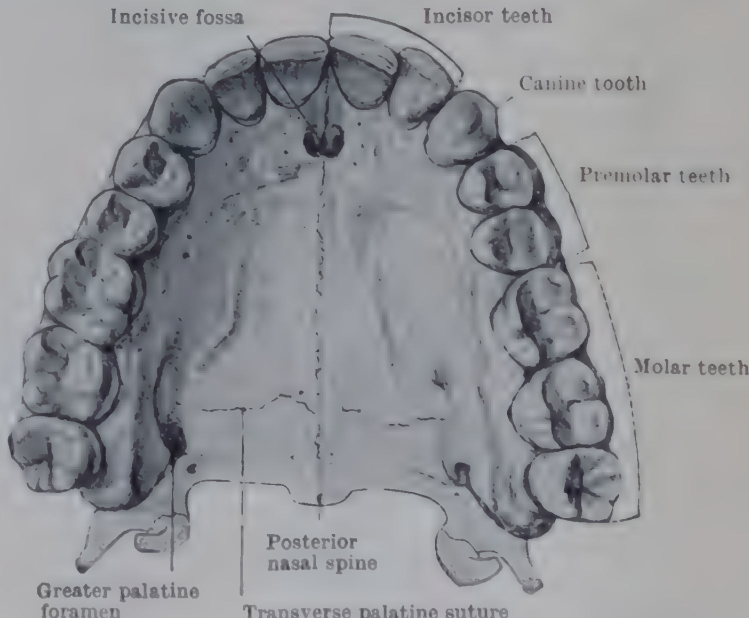

FIG. 482.—HARD PALATE AND UPPER PERMANENT TEETH.

Movements of Cheeks.—The cheeks are of great importance in mastication. By their movements the cavity of the vestibule of the mouth can be obliterated, and food in the vestibule forced into the cavity of the mouth proper. Movements of the cheeks are also required in playing wind-instruments. The principal agent is the buccinator muscle, but the orbicularis oris muscle and the muscles inserted into the lips also participate.

Palate.—The palate forms the roof of the mouth. It separates the mouth from the nasal cavities and nasal part of the pharynx, and it extends backwards into the cavity of the pharynx, forming a partial division between the oral and the nasal parts of the pharynx.

It consists of two portions—an anterior two-thirds, with a bony foundation, termed the *hard palate,* and a posterior third, with a fibro-muscular basis, termed the *soft palate.* The palate is arched antero-posteriorly and also transversely. The transverse curvature is the more pronounced in the hard palate.

The **hard palate** is a horizontal plate formed by the palatine processes of the maxillæ and the horizontal plates of the palatine bones, covered on each surface, superior and inferior, with muco-periosteum. The muco-periosteum of the inferior surface is very thick, and contains in its posterior part a large number of mucous glands and the larger nerves and blood-vessels of the palate (Fig. 483). The epithelium of the muco-periosteum which covers the superior surface forms the floor of the nasal cavity and is largely ciliated in character, while that on the inferior surface is covered with stratified squamous epithelium.

The **soft palate** is attached to the posterior margin of the hard palate. Its lower or posterior margin is free and forms an arch which extends from one side of the pharynx to the other; but the arch is interrupted in the middle by a conical projection, called the **uvula**, which shows great variation in length; in some persons it is short and blunt; in others it is long and thin and its tip may extend downwards to the dorsum of the tongue. On each side, the soft palate is connected with two folds of mucous membrane which are separated

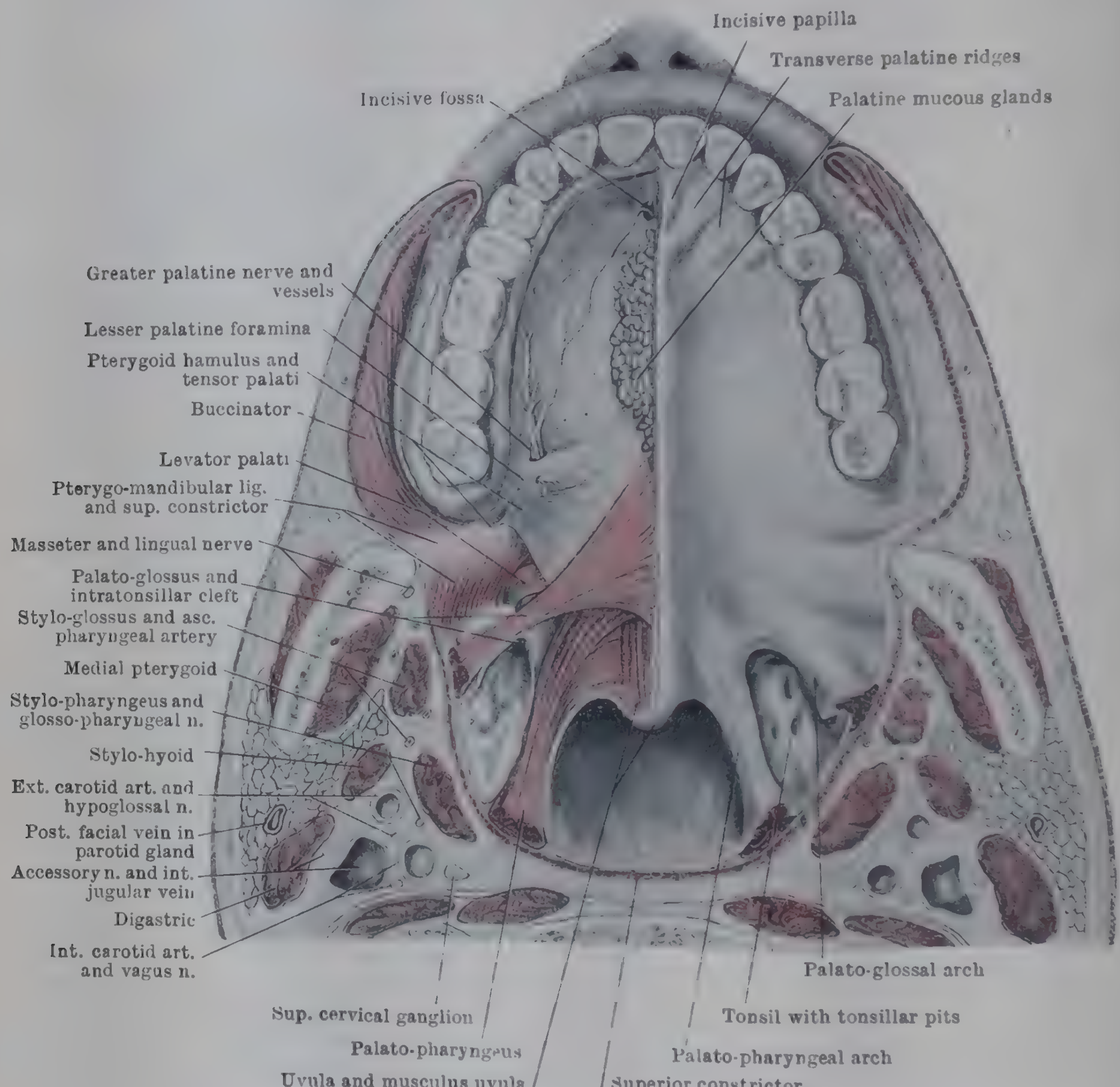

FIG. 483.—HORIZONTAL SECTION AT LEVEL OF ORAL FISSURE SHOWING PALATE FROM BELOW.
The right half of the palate has been dissected to show the palatine glands, arteries and nerves and the muscles of the soft palate.

by a triangular interval occupied by the tonsil. The anterior fold is called the *palato-glossal arch* (p. 566), and it descends to the side of the tongue. The posterior fold descends from the posterior edge of the soft palate and is lost on the side-wall of the pharynx; it is called the *palato-pharyngeal arch* (p. 590).

The superior surface of the soft palate continues the floor of the nasal cavity backwards and downwards and forms the floor of the nasal part of the pharynx.

Along the middle of the oral surface of the palate, a faint median ridge—the **palatine raphe** (Figs. 480, 483)—indicates its original development from two halves; it begins behind at the root of the uvula, and in front it ends in a slight elevation called the **incisive papilla**; in the fœtus, and even at birth, the papilla is continued over the edge of the gum into the frenulum of the upper lip. From the anterior part of the raphe a series of transverse ridges of mucous membrane, about six in number, run laterally

immediately behind the incisor teeth; they are known as the *transverse palatine ridges*, and are composed of dense fibrous tissue adherent to the periosteum. These ridges correspond to the strongly marked ridges seen in the roof of the mouth of lower animals; they are very distinct in a fœtus of five or six months, are less distinct in a child, and become more or less obliterated in old age. Sometimes a small pit which will admit the point of a pin is seen on each side immediately behind the central incisor teeth and about 2 mm. from the median plane. These pits correspond to the inferior openings of the incisive canals, with which they are occasionally continuous.

The soft palate, during rest, as for instance in quiet nasal breathing, is very oblique in direction. When, however, the soft palate is raised, as in swallowing, it continues the plane of the hard palate backwards, and projects across the cavity of the pharynx, forming a nearly complete partition between its oral and nasal parts. In that position it prevents food from passing upwards into the nasal part of the pharynx and the nose.

Structure.—The framework of the soft palate is a strong, thin, flat, fibrous sheet, called the *palatine aponeurosis*, which is confined to the anterior part of the soft palate, and is formed by the expanded tendons of the tensor palati muscles. Its anterior margin is united to the posterior edge of the horizontal plates of the palatine bones. The tensor palati is continuous with its lateral part, but the other muscles occupy chiefly the posterior two-thirds of the soft palate.

The anterior part of the soft palate contains the anterior fibres of the palato-glossus (Fig. 483), and the origins of the musculi uvulæ, but it consists essentially of the palatine aponeurosis, covered by an extremely thick layer of glands on the inferior surface and by mucous membrane on both surfaces. The anterior portion is much less movable than the rest of the soft palate, and forms a relatively horizontal continuation backwards of the hard palate, stretching across between the two medial pterygoid plates. Upon that portion chiefly the tensor palati muscles act. The posterior and larger part contains muscular fibres in abundance, slopes strongly downwards, and is freely movable, and upon it the other palatine muscles act. The muscles of the soft palate (palato-pharyngeus, palato-glossus, levator palati, tensor palati and musculus uvulæ) are described on pp. 441-443.

The mucous membrane of the oral surface of the soft palate is covered with stratified squamous epithelium. In the fœtus the whole of the epithelium on the upper surface is ciliated, but after birth the ciliated epithelium is largely replaced by stratified squamous epithelium, except at the margins.

Mucous glands, the orifices of which can be seen as dots with the naked eye, are extremely abundant in the soft palate and in the posterior half of the hard palate, except near the raphe. The position and limits of these glands are usually clearly indicated by the smooth area of the hard palate. The glands usually extend forward as far as a transverse line drawn behind the canine teeth.

The **uvula** is composed of a mass of mucous glands and areolar tissue covered with mucous membrane, and it contains a slender prolongation of the uvular muscle.

Vessels and Nerves of Palate.—The principal **arteries** are the palatine branches of the maxillary artery. The largest and most important of these is the *greater palatine artery*, which reaches the palate through the greater palatine foramen and runs forward along the lateral margin of the hard palate, near the alveolar margin, towards the incisive fossa, where it anastomoses with a minute terminal branch of the spheno-palatine artery. Some smaller *lesser palatine branches* from the maxillary artery emerge through the lesser palatine foramina and supply the soft palate and anastomose with the ascending palatine branch of the facial artery. The soft palate shares in the blood-supply of neighbouring structures, and so receives a blood-supply from the tonsillar branch of the facial artery, the ascending pharyngeal artery, and the dorsal lingual branches of the lingual artery.

The **sensory nerves** of the palate are all branches from the spheno-palatine ganglion. The largest of these—the *greater palatine nerve*—emerges through the greater palatine foramen and divides in the roof of the mouth into branches which run in grooves in the hard palate and extend forward nearly to the incisor teeth. Some of them join with a small branch of the *long spheno-palatine nerve*, which reaches the palate through the median incisive foramen. The *lesser palatine nerves* emerge through the lesser palatine foramina and are distributed to the hard and soft palate. For the **motor** nerves to the muscles of the soft palate, see p. 444.

The **lymph-vessels** of the palate pass lateral to the tonsil and the palato-glossal arch to the *upper deep cervical lymph-glands*.

Movements of Soft Palate.—The hinder part of the soft palate is freely mobile, moving like a door on its hinge near its junction with the hard palate. It can be raised so that its dorsal surface comes into contact with the posterior wall of the pharynx, where it meets a ridge formed by the contraction of the upper fibres of the superior constrictor muscle of the pharynx, known to surgeons as Passavant's ridge. By means of this mechanism, which has been compared to a sphincter, the oral part of the pharynx is separated from the nasal part. The elevation of the soft palate is effected by the levator

and tensor palati muscles, and the resulting closure of the pharyngeal isthmus takes place in swallowing, in vomiting, and in speech, except with the consonants *m*, *n*, and *ng*, which require nasal resonance for their correct pronunciation. The soft palate can also be lowered and its under surface brought into contact with the posterior part of the upper surface of the tongue through the agency of the palato-glossus and palato-pharyngeus muscles. (See also p. 444.)

Oro-Pharyngeal Isthmus.—The oro-pharyngeal isthmus is the aperture through which the mouth communicates with the oral part of the pharynx (Fig. 480). It is bounded at the sides by the palato-glossal arches, above by the inferior surface of the soft palate, and below by the dorsum of the tongue; in width it corresponds pretty closely to the cavity of the mouth.

Each **palato-glossal arch** is a fold of mucous membrane which contains a palato-glossus muscle in its interior. It begins on the lower surface of the soft palate about one-third of an inch (8 mm.) in front of its posterior edge, near the root of the uvula, and it arches laterally and downwards to blend with the mucous membrane of the side of the tongue a little behind its middle.

Gums.—The gums (gingivæ) are composed of firm fibrous tissue united with mucous membrane. They are attached to the alveolar borders of the maxillæ and mandible and surround the necks of the teeth. They are richly supplied with blood-vessels but sparsely with nerves, and they are covered with stratified squamous epithelium. Around the neck of each tooth the gum forms a free overlapping collar, and at that part particularly it is closely studded with small papillæ, visible to the naked eye. In thickness it usually measures from 1 to 2 mm.

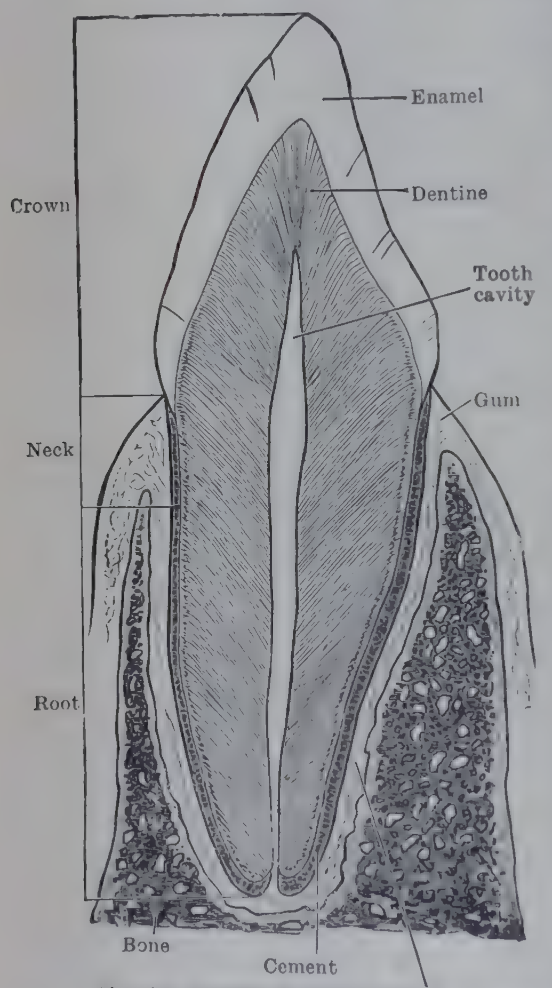

Fig. 484.—Vertical Section of Canine Tooth to illustrate its Parts and Structure.

TEETH

The teeth, rooted in the tooth-sockets of the upper and lower jaws, are of different form and shape, and appear in two sets—a deciduous (milk-teeth) and a permanent.

The deciduous teeth appear through the gums from about the sixth month of childhood. They are gradually shed and are succeeded by the permanent teeth.

General Form and Structure.—Each tooth has a crown, a neck, and a root (Fig. 484). The **crown** is the portion above the gum. It is of different form in the different teeth, being chisel-shaped, conical, or flattened and broad with tubercles on its masticating surface. The surface of the crown which faces outwards is termed its *labial* (or *buccal*) *surface*, that on the opposite side its *lingual surface*. The terminal surface of molars and premolars is termed the *masticating surface*. The **neck** is the faintly constricted part which connects the crown with the **root**, which is the portion of the tooth embedded in the socket. In the majority of teeth, the root is single or nearly so, and it is long, tapering, conical, or flattened—accurately fitting the socket. In the molar teeth (and in some of the others occasionally) the root is divided into two or three tapering or flattened roots or fangs. At the apex of each root there is a minute opening, called the **root-foramen**, through which the vessels and nerves enter the cavity of the tooth.

The **cavity of the tooth** is a space of some size, which is filled in the natural

state by loose areolar tissue, capillaries, nerves, and lymph-vessels; these structures collectively constitute the **pulp of the tooth**. The cavity is prolonged into each root as a slender tapering passage, called the **root-canal**, which opens at the root-foramen.

Short diverticula of the cavity are prolonged into the bases of the tubercles in the molar and premolar teeth, and in the incisors also there are similar slight prolongations towards the angles of the crown.

The root of a tooth, embedded in the **socket** (alveolus), is firmly united to the wall of the socket (Fig. 484) by a layer of vascular fibrous tissue—the **alveolar periosteum**—which is attached to the wall and to the root of the tooth, and above is continuous with the periosteum and with the fibrous tissue of the gum. It is known in dentistry as the *periodontal membrane.*

So accurately are the root and the socket adapted to each other over their whole extent, and so firmly does the periosteum bind them together, that under normal conditions the tooth is quite firmly fixed in the bone, and no movement of the root within the socket can take place; the vessels and nerves entering at the apex are thus secured against pressure or strain.

When, however, the alveolar periosteum is inflamed it becomes swollen and exquisitely sensitive; the tooth, as a result of the swelling, is pushed partly out of its socket, its crown projects above those of its neighbours and strikes against the opposing teeth when the mouth is closed, giving rise to much pain and discomfort.

The **neck** corresponds to the line along which the gum and alveolar periosteum meet, or along which the gum is united to the tooth; but, as already pointed out, the gum does not stop at the neck, but forms a free fold which surrounds the base of the crown collar-wise for a short distance. The outline of the margin of the gum opposite the labial and lingual surfaces of the crown is usually concave, but opposite the contact surfaces of the tooth it is convex, and reaches much nearer to the edge of the crown than on the other surfaces.

Tartar is a hard, calcareous deposit from the saliva, often found on the teeth near their necks. It is composed of lime-salts, and its deposit is largely determined by the presence of organisms (leptothrix, etc.) in the mouth.

Structure of Teeth

Each tooth consists of two chief portions—namely, the **dentine** (ivory) derived from mesoderm and the **enamel** derived from ectoderm. The dentine constitutes the chief mass of the tooth, and the enamel forms a cap for the crown. A third special tissue—the **cement**—is connected with the wall of the socket by the alveolar periosteum.

The dentine and enamel, but particularly the enamel, are the hardest and most resistant structures in the body.

The **enamel** is the dense, white, glistening layer which forms a cap for the crown of each tooth and is thickest over the tubercles. At the neck it ceases gradually, being there slightly overlapped by the cement.

The enamel consists of minute, solid, calcified hexagonal prisms, called the *enamel prisms*, which radiate from the surface of the dentine to the surface of the crown; they terminate there by free ends, and most of them reach from the dentine to the surface of the crown without interruption. The prisms are held together by a very small amount of *interprismatic substance*, but opinions still differ on its nature and the extent of its calcification (Tims & Henry, 1923; Churchill, 1935; Orban, 1944). In old teeth the cap of enamel is often worn away over the tubercles; the dentine is then exposed, and can be recognized by its yellowish colour, which contrasts strongly with the whiteness of the enamel.

Whilst adjacent enamel prisms are in general parallel to one another, they do not usually take a straight course but are rather wavy, and in alternate layers they are often inclined in opposite directions, thus giving rise to certain radial striations seen by reflected light (Schreger's lines). Certain other dark lines, more or less parallel to the surface, are also seen in the enamel (striæ of Retzius). They are due to periodic intermissions in the deposition of calcium during growth.

The *cuticle of the tooth* is an extremely thin (1·5 μ) layer which covers the enamel of recently cut teeth, and is very indestructible—resisting almost all reagents. It is produced by the outer layer of cells of the enamel-organ.

Dentine or **ivory** is the hard and elastic, yellowish-white substance which forms the greater part of every tooth (Fig. 484). Like the enamel it is highly calcified, but it

differs from it in containing a very considerable amount (28 per cent) of organic matter and water incorporated with its salts, which are chiefly phosphate and carbonate of lime (72 per cent).

Dentine consists of a homogeneous, highly calcified, organic matrix, everywhere traversed by tubes—the **dental canaliculi**—which give to that tissue a finely striated appearance, the striæ usually running in wavy lines. The canaliculi begin by open mouths on the wall of the tooth-cavity, whence they run an undulating and spiral course towards the periphery of the dentine. They give off fine anastomosing branches, and in the peripheral zone of the dentine they end in an arborization, a few of the terminal canaliculi penetrating the innermost part of the enamel.

The dental canaliculi are generally described as being lined with special sheaths (*dentinal sheaths* of Neumann) which are composed of a most resistant material, and possibly are calcified. They are occupied by processes prolonged from the outermost cells of the pulp—called after their discoverer, *Tomes' fibrils*. The question whether they contain also neurofibrils (Mummery) cannot be said to be settled, though nerve-fibres have been traced from the pulp through the odontoblast layer (see below) and some of them appear to end in fine branches which enter the mouths of the canaliculi (Lewinsky & Stewart, 1936).

In addition to the radial striation which results from the canaliculi, the dentine shows contour striations or *lines of Owen*. These correspond to the intervals between the concentric laminæ in which the fibrillar branches are arranged at right angles to the canaliculi, and they are associated also with variations in the density with which the dentine is deposited during growth. Certain **interglobular spaces** are left in the dentine as a result of imperfect calcification, and are bounded by the fully calcified surrounding tissue. These spaces form a zone in the outer or "granular layer" of the dentine. The concentric *lines of Schreger*, frequently seen in the dentine, are optical effects due to bends in successive canaliculi along regular lines which run parallel to the periphery of the dentine.

The **cement** is a layer of modified bone which encases the whole of the tooth except its crown. It begins at the neck as a very thin stratum which slightly overlaps the enamel. From there it is continued, increasing in amount, towards the apex, which is formed entirely of this substance. It is relatively small in amount in the child, but it increases during life. In places the dentine seems to pass imperceptibly into the cement, the "granular layer" marking the junction of the two, and some of the dental canaliculi are continuous with the lacunæ of the cement. Like true bone, it is laminated, possesses lacunæ and canaliculi, and, when in large masses, may even contain a few Haversian canals.

The **pulp of the tooth** is composed of a number of branched fibrous tissue cells, whose anastomosing processes form a fine network which contains in its meshes a jelly-like material, in addition to numerous blood-vessels, nerves, and slender lymph-vessels. The most superficial of these cells are arranged in the young tooth as a continuous layer of columnar, epithelium-like cells that lie on the surface of the tooth-pulp against the dentine; they are known as **odontoblasts**, for they are the active agents in the formation of the dentine. The vessels of the tooth-pulp are numerous, and form a capillary plexus immediately internal to the odontoblasts. Fine nerve-bundles run through the pulp from the root-canals towards the crown of the tooth, and some of their fibres enter the odontoblast layer and may possibly supply the dentine.

The **alveolar periosteum** is a layer of fibrous tissue free from elastic fibres but well supplied both with blood-vessels and nerves; it fixes the root of the tooth in the socket, being firmly united by perforating fibres of Sharpey to the cement on the one hand and to the wall of the socket on the other. It establishes a communication between the bone of the jaw and the cement, and it is continuous with the tissue of the gum. Its blood comes chiefly from the arteries which subsequently enter the root-foramina for the supply of the tooth-pulp, but in part also from the vessels of the surrounding bone and of the gum (hence the relief obtained in dental periostitis by lancing the gum).

Permanent Teeth

The **permanent teeth** are thirty-two in number, eight above and eight below on each side. In each set of eight there are:—two incisor teeth, a medial and a lateral; a single canine; two premolars, first and second; and three molars, first, second, and third, arranged in that order from the median plane. When the dentition is perfect each set is bilaterally symmetrical. The human "dental

formula" showing the number of teeth of each class above and below on one side is therefore :—I $\frac{2}{2}$, C $\frac{1}{1}$, PM $\frac{2}{2}$, M $\frac{3}{3}$.

Incisor Teeth.—The **crown** is chisel-shaped, its labial surface convex, the lingual surface concave, the edge chisel-like and, when first cut, surmounted by three small tubercles. These tubercles, however, are soon worn down, and the edge becomes straight or nearly so. The upper incisors usually overlap the lower and hence the cutting edge is bevelled on the lingual aspect of the upper incisors and on the labial aspect of the lower. The upper, and particularly the central upper incisors, are of large size, and slope slightly forwards; the lower incisors, all of nearly equal size, are smaller—being the smallest of all the teeth—and are vertical. The roots of the incisors are single, though a groove is occasionally seen on each side, suggesting a division.

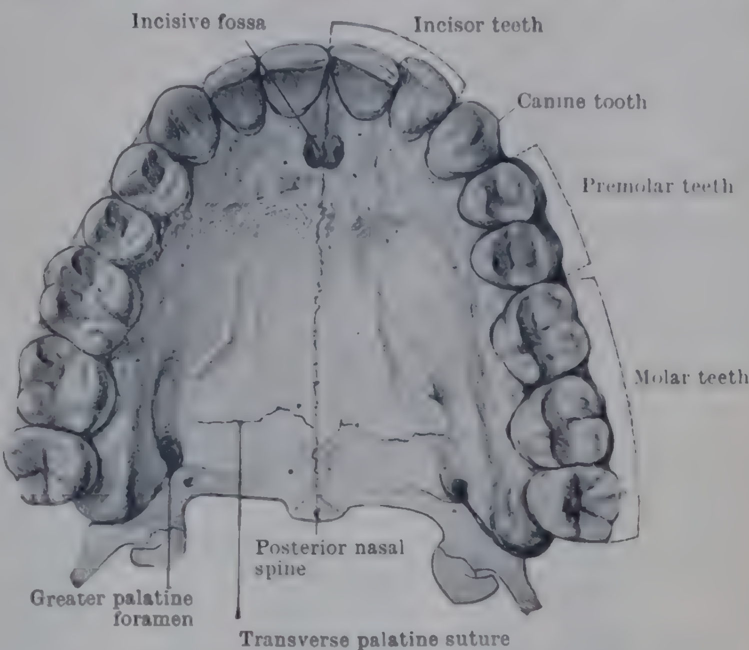

Fig. 485.—Bony Palate and Upper Permanent Teeth.

The central upper incisors are very much larger than the lateral upper incisors (Fig. 486), but in the mandible the lateral incisors are slightly the larger. In all incisors the lateral angle of the crown is more rounded than the medial. The concave lingual surface of the crown in the upper incisors is usually limited towards the gum by a Λ-shaped ridge known as the **cingulum** (Fig. 487). The two limbs of the Λ are continued along the sides of the lingual surface, and the apex points towards

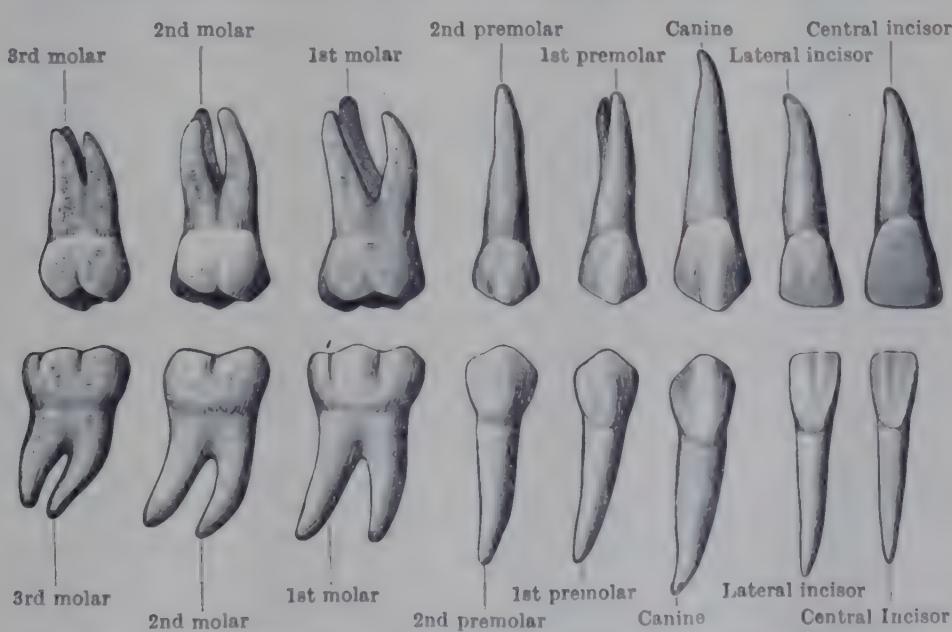

Fig. 486.—Permanent Teeth of Right Side, Labial or Buccal Surfaces.
The wide vertical "labial ridge" is distinct on the upper canine and premolar teeth.

the gum; and here, particularly in the lateral incisor, there is often developed a small **lingual tubercle**. The cingulum is rarely found on the lower incisors.

The roots of the upper incisors and canines are conical and rounded (the lateral incisors and canines not so distinctly as the central incisors), whilst those of the mandible are flattened from side to side.

Canine Teeth.—The **crown** is large and conical, and resembles in general form a very large central incisor with its angles cut away. The labial surface is convex, the lingual is usually slightly concave; and both surfaces show a slight

ridge which extends from the base of the crown to the apex. The root is single and long; that of the upper canine is longer than that of any other tooth, and produces the canine eminence on the anterior surface of the maxilla. The upper canines are larger than the lower ones, and are known as the "eye-teeth".

The upper canine presents on its lingual surface a well-marked cingulum, and often a distinct lingual tubercle; in addition, there is usually a ridge (separated from the lateral part of the cingulum on each side by a slight depression) which runs over the middle of the surface from the apex of the crown to the cingulum. These features are neither so well marked nor so constant in the lower as in the upper canine (Fig. 487). Of the two margins of the crown, the lateral is the longer in both teeth. After it has been a little worn the lower canine is less distinctly pointed than the upper; its root also is more flattened.

Premolar Teeth.—The **crown**, flattened antero-posteriorly, shows a flat chewing surface with two tubercles—the larger one on the buccal side, the other on the lingual side (Fig. 487). The buccal and lingual surfaces are both convex. The **root** is single, but is usually flattened antero-posteriorly and grooved, and it

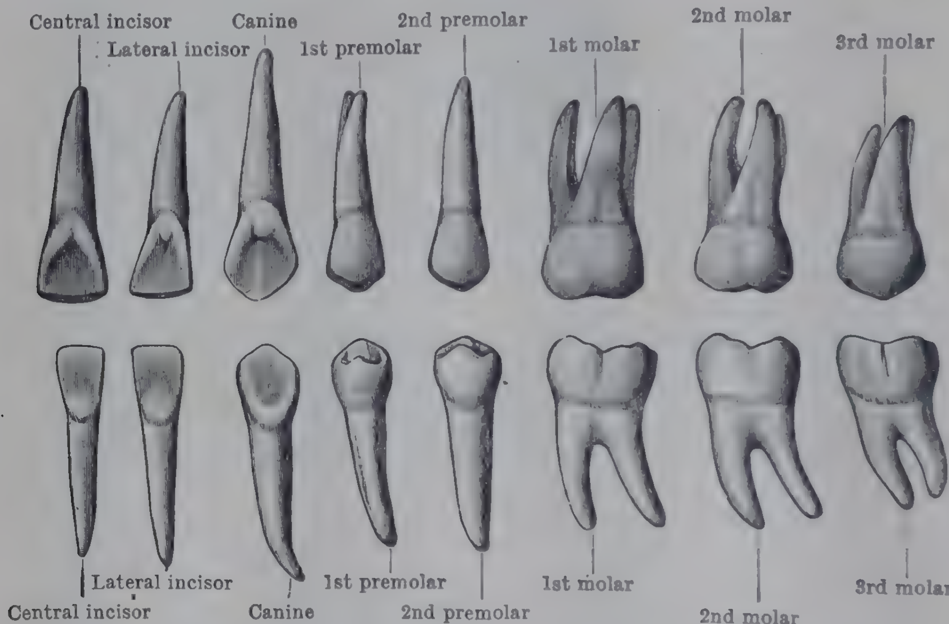

FIG. 487.—PERMANENT TEETH OF RIGHT SIDE, LINGUAL SURFACES.
The cingulum is distinct on the upper incisors and both canines, the lingual tubercle on the upper lateral incisor and the upper canine.

shows a tendency to division which is often actually present in the first upper premolar. In the upper premolars the two tubercles are large and are separated from each other by a distinct antero-posterior fissure (Fig. 485); in the lower premolars they are united by a central ridge between two dimple-like depressions (Fig. 488).

The first premolar is occasionally slightly larger than the second in the upper set but not in the lower. The labial surface of the crown is usually slightly larger than the lingual in all premolars. As a general rule, in the lower premolars the labial surface of the crown is sloped medially near the masticating surface. The first can usually be distinguished from the second by the fact that the lingual tubercle and surface are smaller than the labial in the first, but are of nearly the same size as the labial in the second. In addition, the root of the first upper premolar is bifid or nearly so, and it has a fairly distinct labial ridge, which is indistinct in the second. In the first lower premolar the lingual tubercle and surface are very small; in fact the tubercle is quite rudimentary. It should, however, be added that it is often extremely difficult to identify the various premolars.

Molar Teeth.—The molar teeth are distinguished as first, second, and third molars. Each third molar is known also as a "wisdom tooth" or **dens serotinus** (*serotinus* = late in appearing). All the molars are characterized by the large crown, with three or more trihedral tubercles on its masticating surface (Figs. 485 and 488). They are the largest of all the teeth and diminish in size, as a rule, from the first to the third. In shape the crown is more or less quadrangular, with convex labial

and lingual surfaces. The roots are either two or three in number, but frequently in the last molars they are united to a varying degree.

The molars of the maxilla and mandible differ considerably in detail. Normally the upper molars possess three roots (Figs. 486 and 487); the lower molars have two at most. The number of tubercles, though not so reliable a guide as the form of the root, is also generally sufficient to distinguish them; in the upper molars there are either three or four tubercles, whilst in the lower there are most commonly five.

In the **upper molars**, the **crown** (Fig. 485) is rhomboidal in shape (*i.e.*, quadrangular with the angles not right angles). The number of *tubercles* is either four or three. On the *first* there are invariably four—two on the labial and two on the lingual side—the anterior lingual of these being connected with the posterior labial by an oblique ridge. The *second* has either four or three tubercles in about an

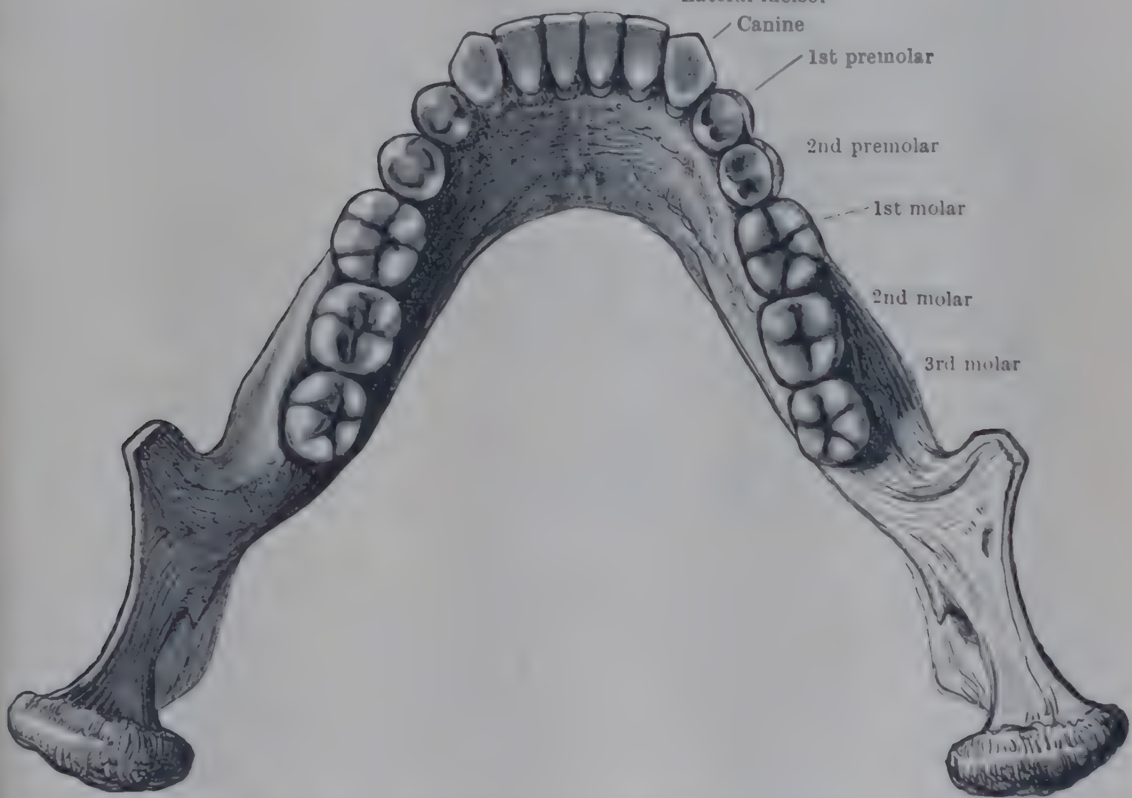

FIG. 488.—MANDIBLE AND LOWER PERMANENT TEETH.

equal proportion; in the *third* the number is much more frequently three. The upper molars have three **roots**—two buccal, and the third lingual—but they are occasionally confluent in the third molar.

In the **lower molars**, the **crown** is nearly cubical and more massive than in the upper. The *first*, as a rule, bears five *tubercles*, two labial, two lingual, and the fifth behind and buccal. The *second* has usually only four tubercles; a fifth, however, is sometimes present. The *third* has either four or five—usually four. Each has two **roots**—one anterior with two root-canals, the other posterior. They are wide roots, flattened antero-posteriorly and grooved; and both are usually recurved in their lower portions (Fig. 486). As in the upper set, the roots of the third are often more or less united into a single mass.

The upper molars slope downwards and laterally; the lower molars slope upwards and medially, and the buccal tubercles of the lower molars lie in the groove between the lingual and buccal tubercles of the upper teeth. As a result, the buccal edge of the crown is sharp and the lingual edge rounded in the upper molars; and the lingual edge is sharp and the buccal edge rounded in the lower set.

The fissures which separate the cusps on the grinding surfaces of the molar teeth are generally continued as faint grooves on the labial and lingual surfaces. A cruciform groove separates the four chief tubercles from one another; it bifurcates behind to enclose the fifth, which lies slightly to the buccal side of the middle of the tooth.

The anterior and posterior surfaces of the upper molars are in oblique planes which converge strongly postero-medially.

The backward curvature of the roots of the lower molars may make their extraction difficult.

Deciduous Teeth

The **deciduous teeth** are twenty in number—namely, two incisors, one canine, and two molars, on each side above and below; and the formula for them is therefore :—$i\,\frac{2}{2}$, $c\,\frac{1}{1}$, $m\,\frac{2}{2}$. They are distinguished from the permanent teeth by their smaller size, their constricted necks, and, in the case of the molars, by the wide divergence of their roots (Fig. 489). Otherwise they correspond closely to the same-named teeth of the permanent set. The first upper molar has, however, but three tubercles—two buccal and one lingual; the first lower molar has four—two buccal and two lingual—and the crowns of both are flattened from side to side. The second upper molar has four tubercles; the second lower has five. In each jaw, the second molar is much larger than the first.

The tubercles are sharper and are separated by deeper fissures than those of the permanent teeth; but the roots, except for their greater divergence, agree with those of the permanent set.

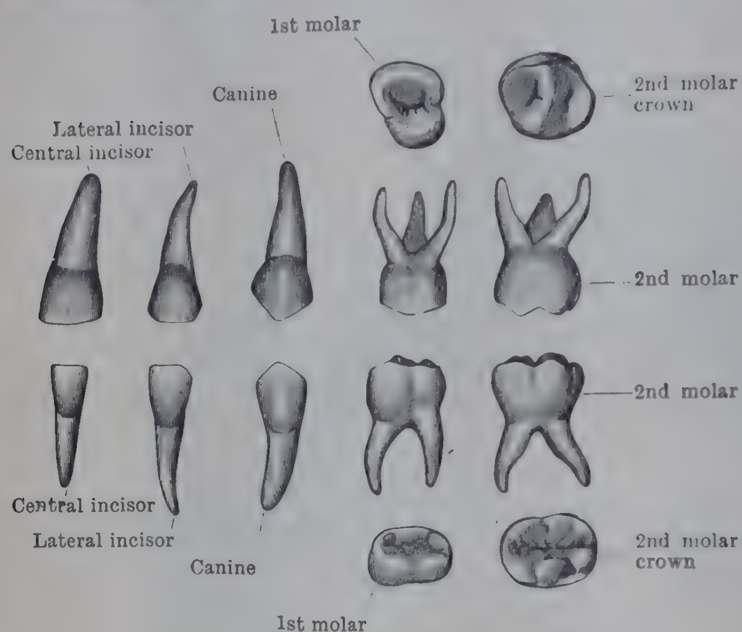

Fig. 489.—Deciduous Teeth of Left Side.

The masticating surfaces of the two upper molars are shown above. In the second row the upper teeth are viewed from the outer or labial side. In the third row the lower teeth are shown from the same side; and below are the masticating surfaces of the two lower molars. In the specimen from which the first upper molar was drawn the two labial tubercles were not distinctly separated, as is often the case.

The marked constriction at the neck of the deciduous teeth (Fig. 489) is due to a great thickening of the cap of enamel on the crown, and its abrupt termination as the neck is reached. The enamel, too, is much whiter as a rule than in the permanent teeth. The buccal surfaces of the lower molars slope strongly inwards from the neck to the crown; and the masticating surfaces of the crowns are, as a result, relatively much reduced in width.

The divergence of the roots of the deciduous molars allows the crowns of their permanent successors (premolars) to fit in between them before they are shed.

Eruption of Teeth.—The mouth of the infant at birth contains no teeth, although a number, partly developed, lie embedded in the jaws beneath the gum. Some six months later, teeth begin to appear; and, by the end of the second year, a set known as the **deciduous** or **milk-teeth**, twenty in number, has been "cut" (Pl. XLVII, p. 558, Fig. 2). The individual teeth of that set usually appear at the following ages: the lower central incisors between six and nine months, the upper incisors between eight and ten months, lower lateral incisors and first molars between fifteen and twenty-one months, the canines between sixteen and twenty months, the second molars between twenty and twenty-four months.

Then follows a pause of about four years, during which no visible change takes place in the mouth, although active preparation for further development is going on beneath the gum.

About the sixth year the next stage in the production of the adult condition begins. It consists in the eruption of four new teeth—the first permanent molars—one on each side above and below, behind those of the deciduous set. That eruption is followed by the gradual falling out of the twenty deciduous teeth, and the substitution for them of twenty new teeth, which take up, one by one, the

vacancies created by the dropping out of each of the deciduous set in the following order :—

First, about the age of seven, the central deciduous incisors are replaced; then the other deciduous teeth are replaced by the permanent teeth in the following order: lateral incisors, 1st premolars, 2nd premolars, canines. It will be observed that the eruption of the permanent canine is delayed until the two premolars, which succeed it in the row, are cut, so that it breaks the otherwise regular order of eruption. Finally, the adult condition is attained by the eruption of eight additional teeth—the 2nd and 3rd molars—two on each side above and below, behind those which have already appeared. All the **permanent teeth** have appeared by the end of the twelfth or thirteenth year, except the four "wisdom-teeth", which are usually cut between the seventeenth and twenty-fifth year, but are often delayed until a very much later period, and occasionally never appear. The 1st molar is sometimes popularly known, owing to the date of its eruption, as the "six-year-old tooth", and the 2nd molar as "the twelve-year-old tooth".

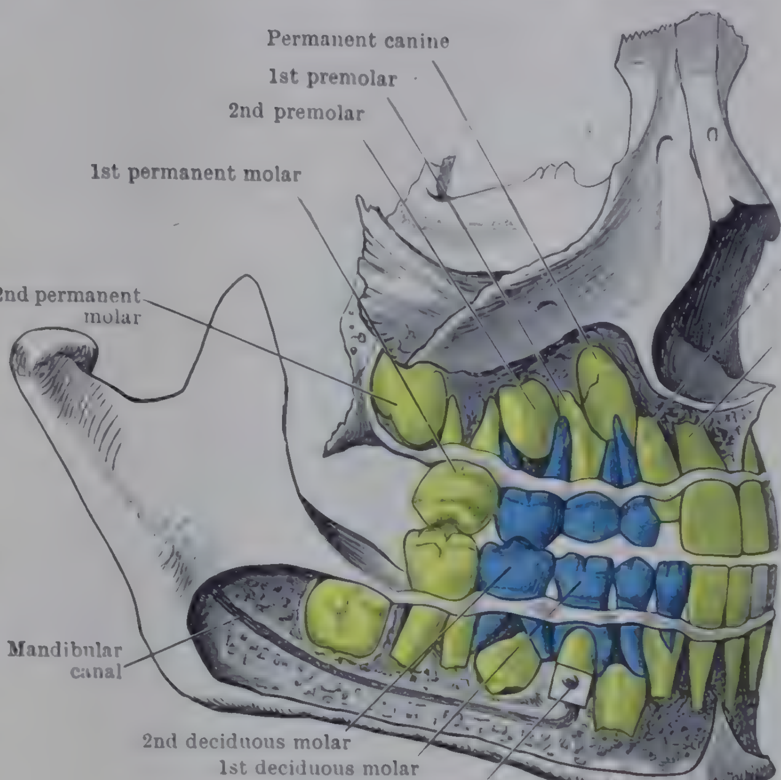

FIG. 490.—TEETH OF CHILD OVER SEVEN YEARS OLD. (Modified from Testut.) Compare with Figs. 2 and 3, Pl. XLVII, p. 558.

By the removal of the bony outer wall of the alveoli, the roots of the teeth which have been erupted, and the permanent teeth which are still embedded in the mandible and maxilla, have been exposed. The deciduous teeth are coloured blue, the permanent teeth yellow. It will be seen that the first permanent molars have appeared, the central and lateral deciduous incisors have been replaced by the corresponding permanent teeth in the maxilla, but the deciduous canine and molars have not yet been shed. In the mandible the central deciduous incisor has been replaced by the permanent central; the lateral has not yet been shed, but its permanent successor is making its way up to the surface on its lingual side. In addition, the canine and two molars of the deciduous set persist. The position of the crowns of the permanent teeth between the roots of the deciduous molars, and the deep situation occupied by the permanent canines, should be noted. Observe also the absorption of the root of the lower lateral incisor.

The usual dates of eruption of the lower permanent teeth may be stated as follows ; those of the upper jaw appear a little later :—

1st molars appear about the 6th year.					
Central incisors appear about the 7th year.					
Lateral	,,	,,	8th	,,	
1st premolars	,,	,,	9th	,,	
2nd ,,	,,	,,	10th	,,	
Canines	,,	,,	11th	,,	
2nd molars	,,	,,	12th	,,	
3rd ,,	,,	from the	17th	,,	to 21st year, or even later.

Stages in the eruption of the permanent teeth are shown in Fig. 490 and, radiographically, in Figs. 2 and 3, Pl. XLVII, p. 558.

Arrangement of Teeth in the Jaws.—The teeth in each jaw are arranged in a curved row—the **dental arch**, upper and lower—of approximately a semi-oval

form (Figs. 485 and 488). The curve formed by the upper teeth, however, is wider than that formed by the lower set, so that when the two are brought in contact the upper incisors and canines overlap the lower ones in front, and the labial tubercles of the upper premolars and molars overlap those of the lower teeth (Fig. 155, p. 162). It will be seen also that, as a rule, the teeth in one jaw are not placed exactly opposite their fellows but opposite the interval between two teeth in the other jaw (Fig. 155). That arrangement is brought about largely by the great width of the upper central incisor as compared with the lower, which throws the upper lateral incisor and the succeeding teeth into a position behind that of the corresponding teeth of the lower set. But as the lower molars are larger in their antero-posterior diameter than those of the upper row—and this remark applies particularly to the third molars—the two dental arches end behind in approximately the same plane.

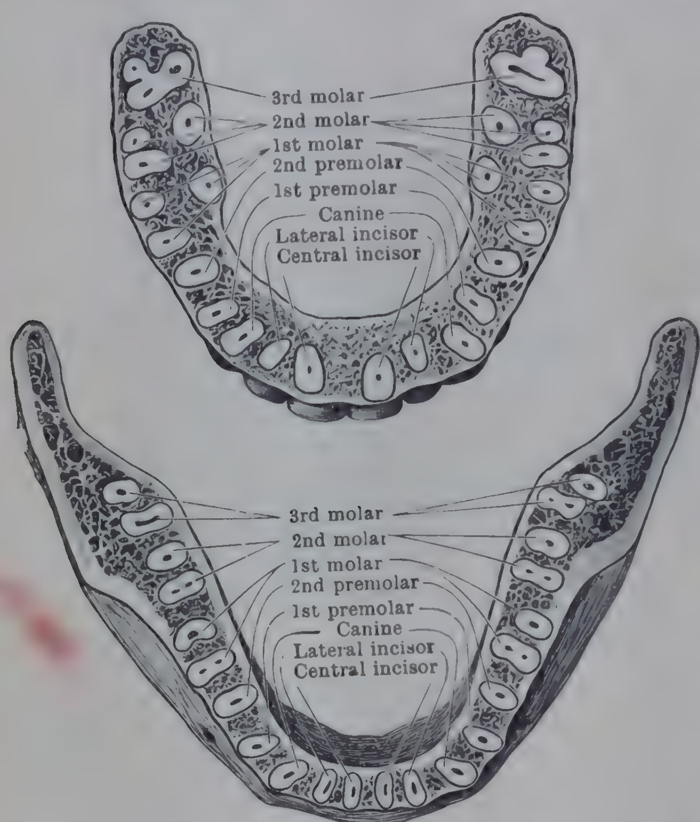

Fig. 491.—Horizontal Sections through Maxilla and Mandible to show the Roots of the Teeth.

The sections were carried through the bones a short distance from the edge of their alveolar borders. Note the flattened roots of the lower incisors, the two root-canals in the anterior root of each lower molar, and the confluence of the three roots of the upper third molars.

The upper dental arch is said to form an **elliptical curve**, the lower a **parabolic** one (Fig. 491). The line formed by the masticating surfaces of the upper teeth, as seen on profile view (Figs. 155 and 500), is usually slightly convex, owing largely to the failure of the third molar to descend into line with the others. Similarly the line of the lower teeth is as a rule concave.

In both jaws the crowns of the front teeth are higher (longer) than those of the molars.

Among civilized peoples it is rare to find a perfect arrangement of the teeth. Irregularities of individual teeth and abnormal relations of the opposed dental arches are of common occurrence and give rise to "malocclusion" (Brash, 1929).

Radiographic Examination of Teeth.—Owing to the density of their structure and to the fact that they are embedded in spongy bone, which is relatively radio-translucent, the general form and arrangement of the teeth are strikingly displayed by means of X-rays (Fig. 1, Pl. XLVII, p. 558). The enamel cannot be distinguished from the dentine or the cement; but the tooth-cavities and the root-canals are clearly visible, and their form and extent may be observed.

The *periodontal membrane* (alveolar periosteum) is seen as a black line surrounding the roots of the teeth; and the layer of compact bone in the wall of the alveolus—known in dentistry as the *lamina dura*—produces a white line on the film external to the periodontal membrane. The periodontal membrane and the lamina dura are often altered in appearance when disease is present.

The position of unerupted teeth can be exactly shown radiographically (Figs. 2 and 3, Pl. XLVII).

TONGUE

The **tongue** is a mass of interlacing bundles of striated muscle mingled with fat and entirely enclosed in mucous membrane except the posterior half of its lower part, which is called its **root** and through which the extrinsic muscles, the vessels, and the nerves gain entrance into the tongue. It lies in the floor of the mouth and also forms part of the anterior wall of the pharynx; the portion in the mouth forms a mobile elevation separated from the teeth and gums by a deep groove which ends posteriorly at the palato-glossal arches.

The movements of the tongue are important and complex, for it participates in the mastication of food, it plays an important part in swallowing, and it is essential for articulate speech. Its sensory activities are twofold, for not only does its mucous membrane possess ordinary sensation, but in addition, most, if not all, of the receptor-organs for the sense of taste are placed upon its surface.

Besides its root, the tongue has an inferior surface, a dorsum, right and left margins and a tip. The **tip** and the **margins** are in relation with the teeth; the margins are blunt; the tip is pointed when the tongue is protruded, but is blunt and rounded when the tongue is at rest. The **inferior surface** belongs to the anterior half of the tongue—the part in front of the root—and is the surface seen when the living tongue is turned upwards. The **dorsum** is a highly arched surface, reaching its maximum antero-posterior curvature at the level of the palato-glossal

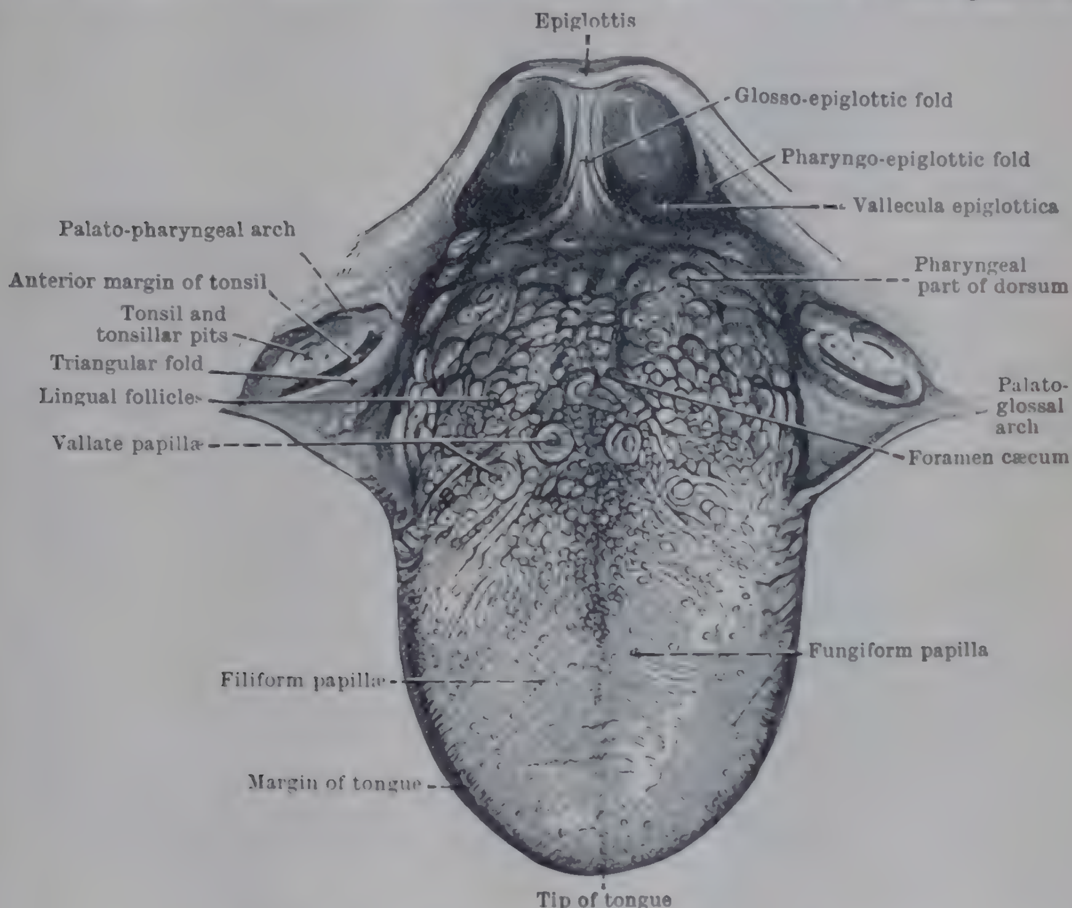

Fig. 492.—Dorsum of Tongue and *the* Tonsils.

arches. It may be conveniently divided into (1) a *palatine part* which looks upwards and is the surface seen in the open mouth, and (2) a *pharyngeal part* which looks backwards into the cavity of the pharynx and forms part of its anterior wall. These two parts are separated by a distinct V-shaped groove called the *sulcus terminalis*; the limbs of the groove diverge widely to reach the margins of the tongue; the apex of the V points backwards and is marked by a pit called the *foramen cæcum*, which indicates the position of the outgrowth of the thyroid diverticulum in the embryo.

Mucous Membrane of Tongue.—The mucous membrane of the *palatine part of the dorsum* of the tongue is inspected in the routine examination of patients. In health, it is moist and is pink in colour; and it shows a velvety or shaggy surface, as it is thickly studded with filiform papillæ, among which may be seen occasional larger, rounded projections called the fungiform papillæ. At other times it is yellowish in colour from the accumulation of shed epithelial cells, remains of the food, and organisms. At its posterior part, immediately in front of the sulcus terminalis, there is a V-shaped row of large papillæ named the vallate papillæ. The mucous membrane of the palatine part of the dorsum is firmly adherent to the underlying corium, and so affords for the filiform papillæ a firm basis, resting upon which they may rub the food against the palate.

The mucous membrane of the *pharyngeal part of the dorsum* has a smooth nodular glistening surface, and contains numerous serous glands; it is separated from the muscular substance by a submucous layer which contains mucous glands and nodules of lymphoid tissue called *lingual follicles* (Figs. 495, 502). Its surface is free from evident papillæ, but it is thickly studded with rounded projections, each presenting, as a rule, a little pit, visible to the naked eye, at its centre. These nodules are produced by the follicles, which are similar to the lymph-follicles found in the tonsils and collectively are called the **lingual tonsil**. At each side the mucous membrane is continuous with the mucous covering of *the* tonsil and of the side-wall of the pharynx. Posteriorly, it is reflected on to the front of the epiglottis, being raised up in the median plane to form a sharp ridge called the **glosso-epiglottic fold**, at each side of which there is a wide depression called the **vallecula epiglottica** (Fig. 492 and Pl. LXI., p. 696). The vallecula is bounded laterally by a less

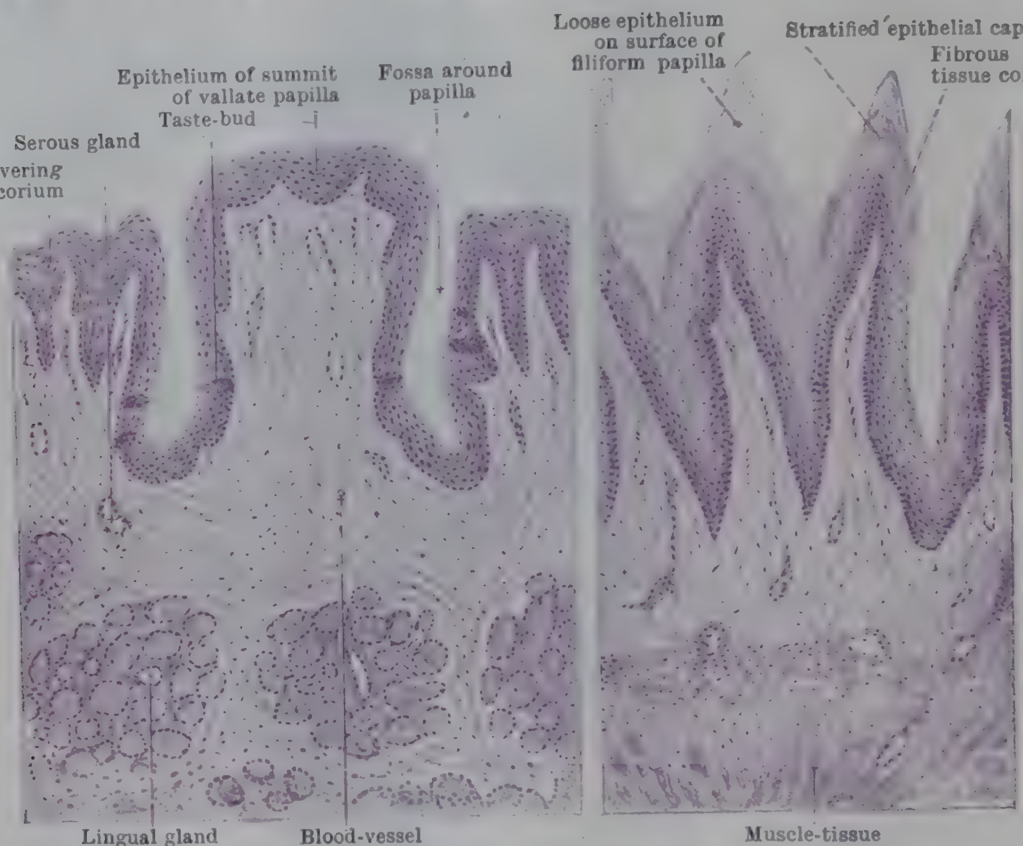

Fig. 493. A. Section of Vallate Papilla of Tongue. B. Section of Filiform Papillæ of Tongue.

distinct ridge of mucous membrane, called the **pharyngo-epiglottic fold**, which passes laterally and upwards from the margin of the epiglottis to blend with the mucous lining of the side-wall of the pharynx.

On the pharyngeal part of the tongue there are also small papillary projections of the corium, but the epithelium fills up all the intervals between the papillæ, and levels off the surface, so that none are visible to the eye as projections above the general level. Over the anterior part of the tongue, on the contrary, the projections of the corium are large and prominent, and the intervals between them are not filled up by the epithelium, so that the projections stand out distinctly and independently, and in places attain a height of nearly 2 mm. above the general surface.

On the margins of the tongue the mucous membrane is thin, usually pink in colour, and, immediately in front of the attachments of the palato-glossal arch, there are five or six vertical folds of mucous membrane, termed the **folia of the tongue**, which are studded with taste-buds. They represent the foliate papillæ on the sides of the tongue in rabbits, hares, and other animals.

The *inferior surface* is covered with a smooth, thin mucous membrane devoid of papillæ. On its middle, except near the tip, there is a depression from which a fold of mucous membrane, called the **frenulum of the tongue**, passes down to the floor of the mouth and the posterior aspect of the mandible. At each side of the frenulum, and a short distance from it, the profunda linguæ vein is distinctly

seen through the mucous membrane. Still farther from the frenulum, on each side, there is a fringed fold called the **fimbriated fold**; these two folds converge slightly as they are followed forwards towards the tip, near which they are lost.

Papillæ of Tongue (Fig. 492).—The papillæ are variously-shaped projections of the corium of the mucous membrane covered with thick caps of epithelium, and they are of three main varieties: filiform, fungiform, and vallate.

The **filiform papillæ** (Fig. 493), the smallest and most numerous, form a dense crop of minute projections all over the anterior two-thirds of the dorsum of the tongue, and on the upper surface of its margins and tip. Posteriorly they lie in divergent rows that run laterally and forwards from the raphe parallel to the limbs of the sulcus terminalis. More anteriorly, the rows become nearly transverse, and near the tip irregular. Each papilla is composed of a conical projection of the corium from which secondary papillæ project, covered by a thick, pointed cap of stratified squamous epithelium.

In many of them the cap of epithelium is broken up into several long, slender, pointed processes. The cap of epithelium is being constantly shed and renewed, and an excessive or diminished rate of shedding or renewal, coupled with the presence of various organisms, gives rise to the several varieties of "tongue" found in different diseases.

The filiform papillæ are highly developed and horny in carnivora.

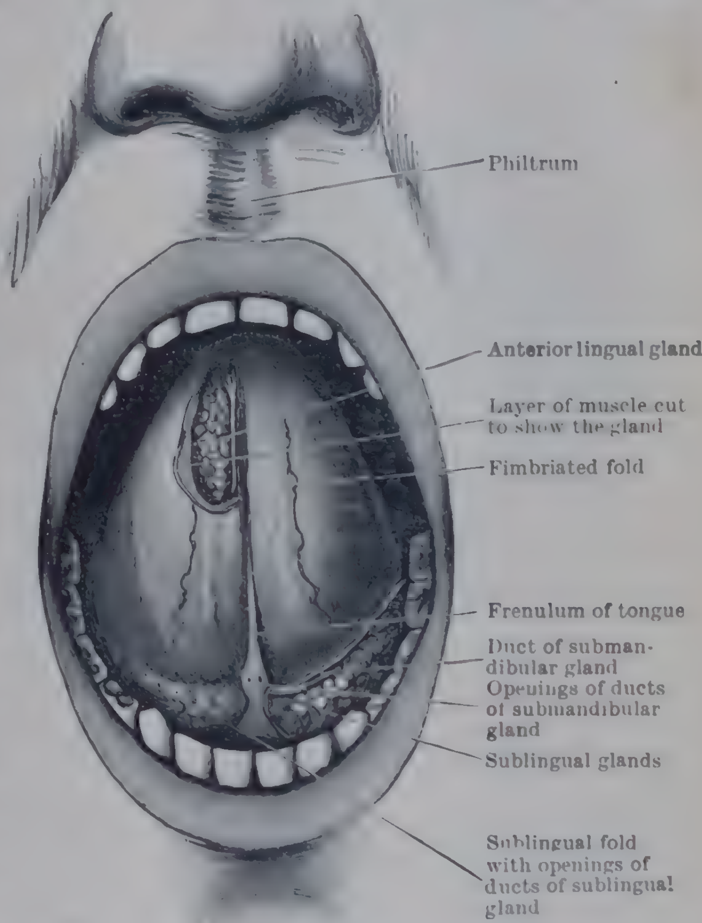

Fig. 494.—Open Mouth with Tongue raised, and the Sublingual and Anterior Lingual Glands exposed.

The sublingual gland of the left side has been laid bare by the removal of the mucous membrane; to expose the anterior lingual gland of the right side a thin layer of muscle, in addition to the mucous membrane, has been removed. A branch of the lingual nerve is seen running on the medial side of the gland. The profunda vein also is faintly indicated on this side.

The **fungiform papillæ** (Fig. 492), larger and redder, but less numerous than the filiform, are found chiefly near the tip and margins of the tongue, comparatively few being present over the dorsum generally. Each is in shape like a "puff-ball" fungus, consisting of an enlarged rounded head attached by a narrower base. As in the filiform papillæ, the corium is studded with microscopic papillæ which are buried in the covering of squamous epithelium. Most of the fungiform papillæ, if not all, appear to be furnished with taste-buds.

The **vallate papillæ** (Fig. 493), are much the largest of all the papillæ of the tongue. They are from nine to fourteen in number and are arranged in the form of the letter V, with the apex behind, immediately in front of and parallel to the sulcus terminalis, one or two of the papillæ being placed at the apex of the V. In appearance a vallate papilla resembles very closely the impression left by the barrel of a small pen pressed on soft wax (Fig. 492). Each is a short cylinder (1 to 2·5 mm. wide) that tapers slightly towards its base and is flattened on its crown, which projects a little above the general surface of the tongue. It is surrounded by a deep, narrow, circular fossa, the outer wall of which is known as the **vallum**. The vallum is an encircling collar very slightly raised above the adjacent surface (Fig. 493). As in the other papillæ, a vallate papilla is made up of a central mass of corium, studded with numerous microscopic papillæ on the crown (but not on the sides), and covered over with stratified squamous epithelium,

as are the walls of the fossa. The ducts of some small serous glands open into the fossa (Fig. 493 A). **Taste-buds**—the special end-organs of the sense of taste—are found in considerable numbers in the sides of a vallate papilla, as well as in the vallum; they are described on p. 1214.

Structure of Tongue.—The tongue is composed chiefly of striated muscular tissue, with a considerable admixture of fine fat. A median septum of fibrous tissue divides its central part into symmetrical halves. In addition, there are vessels, nerves, glands, and lymphoid tissue; and the whole is covered with mucous membrane, except at the root (Fig. 495).

The muscular tissue is derived partly from the extrinsic muscles—namely, the hyo-glossus, stylo-glossus, genio-glossus, palato-glossus, and chondro-glossus; and partly from the intrinsic muscles—superior and inferior longitudinal, transverse, and vertical. The external or **cortical portion** is derived from the superior and inferior longitudinal muscles and the hyo-glossus and stylo-glossus. The central or **medullary portion**—divided into

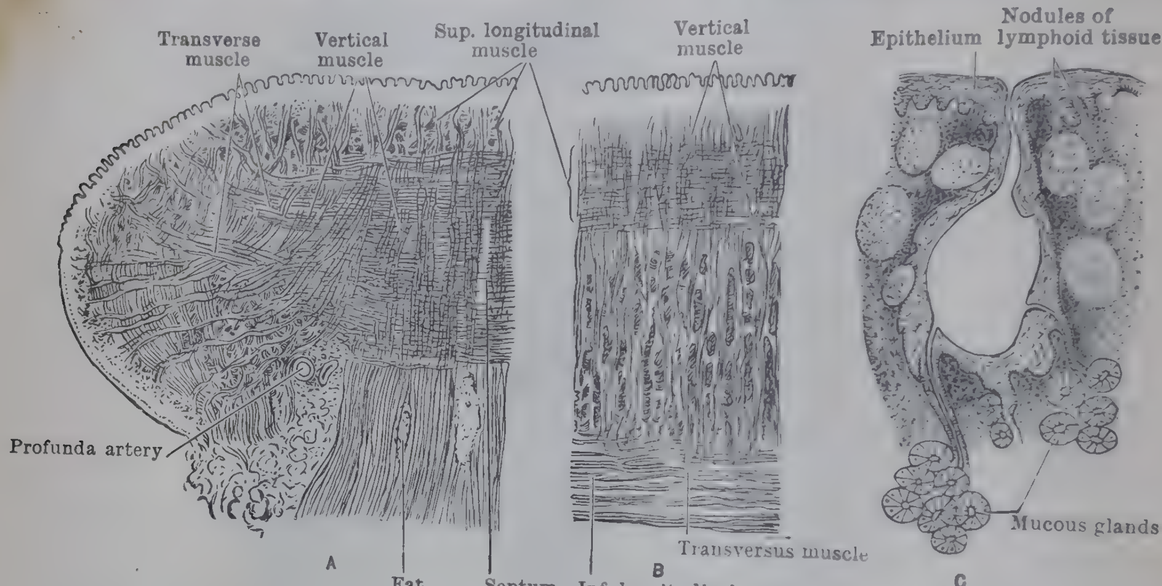

FIG. 495.—A. TRANSVERSE, AND B. LONGITUDINAL VERTICAL SECTION THROUGH TONGUE (Krause); C. LINGUAL FOLLICLE FROM POSTERIOR PART OF TONGUE (Macalister, slightly modified).

two halves by the median **septum**—is composed of the transverse and vertical fibres and of the fibres of the genio-glossi ascending to the dorsum. The muscular fibres end by being inserted into the deep surface of the mucous membrane.

The detailed description of the extrinsic and intrinsic muscles and an account of the movements of the tongue will be found in the Section on Myology (p. 438).

The **septum** is a median fibrous partition found in the medullary portion only. Anteriorly it usually extends to the apex; posteriorly it diminishes in depth and expands transversely into a broad sheet (the hyo-glossal membrane) which is united to the upper border of the hyoid bone and gives attachment to the posterior fibres of the genio-glossus. From the sides of the septum the fibres of the **transverse muscle** of the tongue arise.

Lingual Glands.—Numerous small mucous glands are scattered beneath the mucous membrane of the posterior third of the tongue; and a small collection of similar glands is present at the margin opposite the vallate papillæ. Small serous glands also are embedded in the dorsum near the vallate papillæ, into the fossæ of which their ducts open.

The chief collections of glandular tissue in the tongue, however, are found embedded in the muscle of the under surface, a little way behind the apex, on each side of the middle line (Fig. 494). They are known as the **anterior lingual glands**.

These glands are displayed after the removal, from the under surface of the tongue a little distance behind the apex, of the mucous membrane and a layer of muscle-fibres about 2 mm. thick composed of fibres of the stylo-glossus and inferior longitudinal muscles. The anterior lingual glands are oval in shape, often partly broken up by muscular fibres, and they measure from $\frac{1}{2}$ to $\frac{3}{4}$ in. (12 to 19 mm.) in length. They are mixed serous and mucous glands, and they open by three or four very small ducts on the inferior surface of the tongue.

Vessels and Nerves.—The chief **artery** is the *lingual*. It passes forwards, on each side, medial to the hyo-glossus muscle, and then is continued to the apex—between the genio-glossus on the medial side and the inferior longitudinal muscle laterally—under the name of the *profunda artery*. Anteriorly it is covered by the **inferior longitudinal** muscle, and lies $\frac{1}{8}$ to $\frac{1}{4}$ in.

from the surface. Near the apex the arteries of opposite sides are connected by a branch which pierces the septum; but otherwise, with the exception of capillary anastomosis, they do not communicate. The *dorsales linguae* branches of the lingual artery are distributed to the pharyngeal part of the tongue; and some twigs of the *tonsillar artery* (a branch of the facial) also are distributed in that region.

The **veins** are in three sets. The chief of them is the *profunda vein*, which runs backwards first under cover of the mucous membrane at the side of the frenulum and then over the hyo-glossus with the hypoglossal nerve. The others are the two *venæ comitantes* of the lingual artery and the two or more *dorsales linguæ veins* from the back of the tongue. They end in the internal jugular vein either separately or by a common trunk formed by their union at the posterior border of the hyo-glossus.

The **lymph-vessels** of the tongue end in the *submental* and *submandibular glands*, and in the *deep cervical* group between and including the jugulo-digastric and the jugulo-omo-hyoid glands.

The **nerves** which supply the tongue are the hypoglossal, lingual, and glosso-pharyngeal, and, to a small extent, the internal laryngeal. The *hypoglossal nerve*—the motor nerve of the tongue—enters the genio-glossus and passes up in its substance to the intrinsic muscles, in which it ends. The *lingual nerve* is a branch of the mandibular nerve, and it is joined by the *chorda tympani branch* of the facial nerve. The lingual, after crossing the hyo-glossus, breaks up and enters the inferior longitudinal and genio-glossus muscles, and thus makes its way upwards to the mucous membrane of the anterior two-thirds of the tongue—the lingual itself conferring common sensation on this part, while the chorda tympani carries taste-fibres and parasympathetic fibres to it. The *glosso-pharyngeal nerve* passes forwards beneath the upper part of the hyo-glossus muscle, and sends its terminal branches to the mucous membrane of the posterior third of the tongue, supplying the vallate papillæ and the part of the tongue behind them with both gustatory and common sensory fibres. The *internal laryngeal nerve* distributes a few fibres to the posterior part of the tongue near the epiglottis.

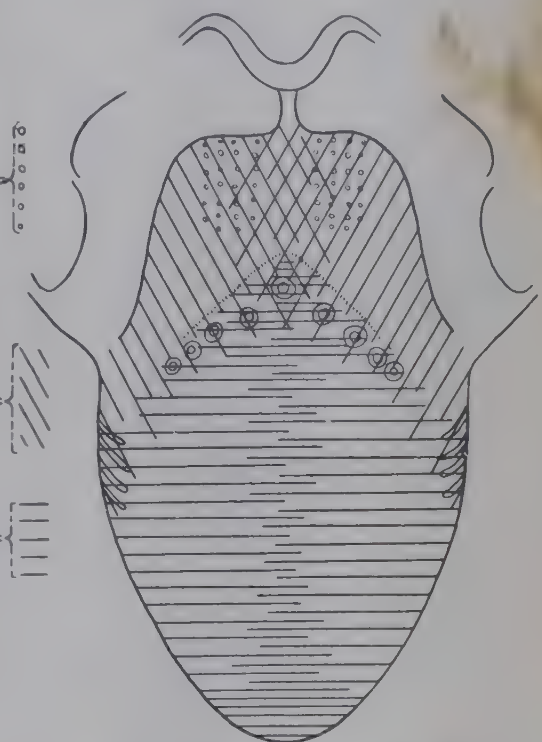

Fig. 496.—Areas of Afferent Nerve-Supply of Tongue.

GLANDS

In the following paragraphs only the true glands of the alimentary system are considered—namely, the glands of epithelial origin characterized by the possession of ducts.

Such glands may be defined as epithelial organs which secrete or excrete some particular substance or substances. Their essential parts are cells; and there may be different kinds of cells in a gland. This type of gland appears as an evagination of an epithelial surface, and it may be of various forms.

The simplest form is a single diverticulum of uniform width forming a simple tubular gland. The intestinal glands are of this kind.

The end of a tubular gland may be widened, forming a sort of pocket, called an alveolus [*alveolus*, small pit or bag]; and this type of gland is known as the simple alveolar gland. It does not exist in the alimentary canal.

In some glands the lower part or fundus of the tube does all the secretion, and the upper part forms a duct that carries the secretion to the surface.

When the outgrowth that forms the gland remains undivided, the gland is known as a **simple gland**. When it breaks up into two or more branches it is

known as a **compound gland**; and a compound gland may be tubular, alveolar, or of a mixed tubular and alveolar form. When the secreting part of a gland becomes differentiated into several enlargements (alveoli) at the end of a single duct, it is called an **acinus** [*acinus* = a unit of a compound berry]. A gland formed of several such structures collected together is often called a **compound acinous** or **racemose gland** [*racemus* = a cluster] from the fancied resemblance to a cluster of compound berries at the end of a stalk.

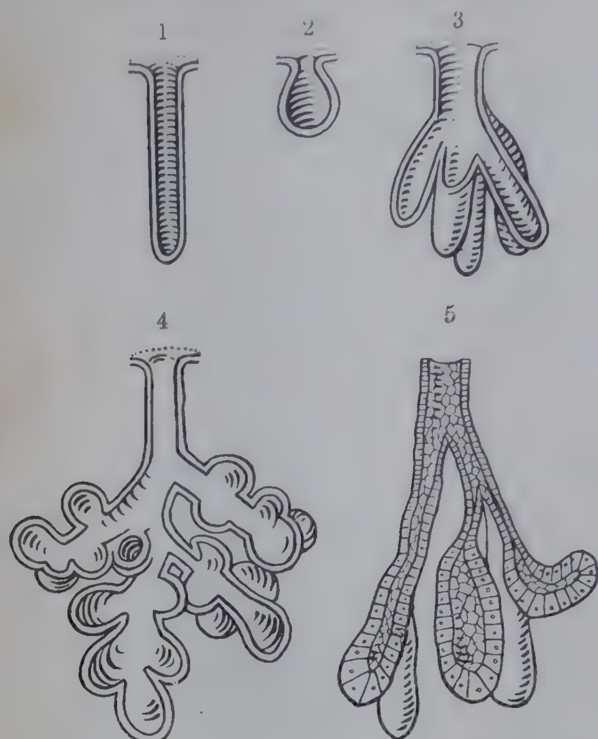

Fig. 497.—Diagram of Structure of Various Types of Glands.

1. Simple tubular gland.
2. Simple alveolar.
3. Compound tubular.
4. Compound acinous or racemose gland.
5. Section of secreting portion of gland and ducts.

General Structure of Glands.—The small glands, such as those of the mouth and pharynx, are placed in the mucous or the submucous coat close to the point at which their ducts open on the surface; but the large glands form distinct masses which often lie at a considerable distance from the points at which their ducts open, and they are generally surrounded by special capsules.

Each of the large glands of the acinous type, such as the parotid or the submandibular, presents the following general arrangement. The gland is made up, as can be seen with the unaided eye, of a number of masses, often as large as peas, which are surrounded and held together by areolar tissue. The masses are known as lobes, and a branch of the duct passes to each. The lobes are in turn made up of a number of smaller masses—lobules—each having a special branch of the lobar duct. Those again are composed of smaller lobules, and finally the smallest are made up of a terminal branch of the duct with a cluster of acini or alveoli leading into it.

The **acini** or **alveoli** are composed of secreting epithelial cells placed on a basement membrane, often fenestrated or basket-like, formed of flattened cells, on the outer side of which the blood-vessels and lymph-vessels lie. The secreting cells, usually polygonal in shape, almost completely fill the alveolus. A small lumen, however, is left, into which the secretion of the cells is shed, and whence it passes into the duct of the lobule, and thus to the main duct.

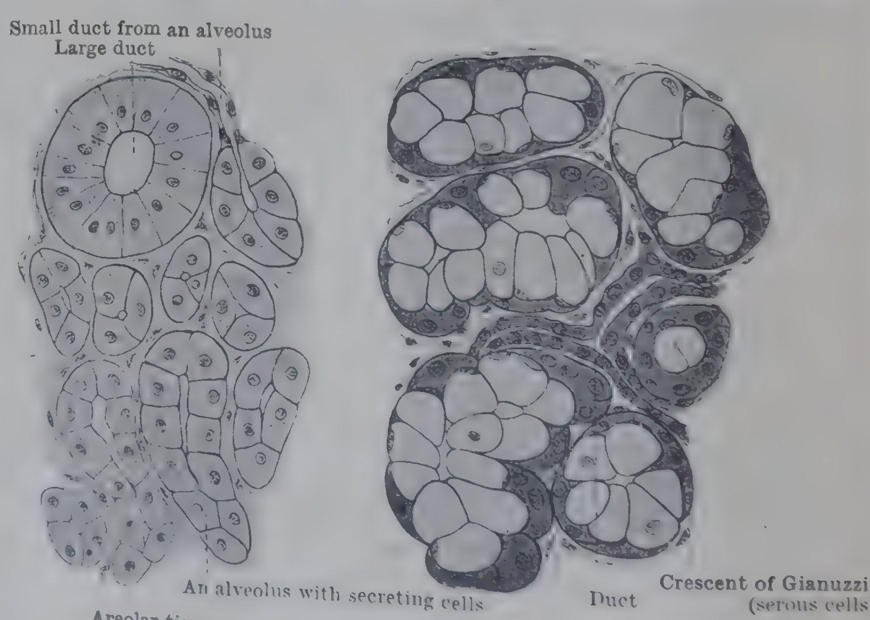

Fig. 498.—Section of a Serous Gland on the left, a Mucous Gland on the right. (Bohm and v. Davidoff.)

In the serous gland the granular secreting cells and the centrally placed nucleus should be noted. The relatively clear (mucus-secreting) cells, with the dark crescents of Gianuzzi, are distinctive in the mucous gland.

Salivary Glands

Saliva is a clear, watery fluid poured by numerous glands into the cavity of the mouth. It moistens the tongue and the walls of the mouth and facilitates the movements of the tongue. Mixed with food by mastication it helps in swallowing. It also contains a ferment which plays an important part in digestion, for it can transform starch into dextrin.

The glands which secrete it are the small glands of the lips, cheeks, and tongue, and also three large paired glands—the parotid, submandibular, and sublingual glands. The three last are the main salivary glands.

Parotid Gland.—The parotid gland, the largest of the salivary glands, is a lobulated mass, of a yellowish or light reddish-brown colour, with a large triangular superficial surface. It lies on the side of the face below and in front of the ear,

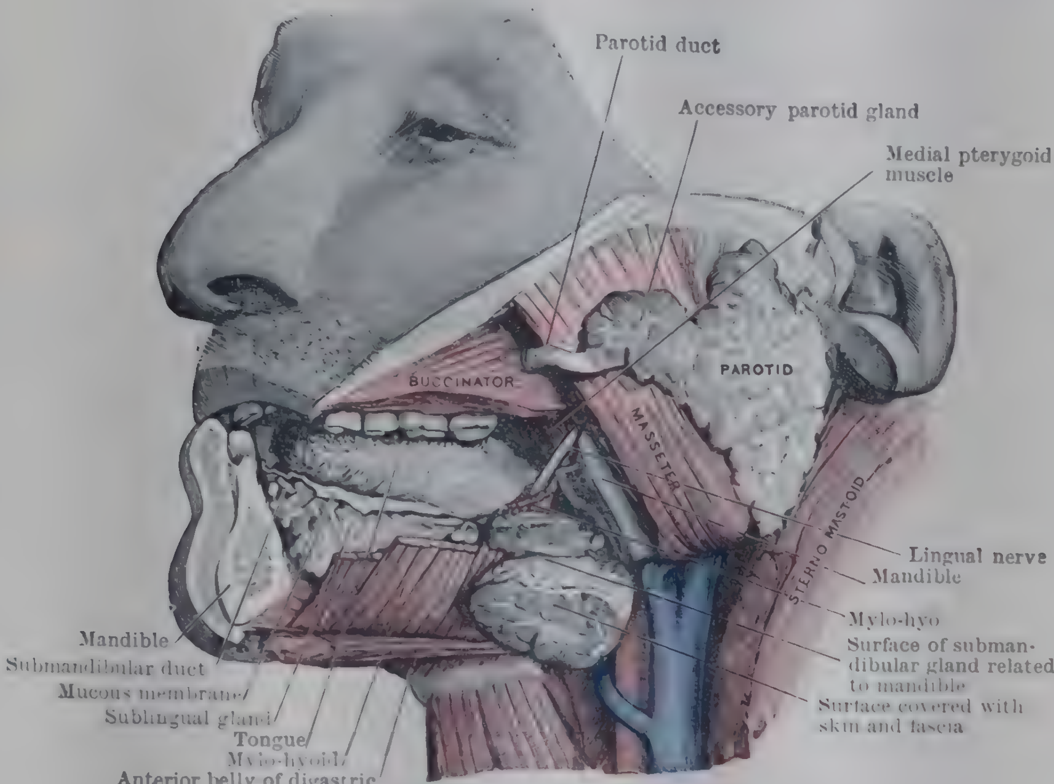

Fig. 499.—Salivary Glands and their Ducts.

mastoid process, and sterno-mastoid muscle, and extends medially behind the medial pterygoid muscle towards the side of the pharynx.

Shape and Relations of Parotid Gland.—In shape the parotid gland with its medial extension is a three-sided wedge (Fig. 507, p. 591), the three surfaces being superficial, anterior, and posterior.

The deeper portion of the gland occupies a space of considerable size, which has two nearly vertical sides, an anterior and posterior, which converge towards each other and meet deeply at an acute angle.

A horizontal section through the head about the middle of the gland (Fig. 507) shows that the posterior wall of the space is formed, medial to the sterno-mastoid muscle, by the posterior belly of the digastric and the stylo-hyoid muscles, and more deeply still, by the root of the styloid process and the carotid sheath and its contents, and especially by the internal jugular vein, which separates the space from the vertebral column. The anterior wall of the space is formed by the ramus of the mandible and the masseter and medial pterygoid muscles. The portion of the gland that lies in the fossa presents a deeply concave anterior surface, and a posterior surface, irregular in outline, directed backwards and medially.

The **superficial surface** is irregularly triangular in outline. Its posterior border lies in front of the external auditory meatus and the sterno-mastoid muscle, and

extends down to the angle of the mandible and the posterior belly of the digastric muscle. Its superior border lies below the zygomatic arch, and the anterior border passes irregularly upwards and forwards to join it. The apex, directed forwards, lies on the masseter muscle, and the duct of the gland issues from it, or immediately below it. A separate portion of parotid tissue, often found lying immediately above the duct, is known as the **accessory parotid gland**. The superficial part of the gland is frequently prolonged downwards over the digastric muscle. It may descend beyond the angle of the mandible, and come into immediate relation with the posterior part of the submandibular gland, from which it is separated merely by a thin layer of the deep cervical fascia. Embedded in the superficial surface there are usually several small, rounded lymph-glands which can be distinguished from the gland-tissue by the difference in their colour.

The **anterior surface** of the gland clasps the posterior border of the ramus of the mandible and the muscles on its surfaces—masseter and medial pterygoid.

The **posterior surface** of the gland is in contact with the sterno-mastoid muscle, the mastoid process, the external auditory meatus, the posterior belly of the digastric muscle, the internal jugular vein, and the root of the styloid process and the styloid muscles. It is often deeply grooved by the posterior belly of the digastric.

The gland is occasionally prolonged medially beyond the lower portion of the styloid process, towards the pharynx. In such cases the lower part of the styloid process lies in a groove on the posterior surface of the gland.

A number of vessels and nerves are found in intimate relation to the parotid gland. The external carotid artery lies at first in a groove in the deep surface of the gland. It then enters the gland substance and lies deeply in it as far as the neck of the mandible, where it divides into its two terminal branches. The superficial temporal artery emerges from the upper border of the gland, and the maxillary artery turns medially and emerges from the deep part of the anterior surface.

The transverse facial artery is given off in the substance of the gland and emerges from it between the zygomatic arch and the duct.

The posterior facial vein descends in the substance of the gland and divides into the two terminal branches which emerge through the lower end of the gland.

The facial nerve enters the posterior surface of the gland slightly below its middle, runs laterally and forwards, and divides into its terminal branches, which radiate through the gland superficial to the external carotid artery and posterior facial vein. Communicating branches to the facial from the auriculo-temporal and great auricular nerves also traverse the gland substance. The suggestion that "the parotid gland is a bilobed structure with the facial nerve running between the lobes" is not borne out by the recent investigation of M'Kenzie (1948).

Parotid Fascia.—The parotid recess is lined by a layer of fascia continuous with the deep cervical fascia. It is connected above to the zygoma, posteriorly to the auditory meatus and anterior border of the sterno-mastoid, and medially to the styloid process; anteriorly it passes over the masseter and blends with the bucco-pharyngeal fascia. Together with the periosteum of the tympanic plate it forms a definite sheath which completely encloses the gland. The lower and anterior part of this sheath is thickened to form a special flat band, called the **stylo-mandibular ligament**, which passes downwards and laterally from the styloid process to the angle of the mandible. It separates the anterior part of the parotid gland from the posterior border of the medial pterygoid muscle and from the upper and posterior part of the submandibular gland.

Parotid Duct.—The parotid duct leaves the anterior border of the gland at its most prominent part (Fig. 499). It first runs forwards across the masseter, below the accessory parotid gland, accompanied by branches of the facial nerve and the transverse facial artery, which is commonly some distance above. The duct turns abruptly round the anterior border of the masseter and runs inwards through the fat of the cheek, almost at right angles to the first part of its course, to reach the buccinator, which it pierces. Then, passing for some distance (5 to 10 mm.) between the buccinator and the mucous membrane, it opens into the vestibule of the mouth by a very small orifice, on a variably developed papilla, opposite the crown of the second upper molar tooth.

The course of the duct can be marked by the middle third of a line from the inferior edge of the auditory meatus to a point midway between the ala of the nose and the red margin of the lip.

The duct measures from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches (40 to 60 mm.) in length, and $\frac{1}{8}$ inch (3 to 4 mm.) in diameter. The calibre of the duct is very much greater than that of its orifice, which admits only a fine bristle, and for that reason the duct may, to some extent, be looked upon as a reservoir for the saliva, as well as a duct for its conveyance. In the child it pierces the buccal pad of fat on its way to the mouth.

Vessels and Nerves.—The **arteries** which supply the gland arise from the *external carotid artery*, and from the branches of that artery in the gland. The **veins** join the *posterior facial vein* and its tributaries. The **lymph-vessels** pass to both the superficial and the deep cervical glands; there are also a few small parotid lymph-glands which lie on the surface of the superior and inferior part of the parotid beneath the sheath. Some are said to be embedded in the substance of the parotid itself.

The **nerves** are derived (*a*) from the *auriculo-temporal*, *great auricular*, and *facial*, and (*b*) from the *external carotid plexus*. The fibres of the sympathetic are mainly vaso-constrictor.

The secretory fibres to the gland arise in the brain-stem, pass through the glosso-pharyngeal

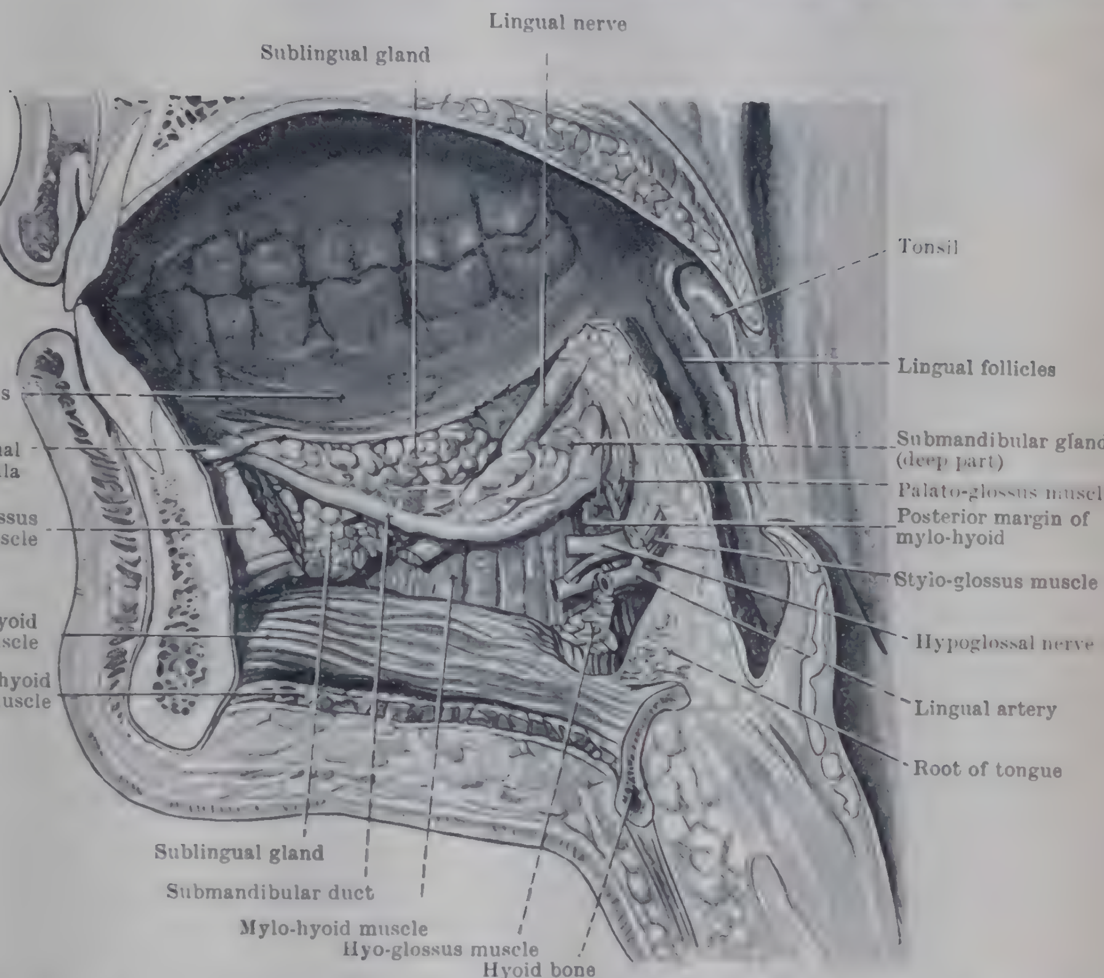

FIG. 500.—SIDE-WALL AND FLOOR OF MOUTH, AFTER REMOVAL OF TONGUE AND MUCOUS MEMBRANE.

nerve and its tympanic branch, and thence through the lesser superficial petrosal nerve to the otic ganglion, and from that ganglion to the gland in the auriculo-temporal nerve (Fig. 906, p. 1036).

Submandibular Gland.—The submandibular gland is smaller than the parotid but resembles it in lobulation and colour. It is placed in the submandibular region, partly under cover of the mandible (Fig. 499), and partly between the mandible and the hyoid bone, overlapping the bellies of the digastric muscle.

In that region there is a three-sided space bounded laterally by the mandible below the mylo-hyoid line, medially and above by the mylo-hyoid muscle, and below and laterally by the skin and fascia passing from the margin of the jaw to the hyoid bone. The gland lies in that space and has therefore three surfaces, which may be named lateral, medial, and inferior.

In each gland two portions may be recognized :—(1) the main part, with three surfaces, which lies in the submandibular triangle, and (2) a thin, deep process which springs from the middle of the medial surface of the gland and passes forwards between the mylo-hyoid and hyo-glossus muscles.

The *lateral surface* of the main part is related to the floor of the submandibular fossa of the mandible and to the medial surface of the medial pterygoid muscle.

The *inferior surface* is covered with skin, superficial fascia, and platysma, and by the investing deep fascia of the neck. It is crossed, under cover of the platysma, by the cervical branch of the facial nerve, and, under cover of the deep fascia, by the anterior facial vein. In the groove between this surface and the lower margin of the mandible there are four to six submandibular lymph-glands.

The *medial surface* is clothed with a thin layer of fascia which extends from the hyoid bone to the mylo-hyoid line of the mandible and separates it from the bellies of the digastric and the stylo-hyoid, from the mylo-hyoid muscle and nerve, and from the hyo-glossus and certain smaller structures that lie on the surface of that muscle.

The posterior part of the gland is the bulkiest. The posterior end is deeply grooved by the facial artery; it reaches as far back as the angle of the mandible,

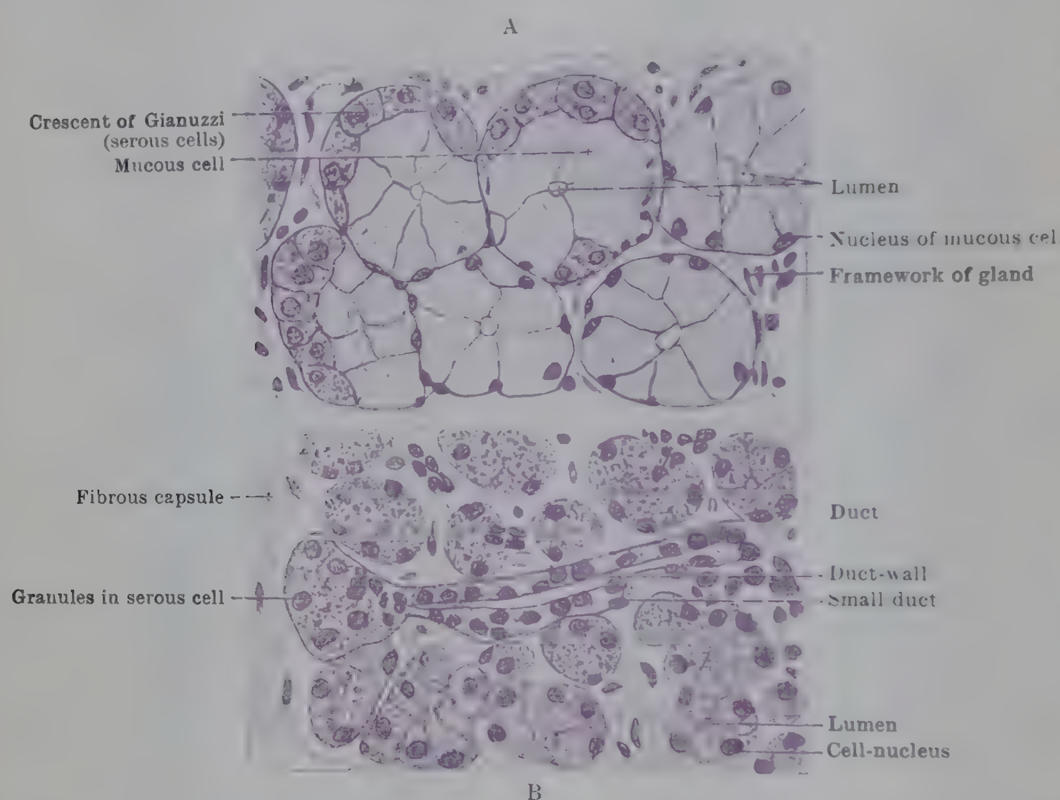

FIG. 501.—SECTIONS OF (A) SUBMANDIBULAR GLAND ($\times$ 400); (B) PAROTID GLAND ($\times$ 400).

where it comes into relation with the lower part of the parotid gland near the anterior border of the sterno-mastoid muscle.

Submandibular Duct.—The submandibular duct is about two inches in length. It leaves the deep surface of the gland about its middle and runs forwards deep to the mylo-hyoid muscle along the medial surface of the deep process of the gland near its upper border (Fig. 500). Pursuing its course forwards beneath the floor of the mouth, on the medial side of the sublingual gland, the duct crosses the hyo-glossus and genio-glossus muscles, and finally opens on the floor of the mouth at the side of the frenulum of the tongue on the summit of the sublingual papilla.

While running forwards beneath the floor of the mouth, the duct is crossed twice by the lingual nerve. In its course to the tongue, the nerve crosses the duct superficially from above downwards at the anterior border of the hyo-glossus opposite the second molar tooth; farther forwards, under cover of the sublingual gland, the nerve curves upwards deep to the duct to reach the tongue.

Like the parotid duct, the submandibular duct is narrowest at its orifice, and may be to some extent a reservoir for the saliva.

Vessels and Nerves.—The arteries come chiefly from the *facial artery* and its *submental branch*: the **veins** accompany the arteries. The **lymph-vessels** pass to the *submandibular lymph-glands*. The **nerves** are derived, through the *submandibular ganglion*, from the *chorda tympani*, *lingual*, and the *sympathetic plexus around the facial artery* (Fig. 903, p. 1033).

Sublingual Gland.—The sublingual gland, the smallest of the principal salivary glands, is situated more deeply than the others. It lies immediately below the mucous membrane of the floor of the mouth in the sublingual fossa between the inner surface of the mandible above the mylo-hyoid line and the genio-glossus muscle. Below, it rests on the mylo-hyoid muscle.

In shape it is almond-like, flattened from side to side, but is much wider (from above downwards) anteriorly than posteriorly. It is usually from $1\frac{1}{2}$ to $1\frac{3}{4}$ inches (37 to 45 mm.) in length, whilst its bulk is about equal to that of two or three almonds.

Its detailed relations are as follows :—Its *lateral surface* rests against the inner aspect of the body of the mandible above the mylo-hyoid line. Its *medial surface* is in contact with the genio-glossus, stylo-glossus, and hyo-glossus muscles, as well as with the submandibular duct, which runs forwards between the gland and the muscles. *Below* it rests on the mylo-hyoid, and at its posterior part on the deep process of the submandibular gland ; its *upper border* is prominent and is covered only by the sublingual fold of the mucous membrane of the mouth (Fig. 494). The anterior half of the gland is much deeper and more bulky than the posterior half, and it meets its fellow in the median plane beneath the frenulum of the tongue. The posterior part grows gradually more slender, but may extend to the posterior part of the mylo-hyoid ridge.

The **sublingual ducts** are about twelve in number and of small size ; they leave the superior part of the gland, and, after a short course, open on a series of papillæ, visible to the naked eye, which are placed along the summit of the sublingual fold.

The gland is not enclosed in a distinct sheath, thus differing from the parotid and submandibular glands ; but its numerous lobules, which are smaller than those of the glands just mentioned, are held together by areolar tissue, loosely, but still in such a manner as to make one more or less consolidated mass out of what was, in the embryo, a number of separate glands.

As a rule all the ducts open separately on the summit of the sublingual fold, and apparently none of them join the submandibular duct. Frequently some of those from the anterior and more bulky part of the gland are larger than the others, but the presence of a large duct running alongside the submandibular duct, and opening with or beside it, is very rare in Man, although normal in the ox, sheep, and goat.

Vessels and Nerves.—The **arteries** are derived from the *sublingual artery*, a branch of the lingual, and from the *submental* branch of the facial. The **nerves** come from the *lingual*, the *chorda tympani*, and the *sympathetic plexus on the facial artery* through a branch of the submandibular ganglion which joins the lingual and is conveyed by it to the gland. The secretory fibres run in the *chorda tympani nerve* and thence through the submandibular ganglion to the gland (Fig. 903, p. 1033).

The **anterior lingual gland** has been described with the tongue.

Structure of Salivary Glands (Fig. 501).—Each of the principal salivary glands is divided into a number of lobules loosely united together by areolar tissue. From each of them one or more ducts emerge. Each duct divides into branches which terminate in a group of saccular or tubular alveoli. The epithelium which lines the ducts is columnar in character, but becomes flattened at the junction with the alveoli. The epithelium of the alveoli shows different characters in different glands. In the parotid and in the small salivary glands of the vallate papillæ, in which the secretion is watery or albuminous, the cells are uniform in character and of small size. When the gland is at rest the cells are filled with small granules which, when the secretion is poured out, are transformed into the gland-ferment—*ptyalin*. After secretion, only the deeper parts of the cells show the presence of granules. The nuclei are rounded and lie near the margin of the cells. In the sublingual, labial, buccal, and other glands of the mouth and palate the secretion is of a mucous character and the cells are larger : and the nuclei are placed deeply. The cells appear clear and swollen unless special methods of preparation are employed, such as examination in serum ; the cells are then seen to contain large and distinct granules of mucigen which in secretion are transformed into mucus.

In the submandibular gland and the anterior lingual gland both varieties of cells are present. In these glands, the larger clear mucous cells line the cavity of the alveolus, and the smaller granular serous cells are arranged upon the basement membrane, deep to the mucous cells, in crescentic masses, termed the *crescents or demilunes of Gianuzzi*. They communicate with the cavity of the alveolus by small channels between adjacent mucous cells.

After secretion, the mucous cells become smaller and stain more deeply than when loaded with mucigen before secretion.

PHARYNX

The **pharynx** lies behind the nasal cavities, the mouth, and the larynx; it communicates with them, and it is continuous inferiorly with the œsophagus or gullet (Fig. 502).

It extends from the base of the skull to the level of the lower border of the

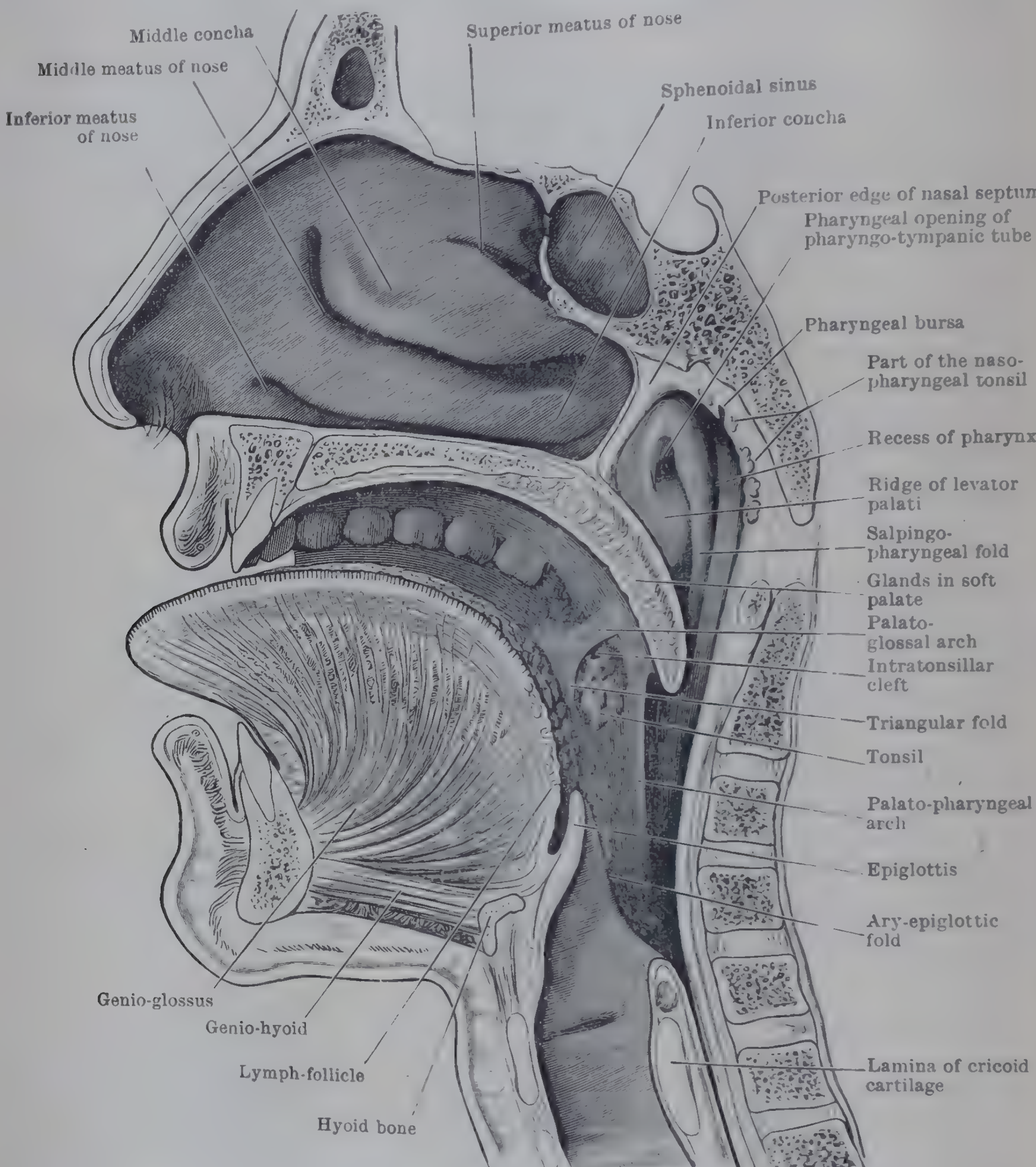

FIG. 502.—SAGITTAL SECTION THROUGH MOUTH, TONGUE, LARYNX, PHARYNX, AND NASAL CAVITY.

The section was slightly oblique, and the posterior edge of the nasal septum has been preserved. The specimen is viewed slightly from below; hence the apparently low position of the inferior concha. For the usual inferior convexity of the crowns of the maxillary molar teeth, see p. 574 and Fig. 500.

cricoid cartilage and of the sixth cervical vertebra (Fig. 502); and in length it varies from 5 to 5½ inches (12·5 to 14·0 cm.).

In the middle part of the pharynx the pathway for respired air, between the nose and the larynx, crosses that of food and drink from the mouth to the œsophagus. The inferior portion alone, below the opening of the larynx, is exclusively a part of the alimentary tract, and the portion above the level of the soft palate is used for respiration only. It is, however, convenient to study the structure and relations of the pharynx as a whole.

Structurally the pharynx is a fibro-muscular bag lined with mucous membrane,

and is of conical form—wide above and narrow below. The fibrous wall of the upper part of the pharynx is firmly attached to the base of the skull, especially around the posterior apertures of the nasal cavities, and hence in that part there is a permanent cavity which contains air. The lower portion gradually assumes a more tubular form, and the anterior and posterior walls approach each other, till, below the level of the opening of the larynx, they are in contact with each other and the cavity is reduced to a slit except during the passage of food.

Dimensions of Pharynx.—From the highest part of the roof to the upper surface of the soft palate at its junction with the hard palate, it measures about $1\frac{1}{4}$ inches, or 3 cm. The

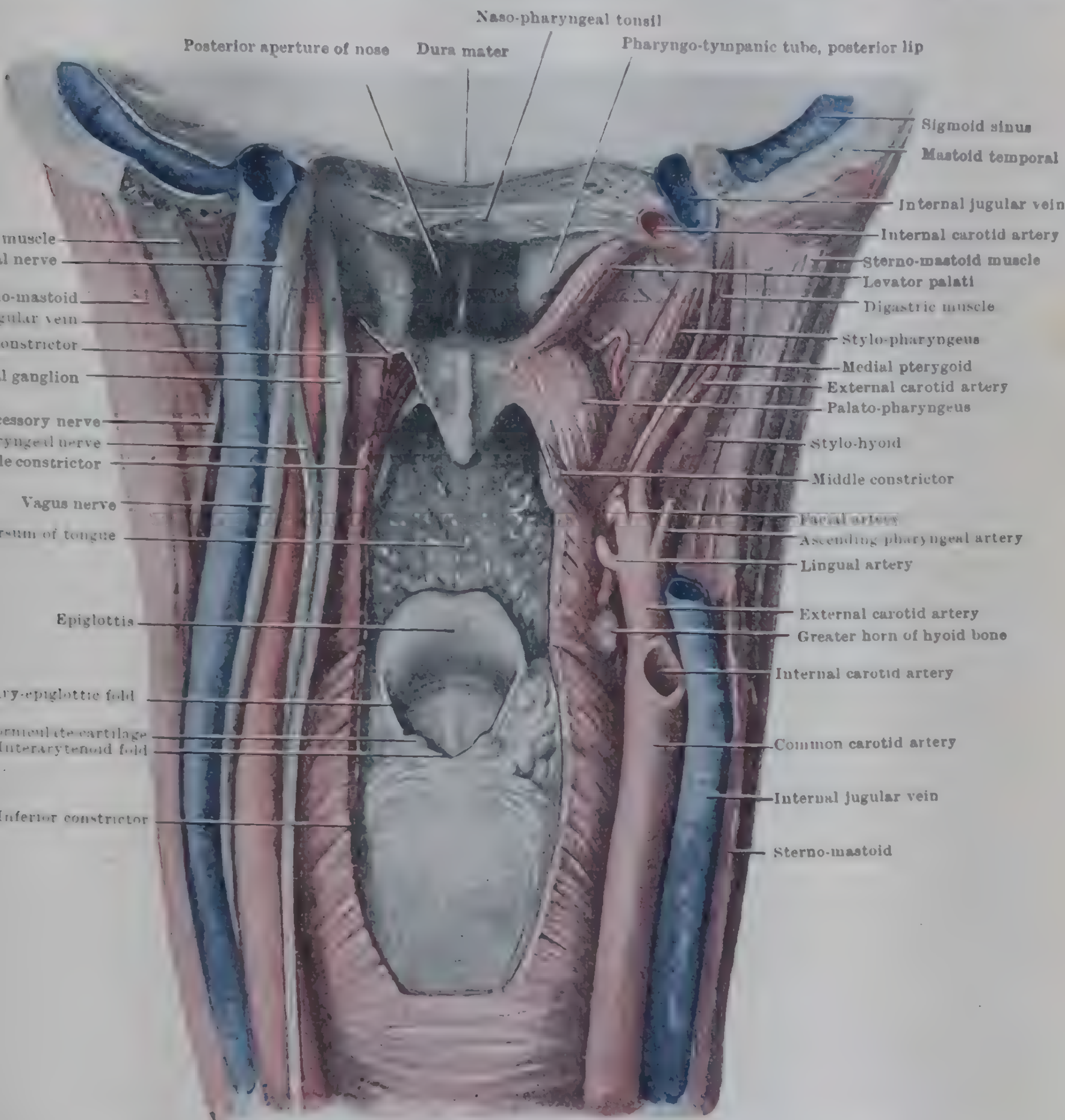

FIG. 503.—INTERIOR OF PHARYNX AND THE STRUCTURES IN RELATION TO ITS SIDE-WALLS, VIEWED FROM BEHIND.

vertical extent of the oral part of the pharynx is about $2\frac{1}{4}$ inches, or 6 cm., and that of the laryngeal part is about $2\frac{3}{4}$ inches, or 7 cm.

The lower end of the pharynx is usually about $5\frac{1}{2}$ to $6\frac{1}{2}$ inches (14 to 16·5 cm.) from the margins of the incisor teeth, in a curved line passing through the cavities of the mouth and oral and laryngeal parts of the pharynx.

The other diameters are as follows:—The antero-posterior diameter of the nasal part, from the lower part of the septum of the nose is 15 to 18 mm., and that of the oral part, from the palato-glossal arches to the posterior wall, is about 10 mm. (two-fifths of an inch).

The **cavity of the pharynx** is incompletely divided into an upper **nasal part** and a lower part (Fig. 502). The lower part is further divided into the **oral part** behind the mouth and tongue, and the **laryngeal part** behind the larynx.

The aperture between the margin of the soft palate and the posterior wall of the pharynx, by which the nasal part of the pharynx communicates with the lower portion of the cavity, is called the **pharyngeal isthmus**.

The pharynx presents *seven openings* by which it communicates with neighbouring cavities (Fig. 502). They are the two **posterior apertures of the nose** on the anterior wall of the nasal part, and the **pharyngeal opening of the pharyngo-tympanic tube** on each of its side-walls; the **oro-pharyngeal isthmus**, which leads into the mouth from the oral part; the **inlet of the larynx** on the anterior wall of the laryngeal part of the cavity; and the **opening of the œsophagus** at its lower end.

Nasal Part (Figs. 502 and 504).—The nasal part is a portion of the true pharynx, but it is functionally part of the respiratory tract. It differs from the rest of the pharynx in that its cavity is, under all conditions, an open

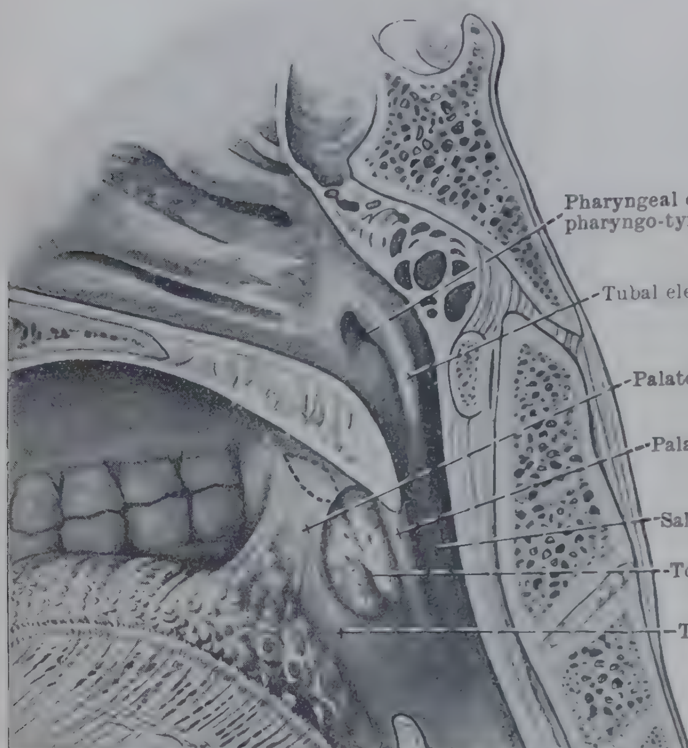

Fig. 504.—Median Section of Pharynx to show the Right Tonsil.
The tonsil is large and divided below by an oblique cleft. The orifice of the intratonsillar cleft is near its upper pole, and the extent of the cleft in this specimen is indicated by a dotted line.

chamber incapable of obliteration, since all its walls, with the single exception of the floor, are immovable.

The cavity of the nasal part is irregular in shape and is enclosed by *six walls*—namely, anterior and posterior, right and left, a floor and a roof or vault.

The *anterior wall* slopes upwards and backwards, and it is a "wall" only in name, for it is represented almost entirely by a pair of large openings—the **posterior apertures of the nose**—separated from each other by the nasal septum.

The *posterior wall* is nearly vertical; it corresponds in extent to the basilar part of the occipital bone, the anterior arch of the atlas, and the body of the axis vertebra.

The *roof* lies under the posterior part of the body of the sphenoid and the basilar part of the occipital bone, and it slopes downwards and backwards to join the posterior wall.

Each *lateral wall* is occupied by the pharyngeal opening of the pharyngo-tympanic tube and the tubal elevation, and, posterior to them, by a vertical depression that leads into a slit-like space called the **pharyngeal recess**. The *floor* is the soft palate.

In the posterior part of the roof and upper part of the posterior wall there is a considerable accumulation of lymphoid tissue, known as the **naso-pharyngeal tonsil**, which is distinct in the child but becomes indistinct, or entirely disappears, in adult life. It is related to that part of the roof which is formed by the body of the sphenoid and the basilar part of the occipital bone (Fig. 502). The mucous membrane which covers it is thickened and thrown into transverse folds.

A similar collection of lymphoid tissue—a lateral prolongation of the naso-pharyngeal tonsil—behind the mouth of the pharyngo-tympanic tube is known as the "*tubal tonsil*".

In the inferior part of the naso-pharyngeal tonsil, there is, constantly in the child and occasionally in the adult, a small median recess, termed the **pharyngeal bursa**, which runs upwards and backwards in the wall of the pharynx for some distance (Fig. 502).

Enlargement of the lymphoid tissue in the nasal part of the pharynx occurs frequently in children, and the swollen lymph-nodules are known as *adenoids*. The enlargement may be so considerable that it extends downwards in front of the upper two cervical vertebræ and bulges

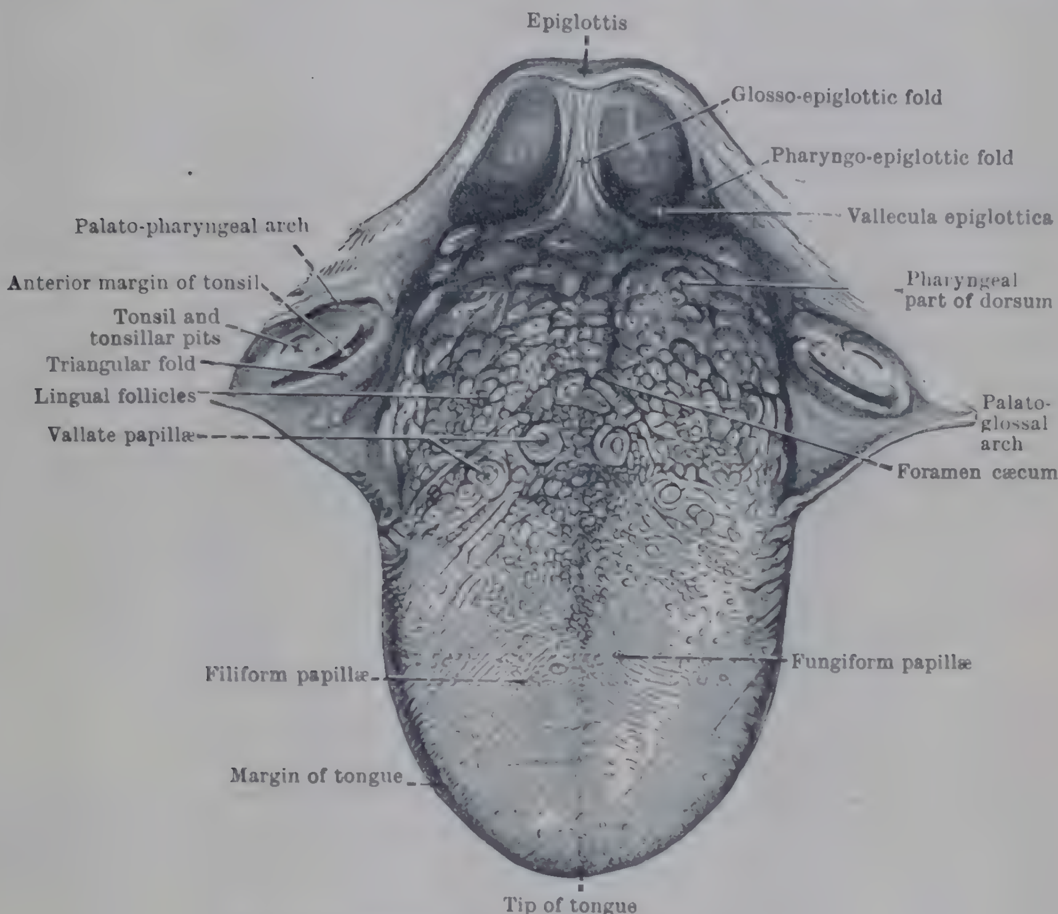

FIG. 505.—DORSUM OF TONGUE AND THE TONSILS.

forwards till it fills up a great part of the cavity of the nasal part of the pharynx. In the operation for adenoids, a prominent anterior tubercle of the atlas sometimes interferes with the manipulation of the curette.

The **pharyngeal opening of the pharyngo-tympanic tube**, oval or triangular, and funnel-like in appearance (Fig. 502), is situated on the side-wall of the nasal part a short distance (about $\frac{1}{3}$ to $\frac{1}{2}$ inch) behind the posterior end of the inferior concha, and immediately above the level of the hard palate (Figs. 502 and 504). It is bounded superiorly and posteriorly by a prominent rounded ridge—the **tubal elevation** (torus tubarius)—formed by the cartilage of the tube. The prominence of the posterior margin, as contrasted with the anterior margin of the orifice, and the direction of the tube itself, which runs backwards and laterally (from the pharynx to the tympanum), greatly facilitate the introduction of a Eustachian (tubal) catheter. The **recess of the pharynx**—a narrow and nearly vertical recess of considerable depth (Fig. 502)—lies immediately behind the tubal elevation. It extends laterally over the upper margin of the superior constrictor, below the petrous portion of the temporal bone (Fig. 376, p. 440).

A slight ridge of the mucous membrane, called the **salpingo-pharyngeal fold**, descends from the lower end of the tubal elevation on the side-wall of the pharynx. Another and less obvious ridge passes from the anterior border of the opening downwards and forwards to join the palate. In front of the latter there is an indistinct groove which indicates the division of the nasal cavity from the nasal part of the pharynx.

The levator palati runs parallel to the tube, and along its lower border. As it enters the palate, it produces, particularly when contracted, an elevation, immediately below the pharyngeal orifice of the tube (Fig. 502), which forms the base of that opening when it assumes its usual triangular shape.

Oral Part.—The oral part of the pharynx lies behind the mouth, between the soft palate above and the inlet of the larynx below. Its *posterior* boundary is the posterior wall of the pharynx, and has no distinguishing feature. *Anteriorly* it communicates with the mouth through the oro-pharyngeal isthmus, and, below that, it is bounded by the pharyngeal surface of the tongue. Each *side-wall* is a triangular area named the **tonsillar sinus** because it is occupied by the tonsil. The sinus is bounded anteriorly by the palato-glossal arch (p. 566), and posteriorly by the palato-pharyngeal arch.

The **palato-pharyngeal arch** is a fold of mucous membrane which contains the palato-pharyngeus muscle. It springs from the posterior edge of the soft palate, passes downwards and slightly backwards, and ends inferiorly on the side-wall of the pharynx (Fig. 502).

From the posterior surface of the palato-glossal arch a thin ***triangular fold***

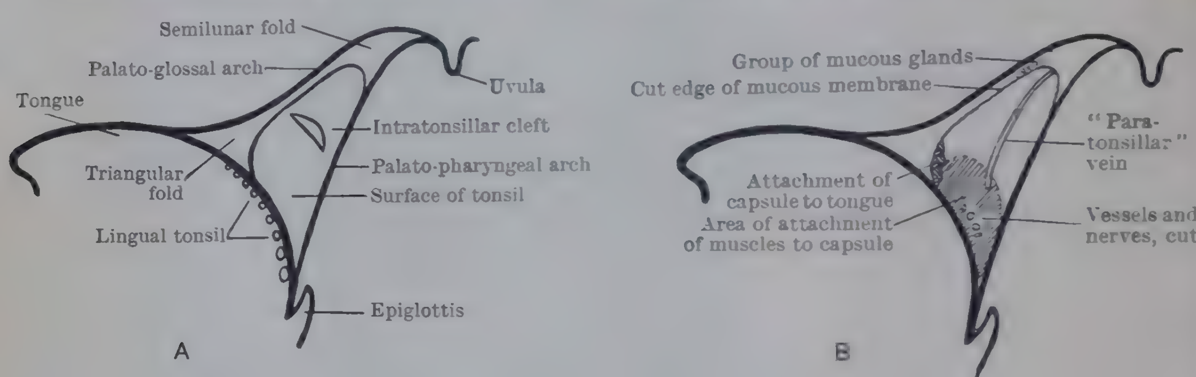

FIG. 506.—DIAGRAMS OF SURROUNDINGS OF TONSIL (Browne, 1929).
A. Tonsil *in situ*; B. After its Removal.

of mucous membrane passes backwards. Its base corresponds to the palato-glossal arch; its superior border passes downwards and backwards, and is free—frequently overlapping the tonsil. Its lower border is attached to the side of the tongue. It covers, medially, the inferior part of the tonsillar sinus.

The **tonsils** are a pair of oval masses of lymphoid tissue which lie one in each tonsillar sinus. The tonsil presents very different forms in different subjects. It may bulge from the sinus into the cavity of the pharynx, or it may be flat and limited to the tonsillar sinus. In some cases the triangular fold is fused with the free surface of the tonsil, and lymphoid tissue may be developed on the medial surface of that fold. It is oval in shape, with the long axis directed vertically; and it has a medial and a lateral surface, a superior and inferior pole, and an anterior and posterior margin. Its size is extremely variable, but as a rule, in early life, it measures a little under 1 inch (20 to 22 mm.) from above downwards, about ¾ inch (18 to 20 mm.) antero-posteriorly, and ½ inch (12 to 15 mm.) medio-laterally.

The medial surface is free, is covered with epithelium and is studded with deep, narrow crypts called the **tonsillar pits** (Fig. 507). On this surface there is a narrow *intratonsillar cleft* which penetrates the substance of the tonsil and extends upwards to the soft palate, into which it may penetrate for as much as a centimetre. The lateral, attached surface is covered by a distinct fibrous sheath which separates the tonsil from the palato-pharyngeus muscle and the superior constrictor muscle of the pharynx. At the lower part of this surface the tonsillar artery enters the tonsil and the veins leave it. The inferior pole projects downwards towards the tongue. The superior pole, rounded and blunt, presents numerous pits.

Structure of Tonsil.—The substance of the tonsil is permeated by the tonsillar pits, each lined with stratified squamous epithelium, external to which there is a layer of lymphoid

tissue 2 to 3 mm. in thickness. In this layer there are rounded germinal centres or nodules, connected together by looser tissue. The lumen of the pits is frequently filled with a cheesy material composed of epithelial cells, of lymphoid cells which have migrated through the epithelial lining, and of organisms. Each tonsillar pit with its wall forms a follicle, and the follicles are connected by loose areolar tissue.

Relations of Tonsil.—The lateral relations of the tonsil are the fibrous sheath, the palato-pharyngeus and the superior constrictor muscle. Lateral to the pharyngeal wall lies the medial pterygoid muscle, and, behind it, a region filled with areolar tissue which contains blood-vessels and nerves. Between the sheath and the muscles one or two veins ("paratonsillar") descend from the soft palate (Browne, 1929).

The sheath of the tonsil is connected by a fibrous band to the base of the tongue, and

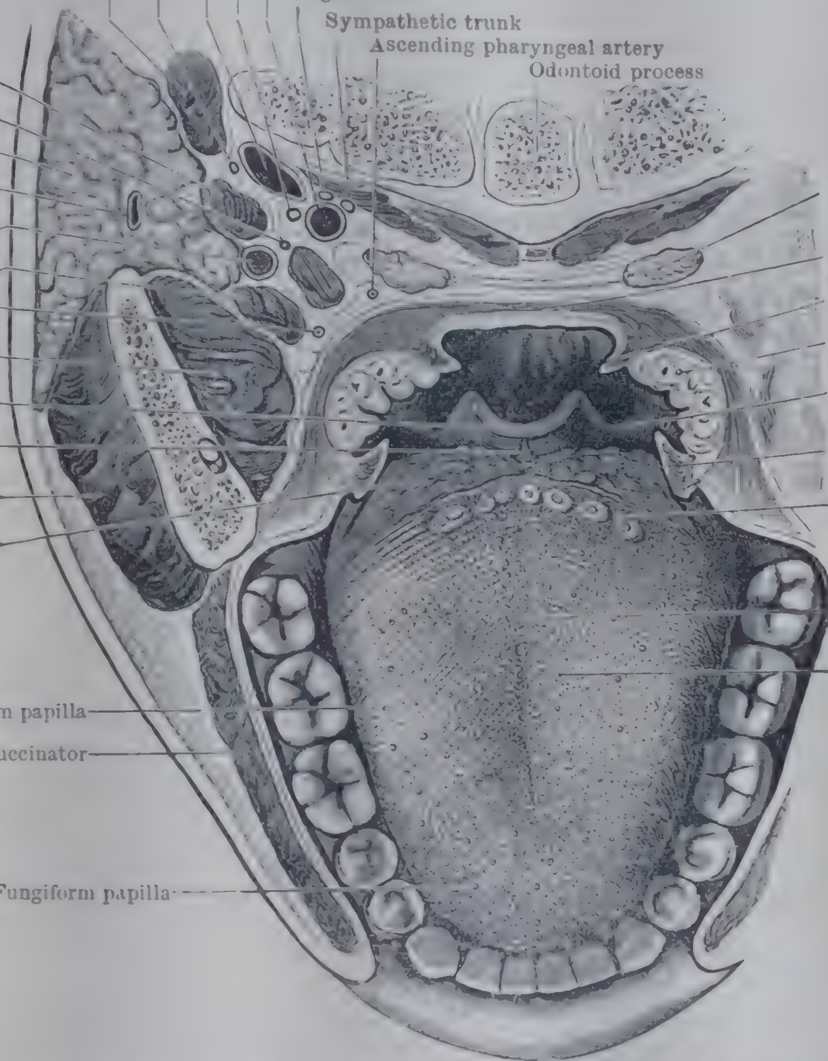

FIG. 507.—HORIZONTAL SECTION THROUGH MOUTH AND PHARYNX AT THE LEVEL OF THE TONSILS.

The prevertebral muscles and the stylo-pharyngeus (which is shown immediately to the medial side of the external carotid artery) are not indicated by reference lines.

decussating fibres of the palato-glossus and palato-pharyngeus muscles run into the lower third of the sheath.

The nearest and most important artery is the facial artery, which, especially if tortuous, has a very close relation to the pharyngeal wall at that level. The ascending palatine and tonsillar branches of the facial artery also are in close relation.

Vessels and Nerves.—The **artery** of the tonsil is the *tonsillar branch of the facial artery*, which enters the lower part of the lateral surface close to the tongue; other arteries from the ascending pharyngeal branch of the external carotid, and the dorsales linguæ of the lingual ramify in the surrounding tissues. The **veins** emerge from the lateral surface as two branches which pierce the superior constrictor muscle and terminate in the *common facial vein*, and connect with the pharyngeal plexus also. The **nerves** are a special branch from the glosso-pharyngeal and branches from the pharyngeal plexus; they unite to form a small *tonsillar plexus* which supplies the organ.

The **lymph-vessels** are numerous. They begin in a plexus which surrounds each follicle, whence vessels pass to the lateral surface of the tonsil; there, they pierce the wall of the

pharynx, and pass to *deep cervical glands* in the neighbourhood of the greater horn of the hyoid bone, behind and below the angle of the mandible.

Laryngeal Part.—The laryngeal part of the pharyngeal cavity is behind the larynx (Fig. 503). It is wide above, but at the level of the cricoid cartilage it narrows rapidly as it passes down to join the œsophagus.

Its *anterior wall* is formed throughout by the larynx, of which the following parts are seen from the pharyngeal cavity:—Above, the epiglottis; below that, the inlet of the larynx bounded at the sides by the ary-epiglottic folds; lateral to each of these folds, there is a deep recess called the **piriform fossa** (Fig. 583, p. 692); lower down still, the mucous membrane which covers the posterior surfaces of the arytenoid and cricoid cartilages.

Relations of Pharynx.—The pharynx as a whole lies anterior to the cervical region of the vertebral column, and is separated from the bodies of the vertebræ and the intervertebral discs by the loose areolar tissue of the retro-pharyngeal space, posterior to which lie the longus capitis and longus cervicis muscles and the anterior longitudinal ligament of the vertebral column.

The lateral relations of the nasal and oral parts on the one hand, and of the laryngeal part on the other hand, are very different.

The laryngeal part, lying in the neck, is in contact on each side with the superior part of the thyroid gland, the carotid sheath, and especially the common and external carotid arteries, and, more posteriorly, the internal carotid artery. The branches that arise from the lower part of the external carotid also are in close lateral relation to it, viz., the superior thyroid and lingual arteries.

The relations of the oral and nasal parts are more complex. Reference to Fig. 507 will help to elucidate them. On each side lies the medial pterygoid muscle. As the medial pterygoid passes backwards and downwards to its insertion, it diverges from the pharynx and a triangular space is left between it and the wall of the pharynx. The styloid process, and the muscles which arise from it, project downwards into that space, and lying beside them are numerous vessels and some nerves. Thus, the stylo-glossus and stylo-pharyngeus come into contact with the side-wall, and the glosso-pharyngeal nerve accompanies the stylo-pharyngeus. The ascending pharyngeal artery runs upwards by the side of the pharyngeal wall. The facial artery, as it passes under the digastric and stylo-hyoid muscles, comes into contact with the superior constrictor muscle; and the ascending palatine and tonsillar branches of the facial artery also ascend in close relation to the pharyngeal wall. The pharyngeal plexus of nerves and also a plexus of veins lie in contact with the side-wall. The internal carotid artery lies a little farther back, with the vagus, accessory, and hypoglossal nerves. In this region the external carotid lies more superficially and is separated by a considerable interval from the pharyngeal wall.

Structure of Pharyngeal Wall.—The fibrous wall of the pharynx is firmly fixed above to the base of the skull, but it is not otherwise attached except to the hyoid bone and the skeleton of the larynx.

The wall is composed of a strong fibrous membrane, called the **pharyngo-basilar fascia**, lined internally with mucous membrane, and covered incompletely on its outer surface by a series of three overlapping muscles—the constrictor muscles of the pharynx. These muscles are covered externally with a thin layer of fascia which passes forwards, at its superior part, on to the surface of the buccinator muscle, and is called the **bucco-pharyngeal fascia**.

With the wall of the pharynx are associated several accessory muscles, viz., the muscles of the soft palate, and also the stylo-pharyngeus muscle, which blends with the wall but is also attached to the larynx (see p. 441).[1]

The pharyngo-basilar fascia is attached to the skull as follows:—

Above, it blends with the periosteum of the basilar part of the occipital bone in front of the pharyngeal tubercle, and on each side it extends to the spine of the sphenoid and the inferior surface of the temporal bone in front of the lower end of the carotid canal, and lateral to the opening of the pharyngo-tympanic tube.

On each side it is attached to the medial pterygoid plate, the pterygo-mandibular ligament, and the mylo-hyoid ridge; and it is eventually lost on the side of the tongue.

PLATE XLIX

FIG. 1.—PAROTID DUCT AND GLAND.

The accessory parotid gland does not appear to have been present.

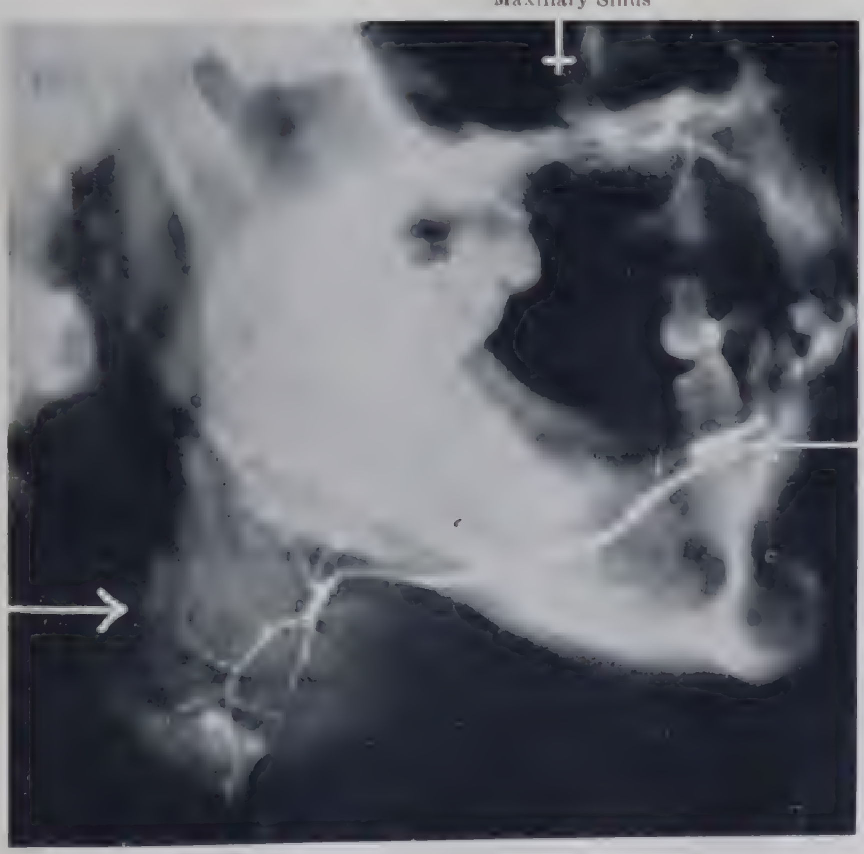

FIG. 2.—SUBMANDIBULAR DUCT AND GLAND.

PLATE XLIX.—RADIOGRAPHS OF SALIVARY DUCTS AND GLANDS AFTER INJECTION OF RADIO-OPAQUE IODISED OIL IN LIVING SUBJECTS. (Sialographs: Dr. R. G. W. Ollerenshaw.)

[*Facing p.* 592

PLATE L

PLATE L.—OBLIQUE LATERAL RADIOGRAPH OF THORAX OF YOUTH AGED 18, DURING THE PASSAGE OF "BARIUM-PASTE" THROUGH THE ŒSOPHAGUS.

For the relation of the Œsophagus to the Vertebral Column and the back of the Pericardium, see Fig. 509, D and E, p. 594; and note that the "post-cardiac space" is part of the posterior mediastinum occupied mainly by the Œsophagus and the Descending Aorta.

The pharyngo-basilar fascia is particularly strong in the superior part, where there is an area on each side which is not covered by the superior constrictor muscle; and there the tensor and levator palati muscles pass through the wall.

The pharyngo-basilar fascia, which is thick above and thin below, and the bucco-pharyngeal fascia, which is thin above and stouter below, are practically blended into one layer above, near the base of the skull, where the muscular coat is absent. Lower down they are separated by the constrictors, and become two distinct sheets. They are strengthened in the median plane posteriorly by a fibrous band which descends from the pharyngeal tubercle.

The **mucous membrane** of the oral and laryngeal parts of the pharynx is covered with stratified squamous epithelium, and that of the nasal part with ciliated epithelium, the difference in structure being an expression of a difference in function. In the roof of the nasal part of the pharynx there are large masses of lymphoid tissue which constitute the naso-pharyngeal tonsil, and on each side of the oral part lies *the* tonsil. Similar tissue is found in considerable amount in the pharyngeal recess and on the pharyngeal portion of the dorsum of the tongue.

There are also numerous racemose glands, of the mucous type, in the walls of the nasal part, in the soft palate, and in the ary-epiglottic folds.

For the details of the attachments and relations of the **pharyngeal muscles**, see p. 440.

Vessels and Nerves of Pharynx.—The **arteries** of the pharynx are derived from: 1, the *ascending pharyngeal*; 2, the *ascending palatine* branch of the facial; 3, the *greater palatine* from the maxillary, with a few twigs from the dorsales linguæ, tonsillar (of facial), the artery of the pterygoid canal, and the pharyngeal branch of the maxillary. The **veins** go to the *pharyngeal venous plexus*. The plexus communicates with the pterygoid plexus above, and with the internal jugular or common facial vein below.

The **lymph-vessels** of the pharynx pass chiefly to the *upper deep cervical glands*.

The **nerves** of the pharynx, both motor and sensory, are derived chiefly from the *pharyngeal plexus*, which is formed by branches of the vagus, glosso-pharyngeal, and sympathetic. The soft palate and the neighbourhood of the tonsil are supplied by the *palatine branches of the spheno-palatine ganglion*. The tonsil receives a branch from the glosso-pharyngeal direct. The vault of the pharynx, and the region around the opening of the pharyngo-tympanic tube, as well as the opening itself, are supplied by branches from the spheno-palatine ganglion. Finally, the *internal laryngeal nerve* supplies the mucous membrane of the back of the larynx.

Movements of Pharynx.—Three different sets of movements of the pharynx or of its parts may be recognized: (1) closure of the pharyngeal isthmus, or separation of the oral part from the nasal part; (2) closure of the oro-pharyngeal isthmus or separation of the mouth and pharynx; and (3) movements in swallowing.

(1) This is effected by raising the posterior part of the soft palate so that its dorsal surface comes into contact with the mucous membrane on the dorsal wall of the pharynx. At the same time a muscular band—*palato-pharyngeal sphincter* (Whillis, 1930), which passes from the inner aspect of the upper part of the superior constrictor to the palatal aponeurosis, raises a constricting elevation on the pharyngeal wall known to surgeons as Passavant's ridge (p. 445). In the movement of raising the soft palate the levator and tensor palati co-operate with one another.

(2) Closure of the oro-pharyngeal isthmus is effected by elevation of the posterior part of the dorsum of the tongue against the soft palate, slight lowering of the palate, and by movement inwards of the palato-glossal folds. The muscles which bring about these various movements are the palato-glossus, the stylo-glossus, and the intrinsic muscles of the tongue.

(3) The middle and inferior constrictor muscles participate in the final part of swallowing, passing the bolus of food onwards into the œsophagus. (See also pp. 445 and 700.)

Radiographic Examination of Pharynx.—The form of the cavity of the pharynx during life can be shown by X-ray examination. The post-cricoid portion of the laryngeal part of the pharynx appears closed in radiographs taken under ordinary conditions (Pl. LXI, p. 696).

ŒSOPHAGUS

The **œsophagus** or **gullet** is, with the exception of the pylorus, the narrowest, and at the same time one of the most muscular parts of the whole alimentary tube.

It extends from the termination of the pharynx, at the lower border of the cricoid cartilage and opposite the sixth cervical vertebra, to the cardiac orifice of

the stomach opposite the tenth thoracic vertebra. Between those two points it traverses the lower part of the neck, the whole length of the thorax, and, having pierced the diaphragm, it enters the abdomen and immediately afterwards joins the stomach. In its course it does not adhere to the median plane of the body but leaves it twice by curving to the left.

In the lower part of the neck and the

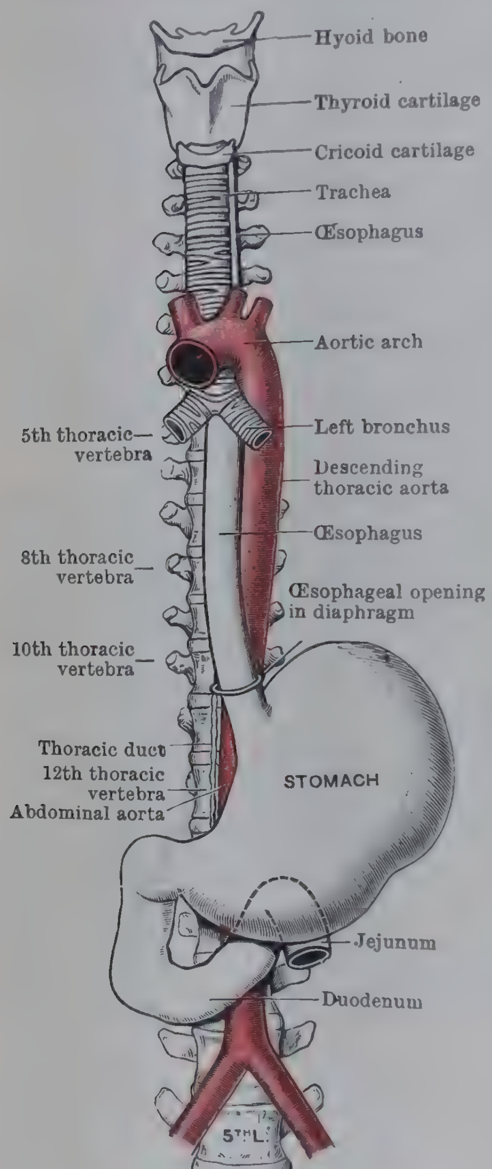

Fig. 508.—Diagram to show Course of Œsophagus in relation to Vertebral Column, Trachea, and Aorta

upper part of the thorax, the œsophagus projects to the left beyond the margin of the trachea to the extent of $\frac{1}{6}$ or $\frac{1}{4}$ inch (4 to 6 mm.). It returns to the median plane at the level of the fourth thoracic vertebra. Lower down, behind the pericardium, at the level of the seventh thoracic vertebra, it again passes to the left, and also forwards, in order to reach the œsophageal opening in the diaphragm, and it

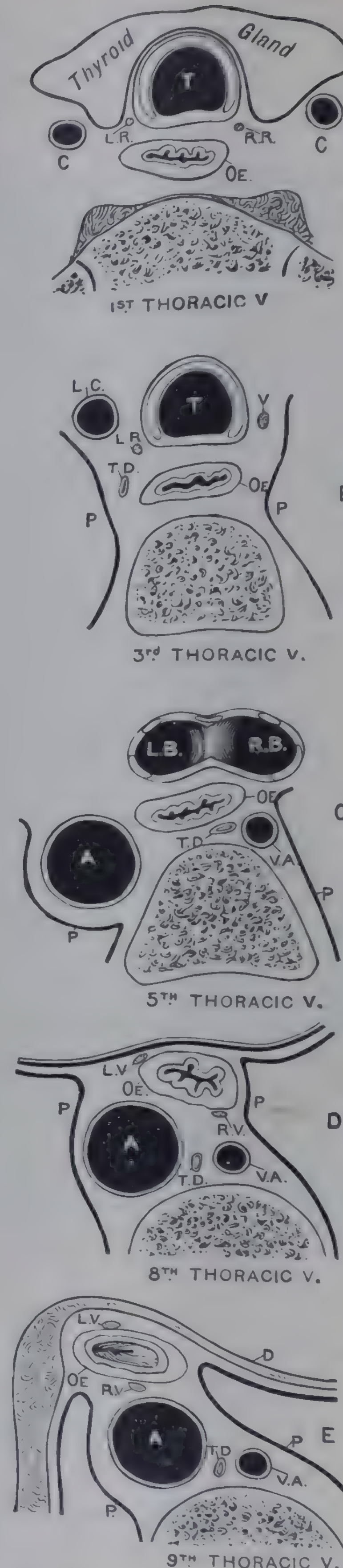

Fig. A is at the level of the superior part of the 1st thoracic vertebra, and shows the chief relations of the œsophagus in the neck and also its divergence to the left.

Fig. B, at the 3rd thoracic vertebra, shows the thoracic duct lying on the left side of the œsophagus. V, Right vagus nerve.

In Fig. C, at the level of the 5th thoracic vertebra, the left bronchus is seen in relation to the anterior surface of the œsophagus.

Fig. D is at the level of the 8th thoracic vertebra, and shows the œsophagus passing behind the pericardium.

Fig. E, at the 9th thoracic vertebra, shows the œsophagus inclining to the left just before piercing the diaphragm.

Fig. 509.—Tracings from Frozen Sections to show Relations of Œsophagus at the levels of the 1st, 3rd, 5th, 8th, and 9th thoracic vertebræ. See also Fig. 593, p. 701.

A., Aorta; C., Common carotid artery; D., Diaphragm; L.B., Left bronchus; L.C., Left subclavian artery; L.R., Left recurrent laryngeal nerve; L.V., Left vagus; OE., Œsophagus; P., Pleura; Pc., Pericardium; R.B., Right bronchus; R.R., Right recurrent laryngeal nerve; R.V., Right vagus; T., Trachea; T.D., Thoracic duct; V.A., Vena azygos.

maintains this direction until the stomach is reached. It passes on to the front of the descending aorta at the level of the eighth thoracic vertebra, and traverses the diaphragm at the level of the tenth.

In addition to the curvatures just described, it is also curved in the antero-posterior direction in correspondence with the form of the vertebral column.

In cross-sections (Fig. 509) the œsophagus appears either as a flattened tube with a transverse, slit-like cavity, or as an oval or rounded canal with a stellate lumen. The former condition is more common in the neck owing to the pressure of the trachea, and the latter in the thorax. When exposed in the ordinary post-mortem examination soon after death, it has rather the appearance of a solid muscular rod or band than of a hollow tube.

The œsophagus presents three distinct *constrictions*—one situated at its beginning, another at the point where it is crossed by the left bronchus, and the third where it passes through the diaphragm. The upper two constrictions are of the same size, and will admit without injury an instrument with a maximum diameter of $\frac{4}{5}$ inch (20 mm.). At each of those points the tube is flattened from before backwards.

In *length* it usually measures from 10 inches to 12 inches (25-30 cm.).

Its *breadth*, where the tube is widest, varies between half an inch (13 mm.) in the empty contracted condition and 1 inch or more (25 to 30 mm.) in the fully distended state.

The distance from the upper incisors to the beginning of the œsophagus averages about 6 inches (15 cm.), to the level of the left bronchus 9 inches, to the opening of the diaphragm 14 to 15 inches, and to the cardiac orifice of the stomach, 16 inches.

Relations of Œsophagus.—The relations (Fig. 509) differ so widely in different regions that they must be described separately for each of them. Three parts may be described—*cervical, thoracic,* and *abdominal.*

Cervical Part.—Anteriorly lies the trachea—to the posterior wall of which the œsophagus is loosely connected by areolar tissue—and in the groove at each side, between the trachea and œsophagus, the recurrent laryngeal nerve ascends to the larynx (Fig. 509, A). Posteriorly lie the vertebral column and the longus cervicis muscles and the prevertebral layer of the cervical fascia. On each side lies the carotid sheath with its contents, a lobe of the thyroid gland and the inferior thyroid artery. Owing to the deviation of the tube to the left in the inferior part of the neck, it lies nearer to the carotid sheath and thyroid gland on the left side than on the right.

Thoracic Part.—The œsophagus passes successively through the superior and posterior mediastina, in the former lying close to the vertebral column, but in the latter advancing into the thoracic cavity and coming into contact with the back of the pericardium. The trachea lies anterior to it as far as the fifth thoracic vertebra, where the trachea bifurcates. Immediately below that level the œsophagus is crossed by the left bronchus (Fig. 509, C), and in the rest of its thoracic course it lies in close relation to the back of the pericardium. Posteriorly, in the upper part of the thorax, it rests on the longus cervicis muscles and the vertebral column; but below the bifurcation of the trachea, it is soon separated from the vertebral column by the vena azygos, the thoracic duct, the upper five posterior intercostal arteries of the right side, and in its lower part by the descending thoracic aorta also.

On its *left side*, in the upper part of the thorax, lie the left pleura and the left subclavian artery, with the thoracic duct posterior to the artery; in the middle region, the aorta, and lower down the left pleura again, for a little way, before the œsophagus pierces the diaphragm. On the *right side* lies the arch of the vena azygos, whilst the right pleura clothes it both below and above that level.

The two vagus nerves, after forming the posterior pulmonary plexuses, descend to the œsophagus, where they form, with each other and with branches of the sympathetic, the **œsophageal plexus.** From this plexus two nerves pass downwards, one on the front and one on the back of the œsophagus, through the opening in the diaphragm. Each of these nerves contains fibres from both vagi, and they are termed the **anterior** and **posterior gastric nerves.**

The terminal part of the thoracic part of the œsophagus, about half an inch in length (1 to 1·5 cm.), passes through the œsophageal opening of the diaphragm and is connected by a considerable amount of strong fibrous tissue to the boundaries of the opening. Above and in front, it is bounded either by the posterior edge of the central tendon or by a few decussating fibres of the muscular portion of the diaphragm. At the sides and behind, decussating bands from the right crus embrace the œsophagus, turn a flat surface (not an edge) towards the opening, and thus, behind and at the sides, the œsophagus is in contact with the diaphragm for a distance of 1 to 1·5 cm.

Immediately above the level at which the œsophagus passes through the diaphragm, there is a fusiform expansion of the tube, of variable length and girth. This dilated portion lies in the lowest part of the posterior mediastinum, where

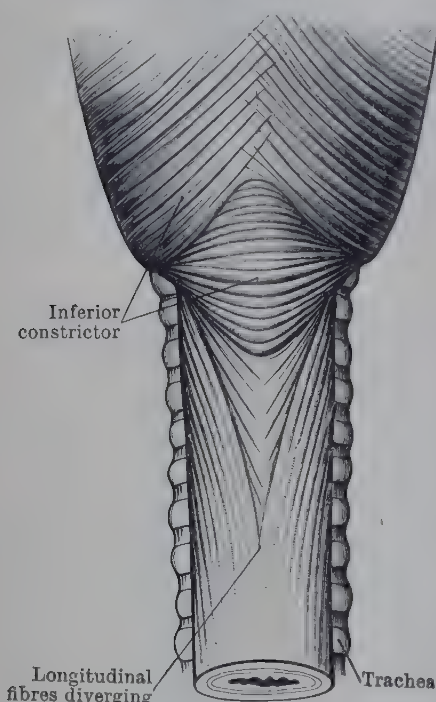

FIG. 510.—ARRANGEMENT OF MUSCULAR FIBRES ON BACK OF ŒSOPHAGUS AND PHARYNX. Traced upwards, the longitudinal muscular fibres of the œsophagus are seen to separate; passing round to the sides, they form two longitudinal bands which meet in front and are united to the cricoid cartilage, as shown in the next figure. Cf. Fig. 376, p. 440.

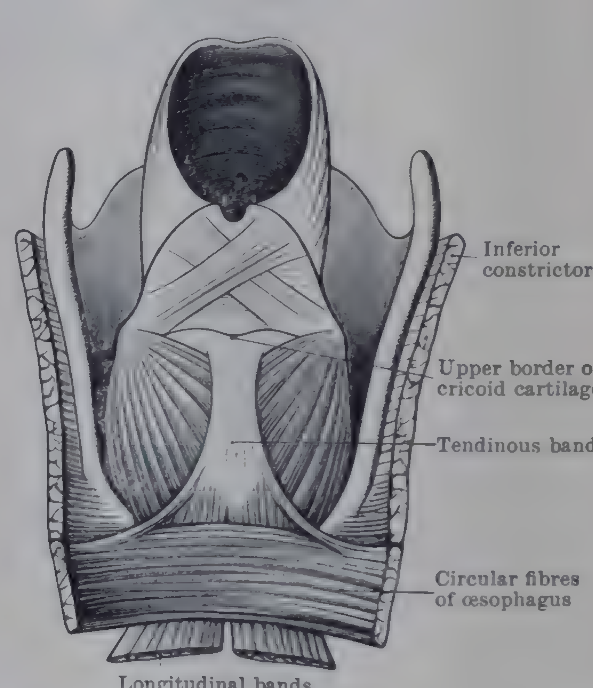

FIG. 511.—RELATION OF MUSCULAR COAT OF ŒSOPHAGUS TO CRICOID CARTILAGE AND PHARYNX. The pharynx and œsophagus have been slit up from behind, and the mucous membrane removed to show the muscular fibres. The two longitudinal bands are seen passing round to the front to be attached by a common tendon to the upper border of the cricoid cartilage. The circular fibres are continuous with the inferior constrictor.

the anterior wall is formed by the sloping posterior part of the diaphragm. Should the œsophagus be obstructed at its passage through the diaphragm, this portion may undergo great distension, and swallowed food may be retained in it and not pass on into the stomach.

Abdominal Part.—This part of the œsophagus is very short and funnel-shaped, widening as it approaches the stomach, and it almost disappears by merging into the stomach wall when the stomach is distended. It lies against the œsophageal groove of the liver in front, with the anterior and posterior gastric nerves on its surfaces.

Relation of Aorta to Œsophagus.—The arch of the aorta, passing back to reach the vertebral column, crosses the left side of the œsophagus; consequently the descending thoracic aorta lies at first to its left; lower down, however, as the aorta passes on to the front of the vertebral column, and the gullet inclines forwards and to the left, the aorta comes to lie posteriorly; and then, as the diaphragm is approached, it lies not only posteriorly, but also slightly to the right of the œsophagus (Figs. 508 and 509).

Relation of Thoracic Duct to Œsophagus.—The thoracic duct, lying to the right of the aorta below, is not directly related to the œsophagus (Fig. 509, E); but higher up (Fig. 509, D and C) it lies posterior to it. About the level of the aortic arch the duct passes to the left, and above that level (Fig. 509, B) it is found on the left side of the œsophagus.

Relation of Pleural Sacs to Œsophagus.—Above the level of the arches of the aorta and of the vena azygos, the pleuræ, though not lying in immediate contact with the œsophagus, are separated from it only by a little areolar tissue, and on the left side also, behind the subclavian artery, by the thoracic duct (Fig. 509, B). There, in thin bodies, the left pleura is very close to the œsophagus, and the thoracic duct may occasionally be seen through the pleural membrane. Below the arch of the azygos vein the right pleura clothes the right side of the œsophagus—and very often even a considerable portion of its posterior surface too, thus forming a deep recess behind it—almost as low down as the opening in the diaphragm. On the left side, below the level of the aortic arch, the left pleura comes in contact with the gullet for a short distance only immediately above the diaphragm (Fig. 509, E).

Variations.—The chief anomalies found in the œsophagus are: (1) Annular or tubular constrictions; (2) diverticula, of which the most interesting are situated on the posterior wall close to its junction with the pharynx; (3) doubling in part of its course; and (4) communication between the trachea and œsophagus.

Structure of Œsophagus (Fig. 512).

—The œsophageal wall is composed of three proper coats—(1) *muscular coat*, (2) *submucous coat*, and (3) *mucous coat*; in addition, it is surrounded by an outer covering of fibro-areolar tissue—(4) *adventitious coat*—by which it is loosely connected to the various structures related to it in its course. That loose covering permits of its free movement and of its increase or diminution in width, during the act of swallowing.

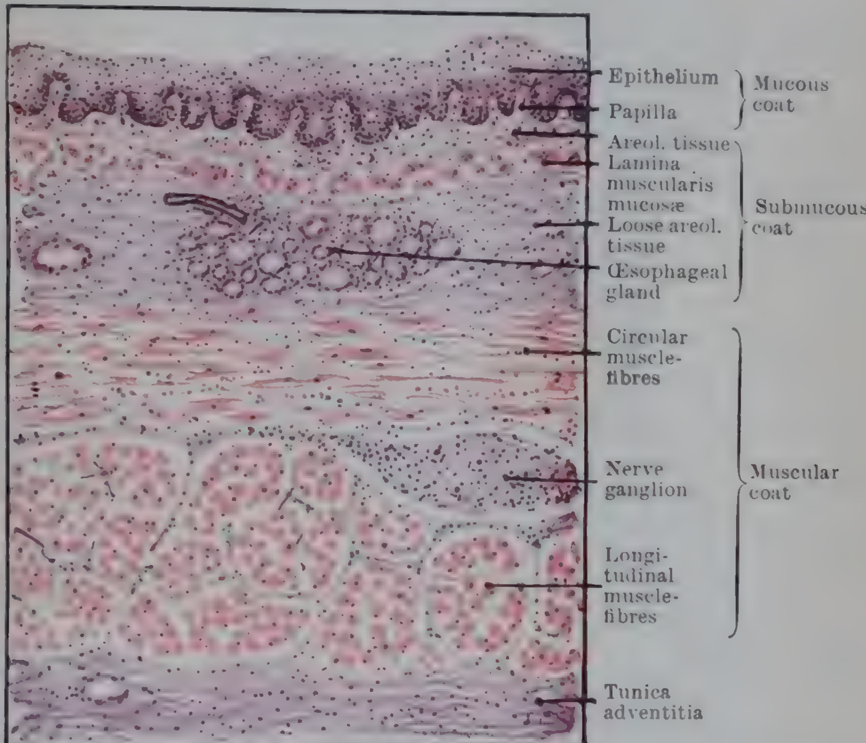

FIG. 512.—TRANSVERSE SECTION OF WALL OF HUMAN ŒSOPHAGUS.

The **muscular coat** is composed of two layers—an outer of longitudinal, and an inner of circular fibres. The *longitudinal layer* is highly developed, and, unlike the condition usually found in the digestive tube, it is as thick as the circular layer and in many places thicker. Along the greater length of the tube its fibres form an even covering and below they are continued into the longitudinal fibres of the stomach. Above, near the upper end of the œsophagus, the longitudinal fibres of each side, separating, at the back, pass round towards the anterior aspect and form two longitudinal bands (Fig. 510); these bands run up on the front of the tube, and are attached by a tendinous band to the ridge on the posterior surface of the cricoid cartilage (Fig. 511). Between these diverging muscular bands there is a thin, poorly supported area on the posterior wall where a protrusion of the mucous coat may occur and form an œsophageal diverticulum.

The *circular muscular fibres*, though not forming such a thick layer as the longitudinal fibres, are nevertheless well developed. Below, they are continued into both the circular and oblique fibres of the stomach. Above, they are continuous with the inferior constrictor of the pharynx. The above account of the fibres of the upper end of the œsophagus is based on Abel (1913).

The longitudinal fibres for about the upper fifth of the tube are entirely striated; in the second fifth striated and plain are mixed; whilst in the lower three-fifths plain fibres only are present as a rule. The circular fibres are entirely striated for the first inch; after that, plain fibres appear; and in the lower two-thirds, only plain muscle-fibres are usually found. For an account of an anomalous case, that of a male negro, with striated muscle in the lower third of the œsophagus, see Arey & Tremaine (1933).

The longitudinal fibres are often joined by slips of plain muscle or of elastic fibres which spring from various sources, including the left pleura (*m. pleuro-œsophageus*), the bronchi (*m. broncho-œsophageus*), back of trachea, pericardium, aorta, etc. (Cunningham,

1876). These slips assist in fixing the œsophagus to the surrounding structures in its passage through the thorax, and they have been aptly compared to the tendrils of a climbing plant.

The **submucous coat**, composed of areolar tissue, is of very considerable thickness in order to allow of the expansion of the tube during swallowing. It connects the mucous membrane loosely to the muscular coat and admits of the former being thrown into folds when empty. In that coat are contained the numerous racemose mucous œsophageal glands which open into the cavity of the œsophagus (Fig. 512).

The **mucous coat** is of a greyish-pink colour, much paler than that of the pharynx, and of a firm and resistant texture. It is covered with a thick, stratified squamous epithelium, on the surface of which the openings of numerous glands are found. Inferiorly, its junction with the gastric mucous membrane is indicated by a distinct, irregularly dentated or crenated line which runs transversely round the tube. In carefully preserved specimens the smooth mucous membrane of the œsophagus above that line contrasts strongly with the mamillated gastric mucous membrane below.

The mucous coat is relatively inelastic, and being but loosely connected to the muscular coat by the submucosa, it is thrown into a series of longitudinal folds when the œsophagus is empty and contracted; hence the stellate lumen often seen in sections of the gullet.

Numerous racemose mucous glands—**œsophageal glands**—large enough to be seen distinctly with the naked eye, are found in the submucous coat and are fairly evenly distributed over the whole tube. In addition to them, other glands, resembling closely those of the cardiac end of the stomach, are found in the mucous membrane of certain portions of the œsophagus. They are entirely confined to the mucous coat and do not extend beyond the lamina muscularis mucosæ. These glands are specially numerous at the ends of the tube.

Vessels and Nerves.—Its **arteries** are numerous small branches derived, in the neck from the *inferior thyroid*, in the thorax from the *bronchial arteries* and *thoracic aorta*, and in the abdomen from the *left gastric artery*, and also from the *left phrenic*.

The **veins** form a plexus on the exterior of the œsophagus from which branches pass, in the lower part of the tube, to the *left gastric vein*, and, higher up, to the *azygos* and *thyroid veins*. There is thus established on the lower part of the œsophagus a free communication between the portal and systemic veins.

The **lymph-vessels** pass to the *lower deep cervical glands* and to the *posterior mediastinal glands*, many of which, of large size, are seen around the tube in the thorax.

The **nerves** are derived from the *recurrent laryngeal* branch of the vagus, from the *cervical sympathetic*, and from the *vagus* and *sympathetic* nerves in the thorax. According to Mitchell (1938) the *sympathetic* nerve-supply of the lower part of the œsophagus and gastro-œsophageal junction comes from (a) the sympathetic trunks between the 6th and the 9th or 10th thoracic ganglia, (b) the greater and occasionally the lesser splanchnic nerves, and (c) the plexuses around the left gastric and phrenic arteries. The *parasympathetic* supply is from the characteristic œsophageal plexus formed by the right and left vagus nerves (Fig. 965, p. 1135).

Radiographic Examination of Œsophagus.—The position and the movements of the œsophagus may be demonstrated by radiographic examinations made during the passage of paste opaque to X-rays (Pl. L, p. 593).

The close relation of the œsophagus to the back of the pericardium, and the interval between the œsophagus and the vertebral column at the same level, as seen in oblique lateral radiographs, are worthy of special note.

ABDOMINAL CAVITY

The abdominal cavity is that portion of the cavity of the trunk which lies below the diaphragm. Its wall is composed in part of bones, muscles, tendons, fascia, etc., and in the cavity lie the greater part of the digestive, urinary, and genital systems of organs, as well as blood-vessels, nerves, and other structures. The greater part of the internal surface of the wall of the cavity and of the external surfaces of the viscera is clothed with a continuous smooth membrane—the peritoneum. The contained organs lie in contact with one another or with the wall, and the so-called cavity is merely a potential space between the peritoneal surfaces of adjacent viscera. When air is admitted, the viscera fall away from one another and an actual space is formed in place of the capillary interval which exists between them under normal conditions.

In the following description the term **abdomen** or **abdominal cavity** is used to indicate the region enclosed by the muscular and bony walls, and the term **peritoneal cavity** the potential space inside the peritoneal membrane.

Shape.—In median section the cavity is of a more or less oval form, with the long axis vertical. The upper end is wider than the lower. In transverse section (Fig. 518) it is almost reniform, flattened from before backwards, and is encroached upon in the median plane posteriorly by the vertebral bodies to such a degree that the front of the vertebral column lies at no great distance from the back of the anterior abdominal wall (usually 2½ to 3 inches), while on each side of the vertebral column there is a deep recess occupied by the kidneys and portions of the intestine.

The abdominal cavity is divisible into the **abdominal cavity proper** and the **pelvis**. Vertical section of the trunk shows that the **pelvis** lies below and behind the abdominal cavity, of which it forms a funnel-shaped termination.

The **inlet of the pelvis** (Figs. 251, 252, pp. 282, 283), which separates these two divisions of the cavity, is bounded behind by the base of the sacrum, on each side by the iliac and pubic parts of the arcuate line, and in front by the pubic crests and the upper border of the symphysis. In the erect position the inlet is inclined backwards at an angle of 55 to 60 degrees with the horizontal. The two portions of the abdominal cavity meet at an angle, the abdomen proper extending almost vertically upwards from it, whilst the pelvic cavity slopes backwards and slightly downwards.

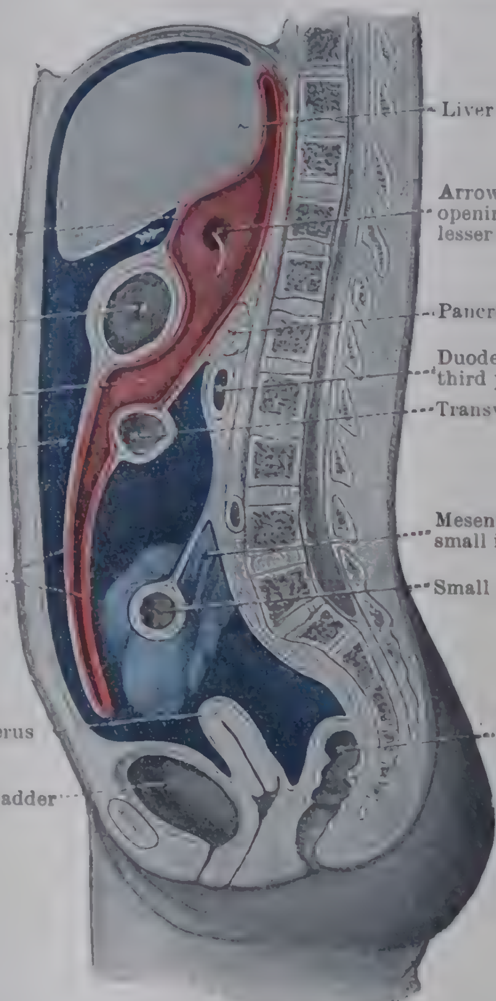

FIG. 513.—DIAGRAMMATIC MEDIAN SECTION OF FEMALE BODY TO SHOW ABDOMINO-PELVIC CAVITY AND PERITONEUM ON VERTICAL TRACING. The greater sac of peritoneum is blue and the lesser sac is red; both are represented much larger than in nature.

As the walls of the two regions are markedly different, the boundaries will be considered separately.

Boundaries of Abdomen Proper.—The **abdominal cavity proper** is limited *above* by the vault of the diaphragm, which presents a right and a left cupola separated by an intervening flatter portion which is slightly convex downwards. On the upper surface of each cupola is placed the base of the corresponding lung, whilst between them, on the flatter portion, rests the inferior surface of the heart.

During expiration the diaphragm ascends almost to the level of the right nipple and may reach the upper border of the fifth rib or even the middle of the fourth intercostal space; on the left side it is half an inch to an inch (12-25 mm.) lower; and in the median plane it is opposite the xiphi-sternal joint.

Whilst the circumference of the diaphragm is attached to the lower part of the thoracic framework anteriorly and laterally and to the lumbar vertebræ posteriorly, the central portion of the dome, formed by the central tendon, is placed high up, under cover of the ribs. As a result, the peripheral, muscular part slopes upwards and inwards from the circumference of the thoracic framework to the

central tendon and lies for a considerable distance in contact with the deep surface of the ribs; thus, the diaphragm not only comes to form the roof of the cavity but also enters into the formation of the sides, of the posterior wall, and, to a less extent, of the anterior wall; and *almost as much of the cavity of the abdomen as of the thorax lies under shelter of the ribs.*

The *anterior wall* is formed by the aponeuroses of the three pairs of wide abdominal muscles—obliquus externus, obliquus internus, and transversus abdominis—with the pairs of rectus and pyramidalis muscles alongside the median plane. Anteriorly, below the junction of abdomen and pelvis, lies the pubic symphysis. The body of the pubis looks upwards more than backwards, and supports the viscera contained within the anterior part of the abdominal cavity.

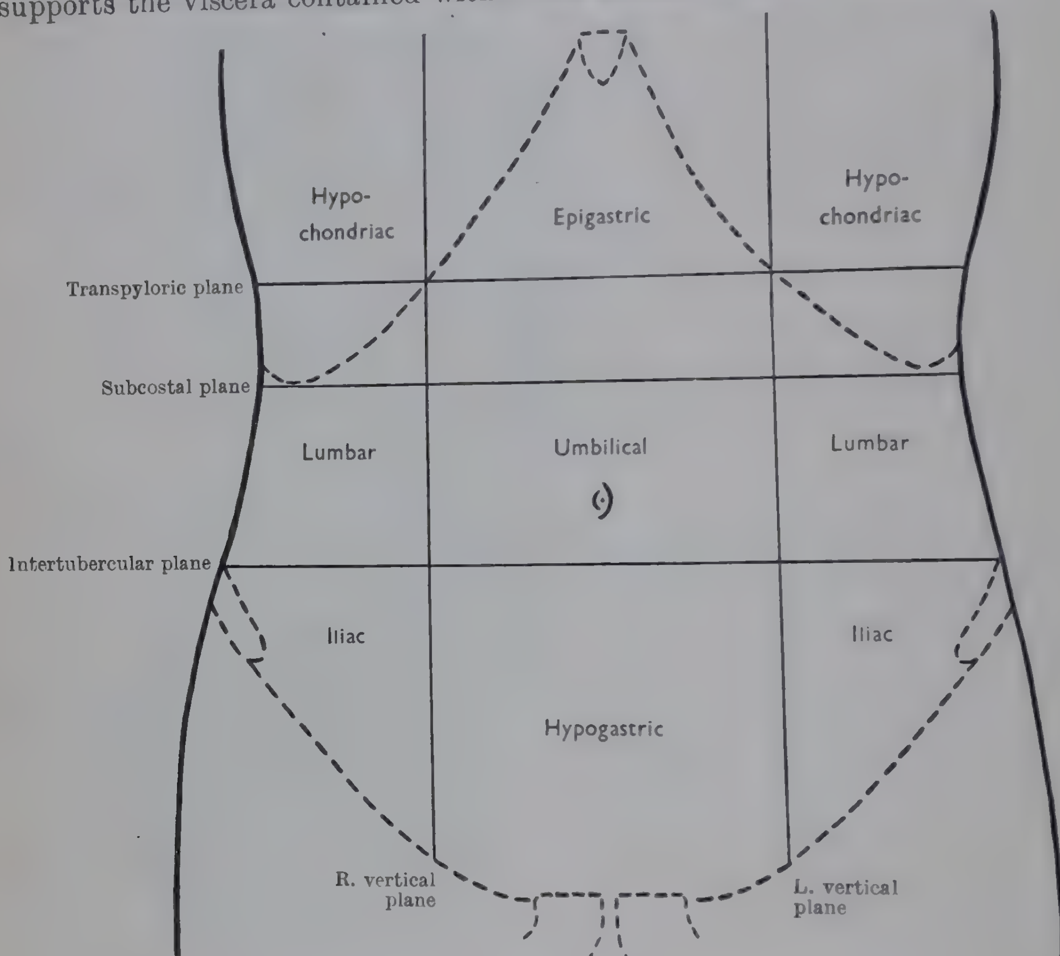

Fig. 514.—Planes of Subdivision of the Abdomen Proper, with the Names of the Nine Abdominal Regions.

The *side-walls* are formed by the muscular portions of the oblique and transverse muscles, and below by the iliac bones and the iliacus muscles.

The cavity is limited *posteriorly* by the lumbar portion of the vertebral column, with the crus of the diaphragm and psoas major muscle on each side, and the quadratus lumborum still more laterally. The iliac bones also enter into the formation of the inferior portion of the posterior wall.

The boundaries of the abdomen are formed chiefly of muscles which by contracting can alter the form and the size of the cavity. Its chief changes in form are due to the descent or elevation of the diaphragm, the contraction or relaxation of the anterior wall and the side-walls, and the raising or lowering of the pelvic floor.

The **pelvic cavity** is bounded ventrally and at each side by the portion of the hip bone below the level of the arcuate line, partly clothed by the obturator internus muscle and fascia down to the origin of the levator ani. The dorsal wall is formed by the sacrum and the coccyx in the middle, and on each side by the piriformis and coccygeus muscles covered with fascia. The floor is composed of the levatores ani. These muscles pass from the side-walls of the pelvis, down-

wards and medially towards the median plane, and present a concave superior surface towards the pelvic cavity.

The internal surfaces of the muscles immediately bounding the abdominal cavity proper and the pelvis are covered with a layer of fascia which separates them from the extraperitoneal areolar tissue and the peritoneum. That fascial layer is distinguished in different localities as: (1) the *transversalis fascia*, on the anterior wall and side-walls, lining the deep surface of the transversus abdominis muscle and continuous above with (2) the *diaphragmatic fascia* on the inferior surface of the diaphragm; (3) the *iliac fascia*, on the posterior wall, covering the psoas and iliacus muscles; and (4) the *fascia of the pelvic muscles* lining the pelvis.

Apertures.—Certain apertures are found in the muscular walls of the abdomen. They are: the three openings in the diaphragm for the passage of the inferior vena cava, the œsophagus, and the aorta; the apertures in the pelvic floor through which the rectum, the urethra, and, in the female, the vagina, reach the surface; the inguinal canal, through which the spermatic cord (or the round ligament) passes; and lastly, the femoral canal—a small passage which extends downwards from the abdomen along the medial side of the femoral vessels. The latter two, particularly, constitute weak points in the abdominal wall through which an inguinal or a femoral hernia may occur. Similar protrusions may occur at other points in the abdominal wall and also in the pelvic wall.

Extraperitoneal Tissue.—A considerable quantity of extraperitoneal areolar tissue more or less loaded with fat lies between the peritoneum and the fascia which covers the inner surfaces of the abdominal muscles. It is part of an extensive layer which lines the whole of the abdominal cavity, and may be regarded as divisible into a parietal and a visceral portion. The former lines the walls, whilst the latter passes between the layers of the peritoneal folds to the viscera. The extraperitoneal tissue contains a vascular plexus through which a communication is established between the vessels of the abdominal wall on the one hand and those of the contained viscera on the other, and also a network of nerve-fibres derived from sympathetic and cerebro-spinal nerves.

The *parietal portion* is thin and comparatively free from fat over the roof and anterior wall of the abdomen. In the pelvis the tissue is loose and fatty and is continued up for some inches on the anterior abdominal wall between the peritoneum and the transversalis fascia, and so permits of the ascent of the bladder during its distension. There also the median and lateral umbilical ligaments will be found passing up in its substance. On the posterior wall the tissue is large in amount and fatty, particularly where it surrounds the great vessels and the kidneys.

The *visceral expansions* are derived from the parietal portion in the form of prolongations around various branches of the aorta. These expansions are connected with the areolar coats of the blood-vessels and pass with them into the mesenteries and other folds of the peritoneum, and thus reach the viscera.

The chief uses of the extraperitoneal tissue are: (1) to unite the peritoneum to the fascial and muscular layers of the abdominal wall; (2) to connect the viscera to these walls and to one another in such a loose manner that their distension or relaxation may not be interfered with; (3) in addition, it is a storehouse of fat, forms sheaths for the vessels and nerves, and establishes, through its vascular plexus, communication between the parietal and visceral vessels.

Subdivision of Abdomen Proper.—Owing to the large extent of the area of the abdominal walls and the still greater size of the abdominal cavity, it is customary to subdivide the abdomen somewhat arbitrarily into nine regions. This is done by drawing two horizontal and two vertical lines on the surface, and by projecting the lines backwards as imaginary horizontal and sagittal planes in order to define various regions of the cavity. The names of these regions are given in Fig. 514, and they are of considerable practical value in locating the general position of the abdominal organs, and in describing and charting the situation of injuries, pain, tenderness and other abnormalities. (See also Fig. 1220, p. 1498.)

The planes most generally adopted and the lines at which they intersect the surface are the following :—

1. The *Subcostal Plane* (Cunningham, 1893). This corresponds to a surface line drawn round the trunk at the level of the lowest part of the costal margin seen or felt when the body is examined from the front. As a rule it passes through the most dependent parts of the tenth costal cartilages, at the level of the upper border of the third lumbar vertebra.

2. The *Transpyloric Plane* (Addison, 1899, 1900, 1901). This plane is of special practical value, and it may be used as an alternative to the subcostal plane in subdividing the abdomen. Its level is the mid-point of a line drawn, on the surface of the trunk, from the upper border of the sternum to the upper border of the pubic symphysis. This plane passes approximately midway between the xiphi-sternal junction and the umbilicus, at the level of the lower border of the first lumbar vertebra.

3. The *Intertubercular Plane* (Cunningham, 1893). This plane corresponds to a line joining the tubercles of the iliac crests, and lies at the level of the fifth lumbar vertebra. It should be noted that although the tubercle of the crest of the ilium is the most prominent lateral landmark in this region, it is not situated at the highest part of the iliac crest, which lies farther back at the level of the fourth lumbar vertebra.

4. The *Vertical Planes*. These are sagittal planes and correspond to vertical lines drawn on each side of the anterior median line midway between the anterior superior iliac spines and the median line. Each of these planes passes through the ninth costal cartilage near its tip, and through the inguinal ligament about ½ an inch (12 mm.) medial to its mid-point.

Contents of Abdomen.—The following structures are found within the abdomino-pelvic cavity :—

1. The greater part of the *alimentary canal*, viz., stomach, small intestine, and large intestine.
2. *Digestive glands:* the liver and pancreas.
3. *Ductless glands:* the spleen and the suprarenal glands.
4. *Urinary apparatus:* the kidneys, ureters, bladder, and part of urethra.
5. The internal *generative organs*, according to the sex.
6. *Blood-vessels* and *lymph-vessels* and *lymph-glands.*
7. The abdominal portions of the *cerebro-spinal* and *autonomic nervous systems.*
8. Certain *fœtal remains.*
9. The *peritoneum*—the serous membrane which lines the cavity, and is reflected over most of its contained viscera.

PERITONEUM

The **peritoneum** is the serous membrane which lines the abdominal cavity and invests most of the abdominal viscera to a greater or less degree. The cavity within this complicated serous sac is called the *peritoneal cavity.* Like other serous membranes, the peritoneum is composed of a thin layer of fibro-elastic tissue, covered with flattened endothelial cells. Like other serous sacs, also, the peritoneal cavity in the male is a completely closed sac, but in the female the *pelvic opening* of each uterine tube is a breach in it, whilst the *uterine opening* of that tube communicates with the interior of the uterus, and thus, indirectly, with the exterior of the body. Normally the membrane secretes only sufficient moisture to lubricate its surface; otherwise the sac is empty, and its opposing walls lie in contact, thus practically obliterating its cavity.

The serous lining of the abdomen permits of the movements of the contained viscera during any changes in size or form which they may undergo, and the stomach and intestines are free to move with a minimum of friction.

The peritoneum which covers an organ is termed *visceral peritoneum*; and it is united so intimately to many of the viscera that it appears at first sight to be a superficial layer of these organs rather than a separate membrane. Peritoneum which lines the walls or forms folds connected with viscera is termed *parietal peritoneum.*

In the adult the arrangement of the peritoneum is complicated by the changes which occur in the form and position of many of the viscera during their development, and it is necessary to explain briefly some of the changes which modify its original simple arrangement.

The peritoneum represents the smooth lining membrane of the abdominal part of the body-cavity or cœlom. Some of the abdominal viscera as, for example, the kidneys, lie dorsal to the membrane on the posterior body-wall, with only their ventral surfaces in contact with the lining membrane. The greater part of the intestinal tube, on the other hand, projects forwards, carrying the peritoneum with it, into the peritoneal cavity; but it remains connected with the dorsal wall by extraperitoneal tissue, containing nerves, blood-vessels and lymph-vessels. These

structures are covered on each side by a thin peritoneal membrane, continuous in front with the peritoneum which surrounds the intestine, and behind with that surrounding the peritoneal cavity.

Organs that show the first relationship are said to lie "behind" the peritoneum, or to be "partly invested" by it, while those of the second relationship are said to be "completely invested" and to have a 'mesentery' which connects them to the abdominal wall.

The intestine originally has a continuous dorsal mesentery, and, in addition, its proximal portion is connected to the ventral wall above the level of the umbilicus by a ventral mesentery; but as it develops it alters in position and form, and the mesenteries grow or become stretched.

The liver, for example, enlarges within the ventral mesentery, and the spleen makes its appearance and grows within the original dorsal mesentery of the stomach; and so the original ventral mesentery passes from the stomach to the liver and from the liver to diaphragm, and the dorsal mesentery of the stomach passes from stomach to spleen and from spleen to left kidney (Fig. 572, p. 677).

Mesenteries are sheets of extraperitoneal tissue (covered on each side with peritoneum) which unite portions of the intestine to the posterior abdominal wall and convey to them their vessels and nerves. There are several mesenteries, viz., the *mesentery proper*, which connects the jejunum and ileum to the posterior abdominal wall, the *transverse mesocolon* (mesentery of the transverse colon), the *pelvic mesocolon* (mesentery of the pelvic colon), mesentery of the appendix vermiformis, and occasionally others (see p. 604).

The term **omentum** is applied to two folds of similar structure derived from the embryonic ventral and dorsal mesenteries of the stomach, which in the adult pass from the stomach, one to the liver—the *lesser omentum*—and the other to the transverse colon—the *greater omentum*.

Greater Omentum.—The greater omentum, a large apron-like fold of peritoneum, usually more or less loaded with fat, is attached to the greater curvature of the stomach and hangs down in front of the intestines to a variable extent. When the abdomen is carefully opened without disturbing the viscera, it is rare to find the greater omentum evenly spread over the front of the intestines. More commonly it is folded in between some of the coils of intestine or is tucked into the left hypochondrium; or perhaps it is carried upwards in front of the stomach by a distended transverse colon. The greater omentum extends between the greater curvature of the stomach above and the transverse colon below, not taking the shortest course from the one to the other but hanging down as a loose fold and containing between the anterior and posterior sheets a part of the lesser sac of peritoneum (Figs. 503, 506).

The greater omentum consists of two sheets, each formed of two layers of peritoneum enclosing fat and areolar tissue. The **anterior** or **descending sheet** begins at the greater curvature of the stomach, where it is formed by the meeting of the layers from the anterior and posterior surfaces of that organ. Thence it descends across the front of the transverse colon (to which it is often adherent, either in part or as a whole). Leaving the colon (see Fig. 503), the two layers proceed to the lower border of the omentum, where, turning back, they pass up as the **posterior** or **ascending sheet**, which runs upwards until it meets the transverse colon. There its two layers separate to enclose that colon—and the greater omentum, properly so called, ceases. The two layers, however, unite at the upper margin of the colon to form the **transverse mesocolon**, which is continued upwards and backwards to the lower border of the pancreas. There, the layers of the transverse mesocolon again separate—the upper running upwards over the anterior surface of the pancreas to the posterior abdominal wall behind the cavity of the lesser sac; the lower passing downwards on the posterior abdominal wall from which it is again reflected as the mesentery.

The greater omentum is continued to the right for a short distance (one inch) along the lower border of the first part of the duodenum. At the left end it shortens very much, and is directly continued into the gastro-splenic ligament; the spleen, as it were, being introduced between the two layers instead of the colon.

The greater omentum contains, between the two layers of its anterior sheet, the greater part of the right and left gastro-epiploic arteries and their accompanying veins, as well as lymph-vessels and nerves. The special interest of the upper part of this sheet is that through it access may be obtained to the part of the lesser sac which is behind the stomach.

The amount of fat contained between its layers is variable, and may be very large in adipose subjects, and almost none in spare ones. It is often fenestrated and may be a fine lace-like net. On its surface there may be milk-like spots formed by accumulations of a special variety of lymphoid cells termed *histiocytes*.

Functions of Greater Omentum.—Numerous uses have been assigned to the greater omentum; the chief seem to be: (1) To act as a movable and easily adjustable packing material, capable of filling all spaces produced temporarily in the abdomen. In this respect it may be compared with the fatty pads in joints. (2) It probably, to some extent, prevents the passage of the small intestines up into the stomach-chamber and helps to keep them from becoming entangled there. (3) It is a storehouse of fat. (4) It is said to be "the great protector against peritoneal bacterial invasions"; being freely movable, it can pass to almost any part of the abdomen, and there "build up barriers of exudations to check infection".

Lockwood (1889) made the interesting observation (in connection with the contents of herniæ), that in bodies under forty-five years of age the omentum can rarely be drawn down below the level of the pubic tubercle; in older bodies the reverse is the rule.

Lesser Omentum.—The lesser omentum is a peritoneal membrane which passes from the inferior and posterior surfaces of the liver to the stomach and duodenum (Fig. 525). Its structure, contents, and attachments are as follows:—

The portion that lies to the left is thin, translucent, and sometimes fenestrated, and it extends from the lesser curvature of the stomach to the left end of the porta hepatis and to the fissure for the ligamentum venosum. It contains the right and left gastric arteries and accompanying veins and lymph-vessels, some lymph-glands, and filaments from the anterior gastric nerve which go to the liver. The right portion is thicker and stronger and passes from the first part of the duodenum to the porta hepatis. On the right it ends in a rounded margin. Traced downwards, the layers of peritoneum which form it clothe the commencement of the duodenum on two sides. In it lie the hepatic artery, the portal vein, and the bile-duct, with lymph-vessels and nerves.

The lesser omentum occasionally extends still farther to the right and forms a thin membrane that connects the gall-bladder to the transverse colon and right flexure of the colon. This portion is termed the *hepato-colic ligament*.

The **gastro-splenic ligament** is a short fold attached by one margin to the fundus and greater curvature of the stomach, and by the other to the gastric surface of the spleen immediately in front of the hilum. Between its two layers the short gastric branches of the splenic artery pass from the spleen to the stomach. Below and in front, its layers are continued into the corresponding layers of the greater omentum; above and behind, they separate at the "bare area" of the stomach (Fig. 538, p. 630).

The **lieno-renal ligament** is a short fold that stretches from the front of the left kidney to the hilum on the visceral surface of the spleen (Fig. 517, p. 608). Its medial layer becomes continuous there with the medial layer of the gastro-splenic ligament; and its lateral layer is continuous with the peritoneal covering of the spleen. The splenic vessels and nerves lie between its layers.

The **gastro-phrenic ligament** is a short fold reflected from the under surface of the diaphragm on the left side of its œsophageal opening to the posterior surface of the fundus of the stomach. It is merely a fold on the peritoneum which passes from the diaphragm to this part of the stomach.

The **mesentery** is described on p. 634.

The **mesentery of the vermiform appendix** is a small triangular fold attached by one margin to the whole length of the appendix, by another to the under surface of the mesentery close to the termination of the ileum, while the third margin is free. The vessels to the appendix are found in it.

The **transverse mesocolon** is a typical mesentery containing a considerable thickness of extraperitoneal tissue as well as the middle colic vessels and branches from the right and left colic vessels and nerves and lymph-vessels. Its root extends horizontally over the posterior abdominal wall from the right to the left colic flexure across the second part of the duodenum and the head of the pancreas and along the lower border of the body of that organ.

The **pelvic mesocolon** is described on p. 647.

Other folds, specially named, but described elsewhere, are the right and left gastro-pancreatic folds (p. 617) and the ligaments of the liver (p. 659).

Peritoneal "Adhesions" and Variations.—In addition to the peritoneal folds which have been mentioned, many other peritoneal bands and folds are sometimes found. (1) The gall-bladder is often united to the first part of the duodenum by a dense, strong layer of fibrous tissue which blends with the lateral part of the lesser omentum. (2) The duodeno-jejunal junction is occasionally firmly joined by similar bands to the transverse mesocolon. (3) Around the cæcum, vermiform appendix, terminal part of the ileum, and lower part of the ascending colon, it is common to find bands of fairly dense tissue passing (*a*) from the colon to the lateral abdominal wall, (*b*) from the terminal portion of the ileum to the cæcum, (*c*) from the cæcum itself to the parietes. Such bands are usually ascribed to "peritonitis". (4) The greater omentum may be united to the anterior surface of the ascending colon. (5) Fibrous bands often pass from the left side of the lower part of the descending colon to the parietes. They have been ascribed to faults in development, to peritonitis, and to mechanical traction; but it is not possible to state definitely the exact mode and cause of their origin.

Peritoneal Folds and Recesses.—In certain places there are small folds of peritoneum which bound recesses or pockets of the peritoneal cavity (pp. 631, 642, 647). Some of these may become the seat of an 'internal' or retroperitoneal hernia.

CAVITY OF PERITONEUM

The peritoneal cavity is described as consisting of two portions—the general peritoneal cavity or **greater sac** and the **lesser sac**. The greater sac is opened when the anterior abdominal wall is removed or incised; the lesser sac is chiefly behind the stomach and in the greater omentum, and it is much smaller. The two sacs are not separate cavities, for the lesser sac is merely a recess of the greater sac, formed by changes that take place in the position of the viscera and their mesenteries during development. If the general peritoneal cavity is compared to a bag, the lesser sac might be represented as a pocket lying behind it and opening into it by a narrow orifice.

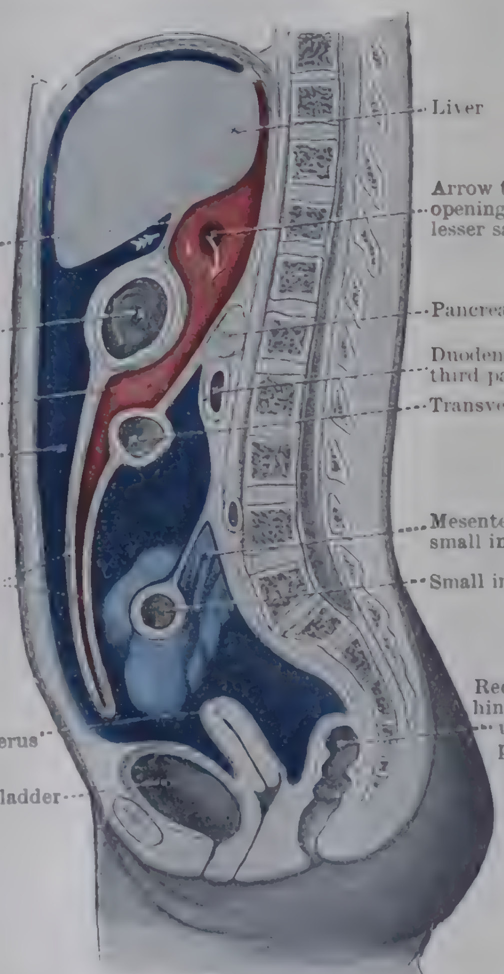

Fig. 515.—Diagrammatic Median Section of Female Body to show Abdomino-Pelvic Cavity and Peritoneum on vertical tracing. The greater sac of peritoneum is blue and the lesser sac is red; both are represented much larger than in nature.

Greater Sac of Peritoneum.—The general peritoneal cavity is placed between the parietes anteriorly and the abdominal viscera posteriorly. It is bounded anteriorly by the parietal peritoneum on the posterior aspect of the anterior abdominal wall, and posteriorly partly by the visceral peritoneum covering the viscera and partly by the parietal peritoneum on the posterior abdominal and pelvic walls.

Anterior Wall of General Peritoneal Cavity.—The anterior abdominal wall is covered completely with parietal peritoneum from the diaphragm to the pelvis. Over the greater part of its extent it is connected to the wall by a small amount of fatty extraperitoneal

areolar tissue; but below, near the pubic region, the fat is more abundant and the connexion between the two becomes much looser.

In this tissue there are five cord-like structures—one in the median plane, and two at each side. They are (*a*) the **median umbilical ligament** (*urachus*)—the remains of the allantois of the fœtus—which in the adult is a slender fibrous band connected to the umbilicus above and to the apex of the bladder below, where it usually becomes much stouter. At the sides of the median ligament, and some distance from it (Figs. 556, p. 651, and 625, p. 744), (*b*) a pair of stouter fibrous cords—the **lateral umbilical ligaments**—pass upwards and medially. They become more slender as they approach the median ligament, along with which they are connected to the umbilicus. Below, they grow thicker, and each can be followed backwards along the side-wall of the true pelvis to the internal iliac artery, which they join. The lateral umbilical ligaments are obliterated portions of the **umbilical arteries**, by which in the fœtus blood passes from the internal iliac arteries to the placenta. (*c*) More laterally still, the **inferior epigastric arteries** run upwards and medially from the external iliac trunks.

When the anterior abdominal wall is examined from behind, it will be seen that the five structures form five more or less distinct peritoneal ridges, known as the *median* and *lateral umbilical folds* and the *folds of the epigastric arteries*

Three pairs of shallow peritoneal fossæ are associated with these folds—one lateral to each fold. The most lateral of them—the one lateral to the epigastric artery—corresponds to the position of the deep inguinal ring. At its bottom, a dimple-like depression of the peritoneum indicates the point from which the processus vaginalis passed down during the descent of the testis.

Between the epigastric artery laterally, the margin of the rectus abdominis muscle medially, and the inguinal ligament below, there is a small triangular region called the **inguinal triangle.** The lateral umbilical ligament, in passing upwards, crosses this triangle and divides it into a lateral and a medial part; the intermediate one of the three fossæ mentioned above corresponds to the lateral division of the triangle.

Still another fossa of the peritoneum is seen in that region, just beneath the medial part of the inguinal ligament, corresponding to the position of the femoral ring; the vas deferens crosses its lateral part and the lateral umbilical ligament its medial part.

Near the median plane, above the umbilicus, the peritoneum is carried back from the anterior abdominal wall and diaphragm to the parietal surface of the liver in the form of a crescentic fold—the **falciform ligament** of the liver—which is described with that organ. The fold lies a little to the right of the median plane, and extends almost as low as the umbilicus. It consists of two layers of peritoneum between which, in the lower border of the fold, runs the round ligament of the liver—the remains of the umbilical vein of the fœtus.

Posterior Wall of General Peritoneal Cavity.—The peritoneum of the anterior abdominal wall is continued on to the inferior surface of the diaphragm. Thence it is reflected on to the superior surface of the liver, covers the anterior surface, turns round its inferior border, and is continued backwards on its inferior surface as far as the attachment of the lesser omentum, where it is reflected, as the anterior layer of the lesser omentum, to the stomach and the duodenum (Fig. 515).

Having reached the lesser curvature of the stomach, it passes down over the front of that organ to the greater curvature. From that curvature it descends as the most anterior layer of the greater omentum. Arrived at the lower border of the greater omentum, the membrane returns on itself, and passes upwards towards the transverse colon, forming the most posterior layer of the omentum. After covering the posterior surface of the transverse colon it is continued, as the posterior layer of the transverse mesocolon, to the posterior abdominal wall, which it reaches at the lower border of the pancreas (Fig. 515).

From the lower border of the pancreas it is continued downwards again, clothing first the lower surface of the pancreas, then the front of the third and fourth portions of the duodenum, and, below that, the posterior abdominal wall. But it is soon carried forwards again by the branches of the superior mesenteric vessels passing to the small intestine. Running out along those, it forms the right layer of the mesentery (Fig. 552): on reaching the small bowel at the border of the mesentery, it invests that tube, giving it its serous coat, and then returns—as

the left layer of the mesentery—to the posterior abdominal wall, on which it runs down, covering the great vessels near the median plane and the psoas major muscle and ureter at each side, to enter the pelvis.

Pelvic Peritoneum.—The arrangement of the peritoneum in the true pelvis is different in the two sexes, and is described in connection with the pelvic viscera.

Transverse Tracing of Peritoneum.—If the peritoneum is followed transversely around the abdomen just above the level of the iliac crest (Fig. 518), few difficulties will be encountered. From the anterior abdominal wall it passes round on each side to the back, lining the sides and the posterior wall. Passing medially on the posterior wall, it meets the colon—ascending on the right side, descending on the left—over which it is carried, in each case covering the bowel in front and at the sides only and leaving the posterior surface bare as a rule. Sometimes, however, the covering is complete and a short mesentery is formed. It is next

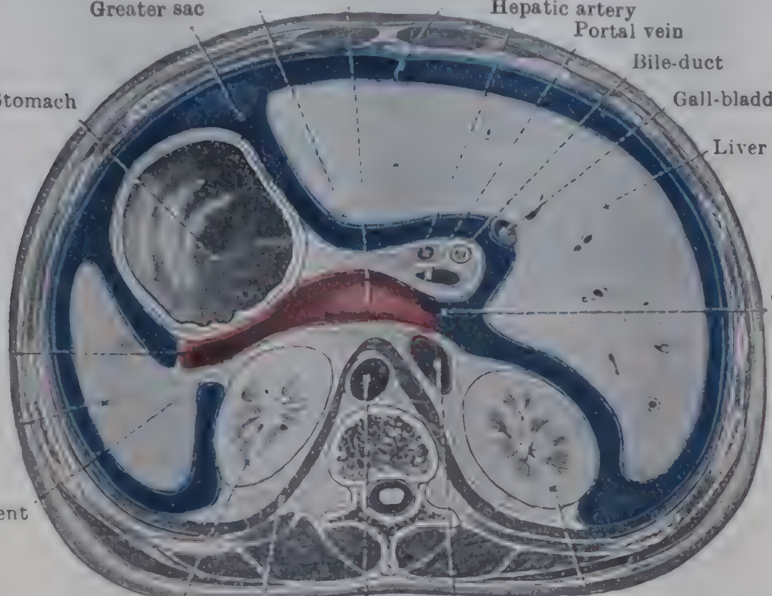

Fig. 516.—Transverse Section of Abdomen at Level of Opening into Lesser Sac of Peritoneum.

continued *medially* over the psoas muscle, the ureter, and the great vessels, on the front of which it meets the superior mesenteric artery and vein. From both sides it passes forwards on those vessels, forming the right and left layers of the mesentery; and finally, having reached the intestine, it clothes it completely, and the two portions become continuous on the bowel.

Transverse tracings at a higher level would include the lesser sac; it will therefore be well if we describe this portion of the peritoneal cavity before directing attention to such tracings.

Lesser Sac of Peritoneum.—The lesser sac is behind the stomach, lesser omentum and part of the liver, and in the greater omentum; and it communicates with the greater sac by a narrow mouth, on the right side, just below the liver, called the opening into the lesser sac. From the opening the lesser sac can be traced towards the left behind the lesser omentum and stomach as far as the spleen, upwards behind the caudate lobe of the liver, and downwards behind the stomach and into the greater omentum.

The **opening into the lesser sac** is situated just below and behind the porta hepatis. It is bounded *in front* by the right, free border of the lesser omentum passing up from the first part of the duodenum to the porta hepatis and containing between its two layers the portal vein, hepatic artery, and bile-duct. *Behind* lies the inferior vena cava, covered, of course, with peritoneum. *Above* is placed the caudate process of the liver. And *below* lies the first part of the duodenum with

the hepatic artery running forwards and to the right before turning up into the lesser omentum. It should be remembered that, normally, the various boundaries of the opening are in contact with one another, and that its cavity can be said to exist as such only when its walls are drawn apart.

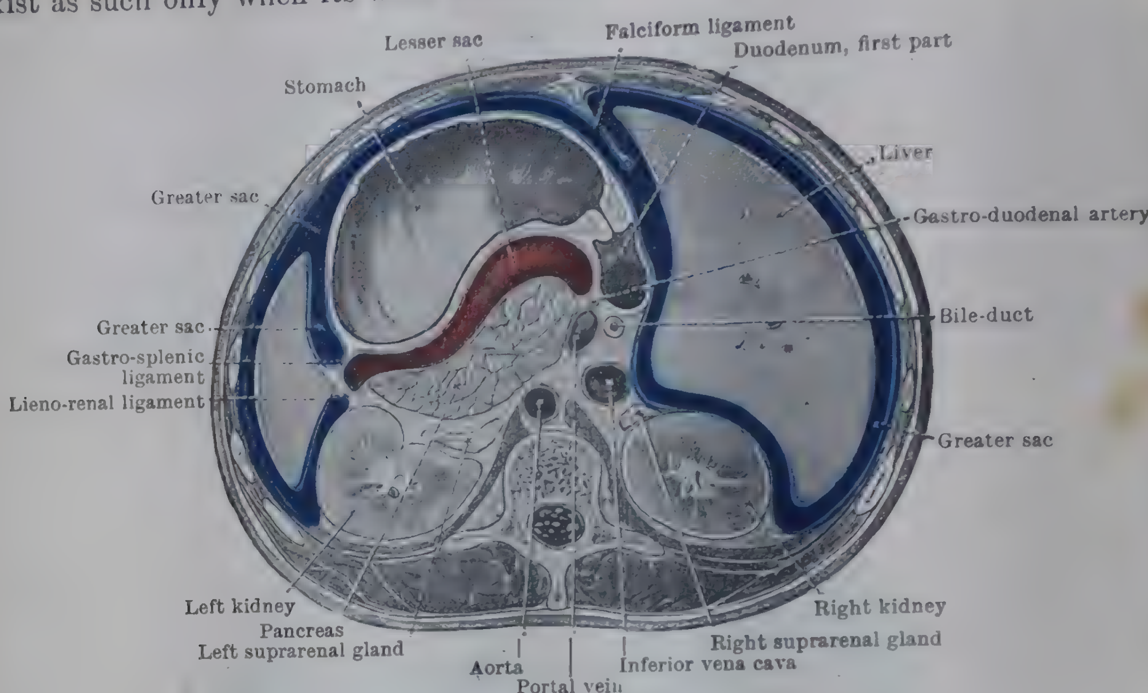

FIG. 517.—TRANSVERSE SECTION OF ABDOMEN IMMEDIATELY BELOW OPENING INTO LESSER SAC OF PERITONEUM.

To the left of the opening, there is a small portion of the lesser sac, termed the *vestibule*, which lies below the caudate process of the liver and above the first part of the duodenum and the head of the pancreas. The anterior wall of that portion is formed by the hepato-duodenal part of the lesser omentum, with the bile-duct, hepatic artery, and portal vein.

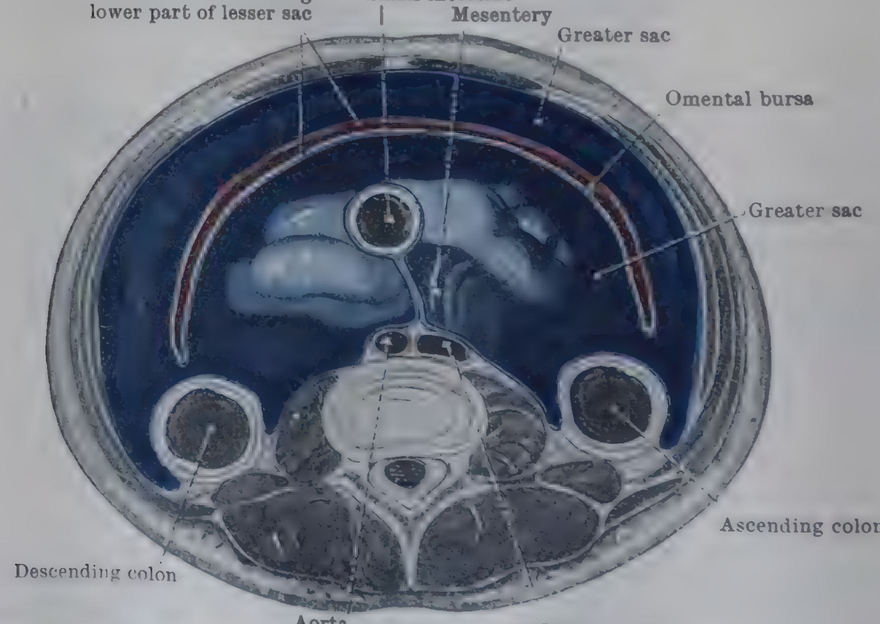

FIG. 518.—TRANSVERSE SECTION OF ABDOMEN THROUGH FOURTH LUMBAR VERTEBRA.

The vestibule is continued into the true lesser sac, which presents two recesses—upper and lower. The **upper recess** passes from the vestibule upwards behind the porta hepatis and the caudate lobe, in front of the diaphragm. The **lower recess** passes in front of the pancreas and behind the stomach towards the spleen (Fig. 517).

The lower recess and the vestibule of the lesser sac communicate with each other by a rounded orifice which is constricted by the sickle-shaped, forward-projecting *gastro-pancreatic*

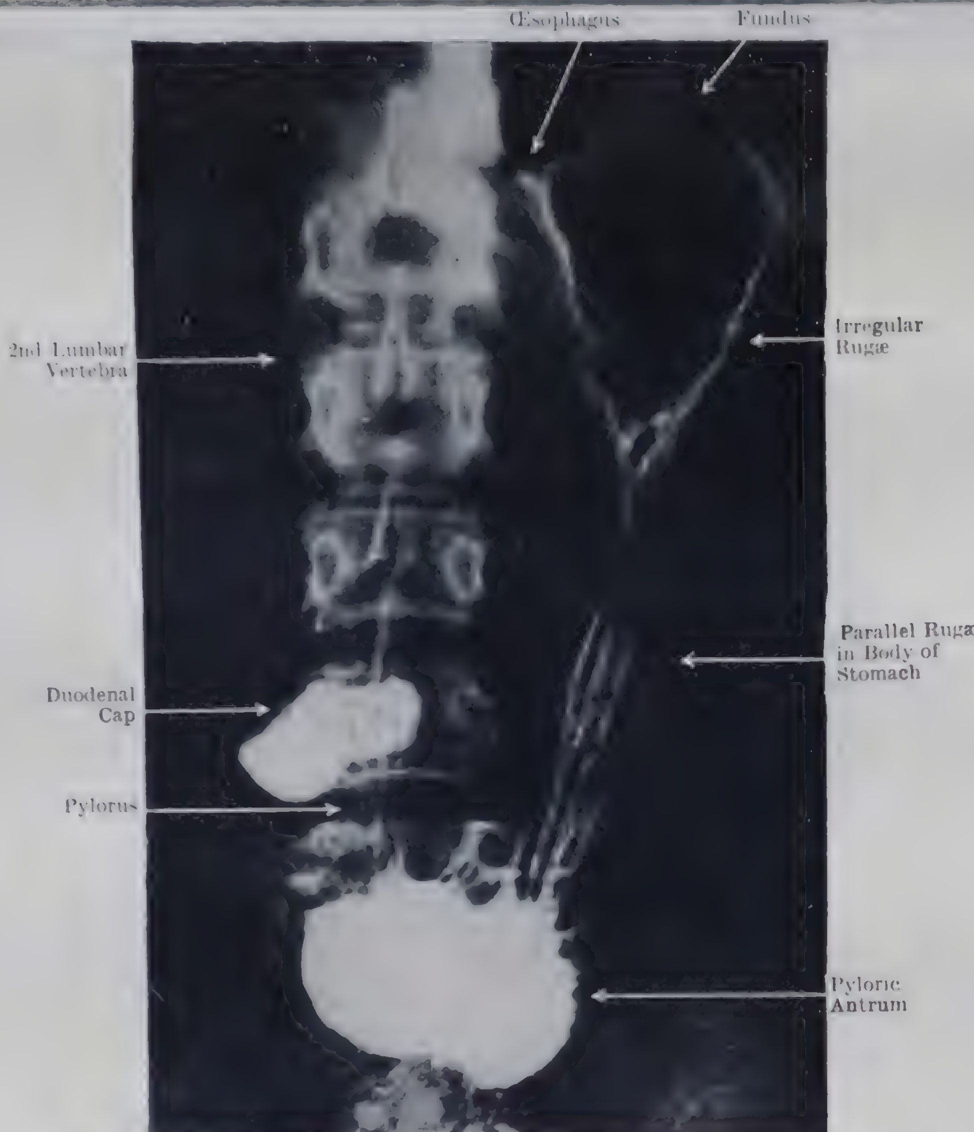

FIG. 1.—RADIOGRAPH OF NORMAL J-SHAPED STOMACH (WOMAN, AGED 39), SHOWING THE GASTRIC RUGÆ MADE EVIDENT BY A SMALL AMOUNT OF BARIUM.

Note the tubular appearance of the body of the stomach with parallel rugæ, the collection of barium in the most dependent part of the stomach, and that some of it has passed into the small intestine to form a well-defined duodenal cap.

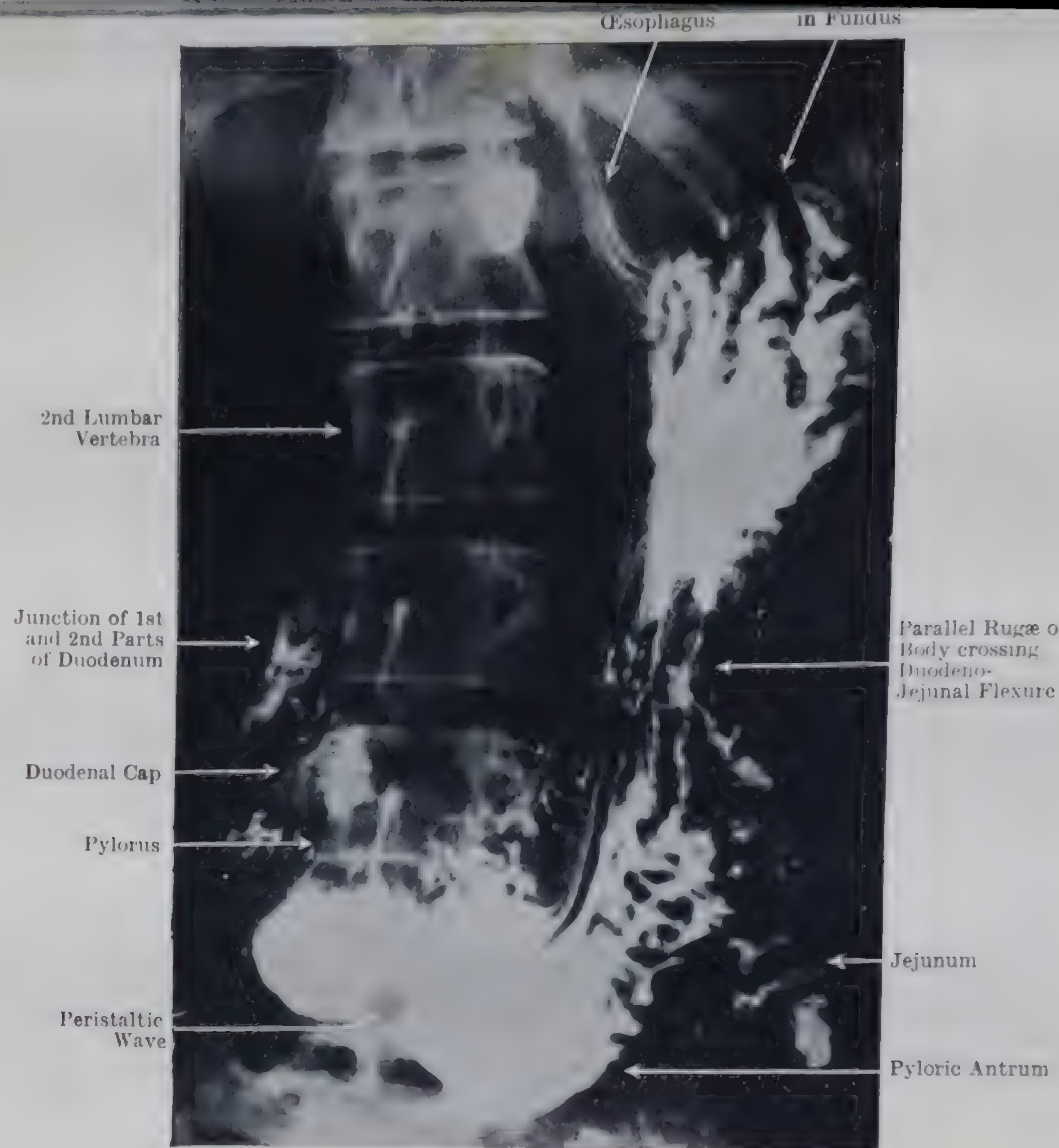

FIG. 2.—RADIOGRAPH OF NORMAL J-SHAPED STOMACH (WOMAN, AGED 41) WITH MORE BARIUM THAN IN FIG. 1.

Note the irregularity of the rugæ in the fundus, the irregular outline of the greater curvature in the lower part of the body, and the presence of a peristaltic wave.

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PLATE LII

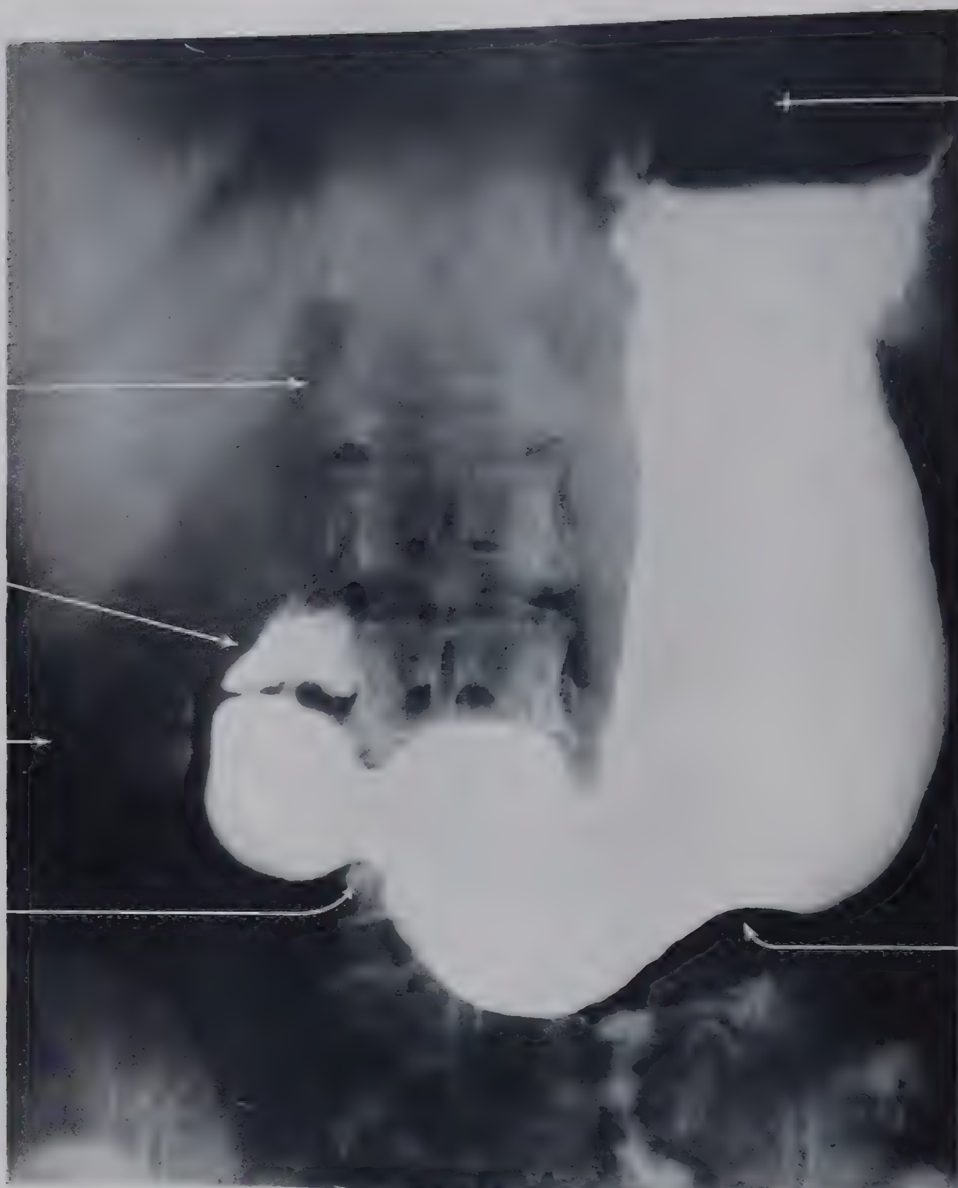

PLATE LII.—RADIOGRAPH OF J-SHAPED STOMACH OF WOMAN AGED 62, TAKEN IN THE ERECT POSTURE A FEW MINUTES AFTER AN OPAQUE MEAL.

Note the low position of the Greater Curvature and of the Pylorus. Cf. Plates LIII and LIV, p. 612. The Gall-Bladder, intercepting the X-Rays because of calcification in its wall, is seen in relation to the Pylorus. For the position of the gall-bladder see also Plate LX, p. 649.

folds. Those folds are elevations of the peritoneum of the posterior wall of the lesser sac raised up by the left gastric and hepatic arteries as they pass forwards from the posterior wall to the stomach and duodenum respectively (p. 617). The nature and variation of these folds (which may even, though rarely, be continuous, thus dividing the lesser sac) have been studied by Crymble (1913); whilst Reid (1913) has given an account of their disposition in the human fœtus.

As the peritoneal wall of the lesser sac is described in two main parts—an anterior and a posterior—it will be necessary to follow each of them separately. The peritoneum which forms the **anterior wall** clothes the caudate lobe of the liver; it then passes down from the posterior margin of the porta hepatis and the fissure for the ligamentum venosum to the lesser curvature of the stomach and the duodenum as the posterior layer of the lesser omentum. It then clothes the posterior surface of the stomach as far as the greater curvature, with the exception of the small "bare area" below and to the left of the cardiac orifice (Fig. 538). On the left, it is reflected from the back of the stomach to the spleen as the deeper layer of the gastro-splenic ligament. From the greater curvature of the stomach it is continued down as the posterior layer of the anterior sheet of the greater omentum, and, at the inferior part of the omentum, it meets and becomes continuous with the posterior wall of the lesser sac.

The peritoneum which forms the **posterior wall of the lesser sac** clothes the front of the inferior vena cava (Fig. 516), covers the cœliac artery, and passes upwards to cover the diaphragm behind the caudate lobe of the liver. Passing to the left, it covers the anterior surface of the pancreas, the suprarenal gland, and a portion of the left kidney, from which it is reflected to the spleen as the deep layer of the lieno-renal ligament (Fig. 517). From the pancreas it is prolonged downwards—as the anterior layer of the transverse mesocolon—to the transverse colon (Fig. 515). Thence it is continued down as the anterior layer of the posterior sheet of the greater omentum almost to its inferior border, where it becomes continuous with the anterior wall of the lesser sac already described.

Transverse tracings at the levels of the opening into the lesser sac and of the pylorus are shown in Figs. 516 and 517 and can be easily followed without any further description.

STOMACH

The **stomach** (gaster) is a receptacle in which food accumulates after its passage through the œsophagus, and in it take place some of the earlier processes of digestion, resulting in the conversion of the food into a viscid fluid known as *chyme*. The chyme escapes through the pylorus into the small intestine, where the digestive processes are continued.

The form and the position of the stomach present great variations not only among different people but also in the same person at different times. The degree to which it is filled, the size and position of adjacent organs, the condition of the abdominal walls, and even the assumption of the erect or the recumbent attitude can influence its shape and relations.

General Shape.—In shape, the stomach is irregularly piriform, with a wide end that lies deeply in the hollow of the left cupola of the diaphragm, and a narrow tapering extremity which passes downwards and forwards and is bent over to the right side in the epigastric region.

The long axis of the organ forms a spiral curve directed downwards, forwards and to the right, and finally backwards.

The stomach has two surfaces—an anterior directed forwards, upwards, and to the left, and a posterior which looks backwards, downwards, and also to the right. These surfaces meet above and to the right at the **lesser curvature**, and below and to the left at the **greater curvature**. The œsophagus enters the stomach at the upper end of the lesser curvature, at the cardiac orifice, whilst at the lower end the stomach passes into the duodenum at the pyloric orifice. The dome-shaped portion above and to the left of the œsophagus is the **fundus**, and the remainder of the stomach is divisible into the **body** and the **pyloric portion**.

Cardiac Orifice.—The cardiac orifice is at the upper end of the lesser curvature, to the right of the fundus, and more on the anterior than the posterior surface of the stomach. The orifice is oval or angular rather than round, being compressed from side to side. Around the opening the muscular walls of the œsophagus and its mucous membrane become continuous with corresponding coats of the stomach-wall. The longitudinal muscular coat passes onwards into a longitudinal set of fibres, and the circular œsophageal fibres pass into the circular and oblique layers. The whitish stratified squamous epithelium of the œsophagus is continuous with the pinkish-coloured columnar epithelial wall of the stomach, and the junction is marked by a sharp, irregular line around the margin of the opening.

To the right of the orifice, the right margin of the œsophagus merges with a slight curve into the lesser curvature of the stomach, while on the left side there is a deep notch—the **cardiac notch**—between the end of the œsophagus and the fundus, in which lies a projecting ridge of the right crus of the diaphragm.

The cardiac notch on the outer surface produces a fold in the interior of the stomach, which may assist in closing the œsophageal opening, and that, with the decussating fibres of the diaphragm and the strengthened circular fibres of the lower end of the œsophagus, forms a kind of sphincter for this orifice which serves to prevent regurgitation from the stomach under ordinary conditions.

The cardiac orifice is very deeply placed—about four inches behind the seventh left costal cartilage—and is about one inch from the median line. Posteriorly it corresponds to the level of the body of the tenth thoracic vertebra.

Owing to the fixation of the œsophagus by its passage through the diaphragm, and the close connexion between the stomach and the diaphragm near the cardiac orifice where the peritoneum is absent, this is the most fixed part of the whole stomach.

Pyloric Orifice.—By the pyloric orifice the cavity of the stomach communicates with that of the duodenum. It is placed at the distal (right) extremity of the stomach, which is cylindrical in shape, and it is surrounded by a ring of thick muscle tissue named the **pyloric sphincter**. The term **pylorus** is applied to the area of the stomach which contains this sphincter.

The position of the pylorus is indicated to sight by a slight annular constriction on the external surface termed the *pyloric constriction*, and also by an arrangement of blood-vessels which is nearly constant. On the peritoneal surface a thick vein passes upwards from the lower side somewhat more than half-way on the anterior surface, and from the upper border a second vein (pre-pyloric vein) reaches downwards in the same line, nearly, if not quite, meeting the first (Mayo, 1908). The pylorus is also evident to touch—the thickening of the wall produced by the sphincter being readily distinguishable from the thinner wall of the pyloric canal on the proximal side and of the duodenum on the distal.

When the sphincter is in a state of contraction, the lumen of the outlet is a stellate fissure. A section through this part of the stomach (Fig. 521) shows that the mucous membrane which covers the sphincter slopes gradually into the lumen of the pylorus on the gastric side and abruptly or steeply at its duodenal end.

Viewed from the interior of the duodenum, the sphincter when contracted forms a dome-shaped elevation covered by the mucous coat and bulging into the duodenum, the centre of the dome being perforated by a narrow cylindrical depression—the pyloric orifice.

At the pylorus the peritoneal covering of the stomach is continued on to the first part of the duodenum, and the longitudinal fibres of the stomach are in part continued onwards into the longitudinal fibres of the duodenal coat, but many of them bend inwards into the thickened ring around the opening and spread out in diverging bundles which interlace with the circular fibres, and some of them reach and terminate in the subjacent submucosa (Cunningham, 1906).

The circular muscular fibres of the stomach are not continuous directly with those of the duodenum. On the contrary, at the pylorus they become very much increased in number, and they form the sphincter, which is separated from the circular muscular coat of the duodenum by a fibrous septum. The sphincteric ring is thus sharply marked off from the duodenum, but there is no sharp line of

demarcation on the gastric side, for it gradually merges into the circular muscular coat of the pyloric canal.

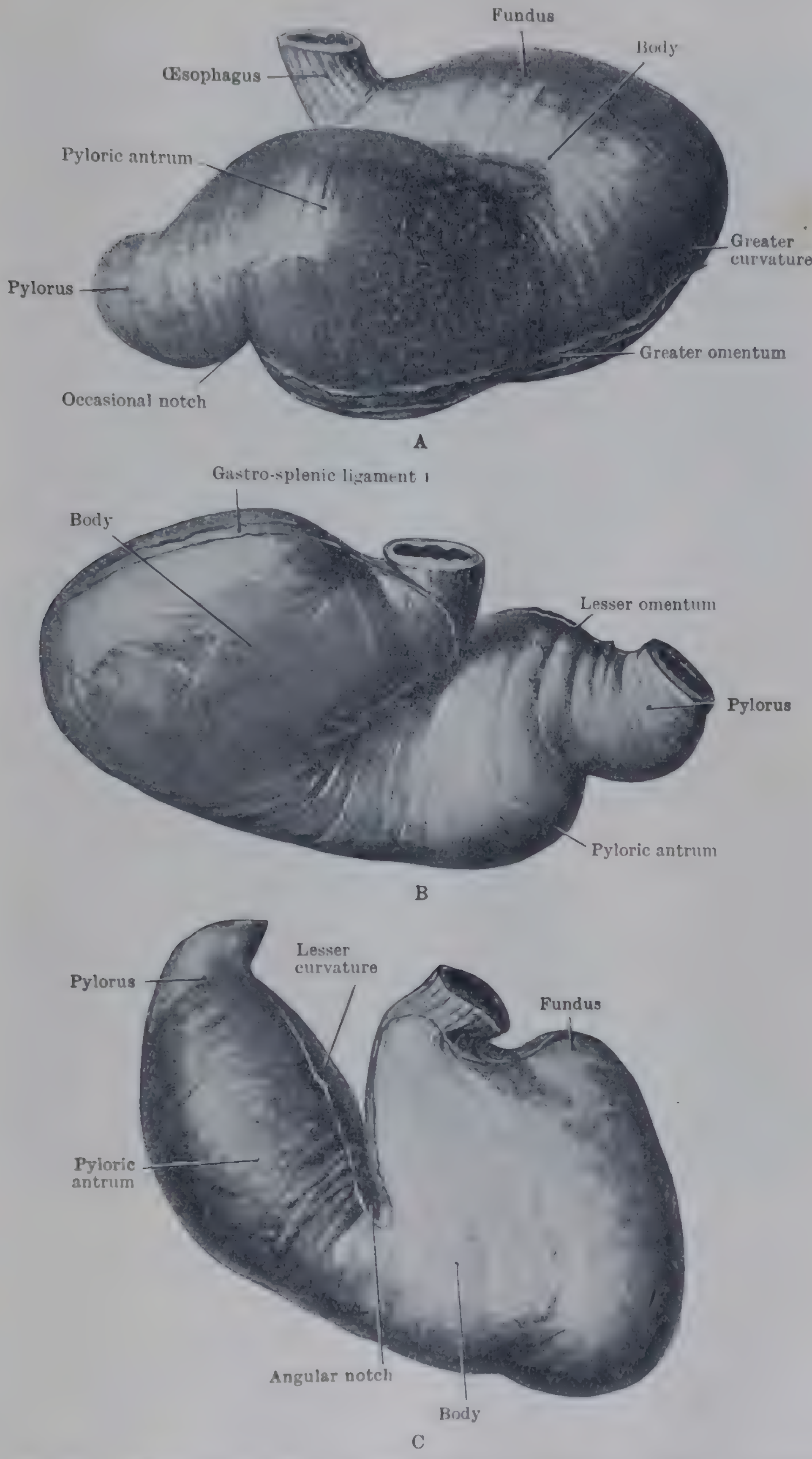

Fig. 519.—Three Views of a Stomach fixed by Formalin Injection *in situ*.
A. From the front. B. From the back. C. From above.

The orientation of the stomach was determined by the insertion of long pins into it in the sagittal, coronal, and transverse planes. These views show the comparatively horizontal position assumed by the stomach when the body lies supine. They also show the partial division into chambers produced by temporary constriction of the stomach wall fixed by the action of formalin.

The gastric mucous membrane (mucous coat), which is considerably thickened where it covers the sphincter muscle, is continued into the duodenum without any

alteration visible to the naked eye. When examined post mortem in the ordinary way, the gastro-duodenal aperture, viewed from the duodenal side, is more or less oval in form. When seen from the opposite side, it presents a stellate appearance, owing to the fact that the rugæ of the gastric mucous membrane are continued as far as the orifice.

The orifice is directed horizontally backwards and to the right. When the stomach is full, however, it looks almost directly backwards.

The pylorus rests on the neck of the pancreas below and posteriorly, and it is overlapped by the liver above and anteriorly. When the stomach is empty the

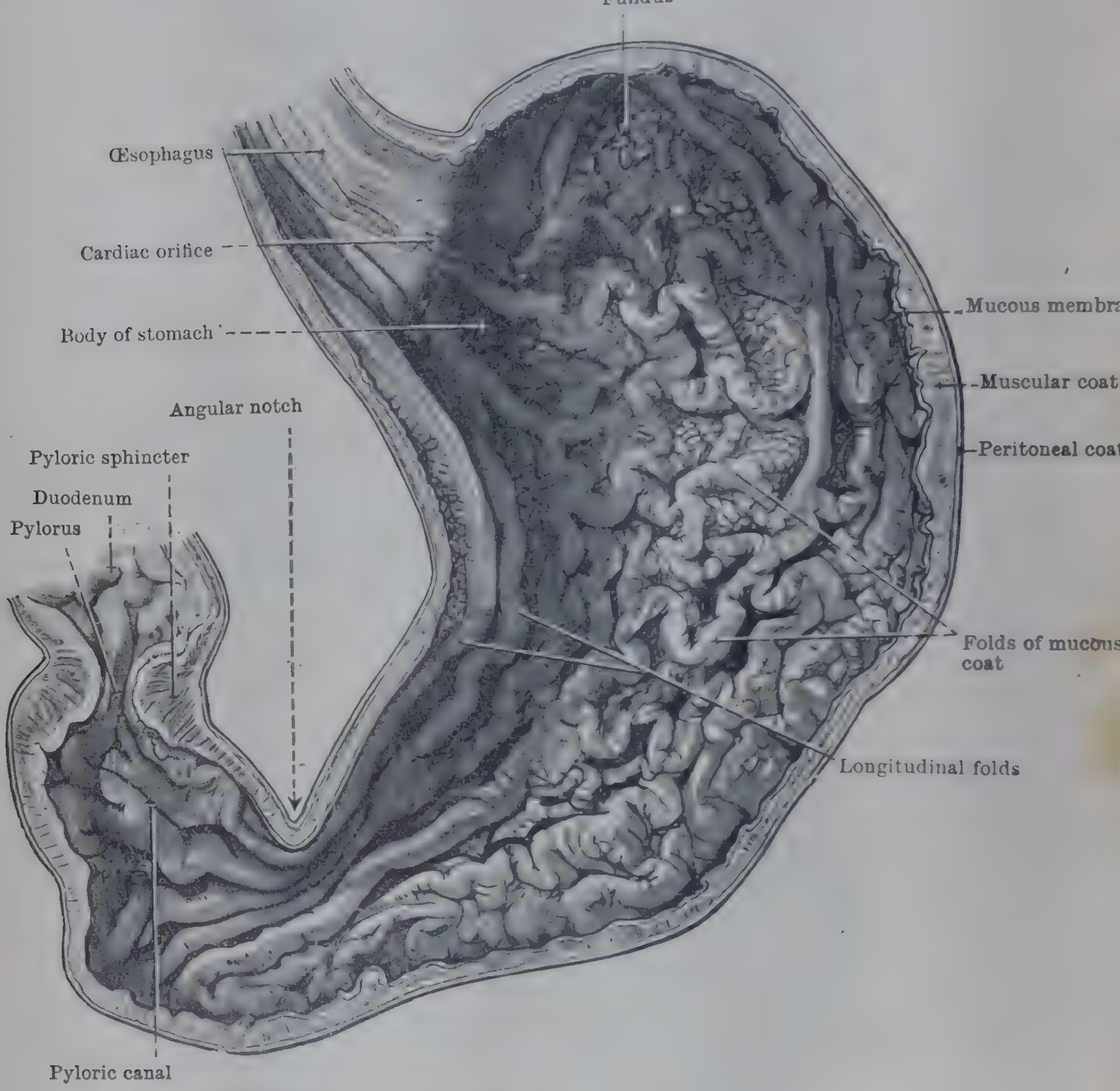

FIG. 520.—INTERIOR OF STOMACH, SHOWING ITS MUCOUS COAT AND ITS PARTS WHEN MODERATELY FILLED.

pylorus usually lies at the level of the transpyloric plane (p. 602) near (*i.e.*, within half an inch of) the median plane, below the left lobe of the liver or sometimes below the quadrate lobe. During distension it is pushed over beneath the quadrate lobe for a variable distance, but very rarely more than 1½ or 2 inches to the right of the median plane.

During the earlier stages of gastric digestion the pyloric sphincter is strongly contracted and the aperture firmly closed, but it opens intermittently to allow the passage of properly digested portions of the food.

The lumen of the pylorus is stated to be about half an inch in diameter, but that represents neither its full size nor its calibre when at rest. Foreign bodies with a diameter of almost an inch have been known to pass through the pylorus without giving rise to trouble, even in children. On the other hand, when at rest, with an empty stomach and duodenum, the aperture is closed.

PLATE LIII

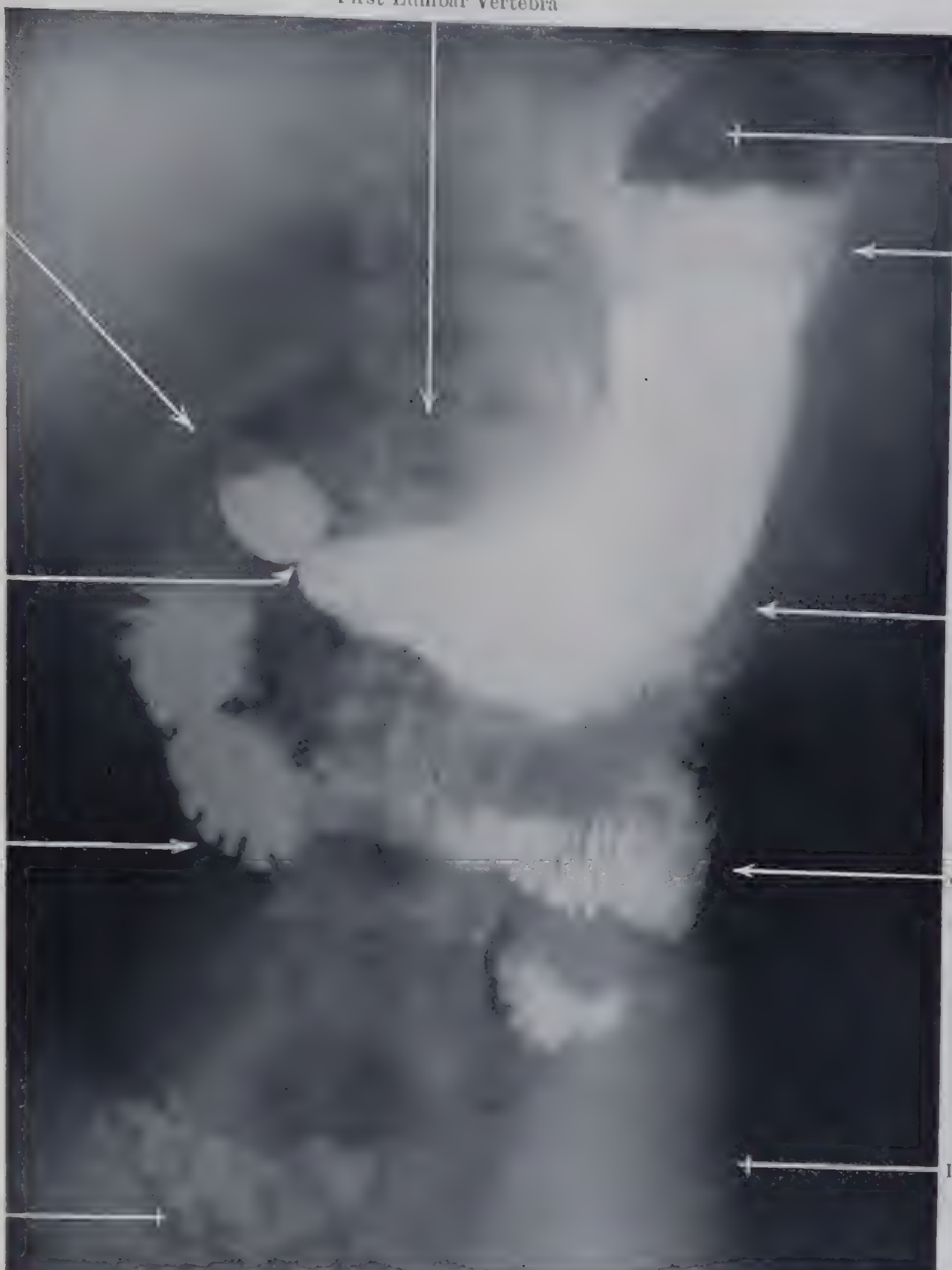

PLATE LIII.—RADIOGRAPH OF STOMACH OF MAN AGED 28 IN THE ERECT POSTURE AFTER OPAQUE MEAL, SHOWING THE INTERMEDIATE FORM (see p. 621, and compare with Plates LII, p. 609 and LIV).

The Body and the Pyloric Portion of the Stomach exhibit a more continuous curvature than those of the J-shaped Stomach in Plate LII, the Pyloric Canal is horizontal rather than vertical, and the Pylorus lies high in the abdomen. A previous opaque meal, taken three hours before, is seen in the Ileum. Compare also with Plate XLVIII, p. 559, in which the same stomach is seen half-filled.

PLATE LIV

FIG. 1. RADIOGRAPH OF "STEER-HORN" STOMACH OF MALE ADULT.

The Stomach lies almost transversely, high in the abdomen; the Pylorus and Duodenal Cap are hidden by the Pyloric Portion. The position of the air in the Fundus shows that the radiograph was taken in the erect posture. Cf. Plates LII, p. 609 and LIII.

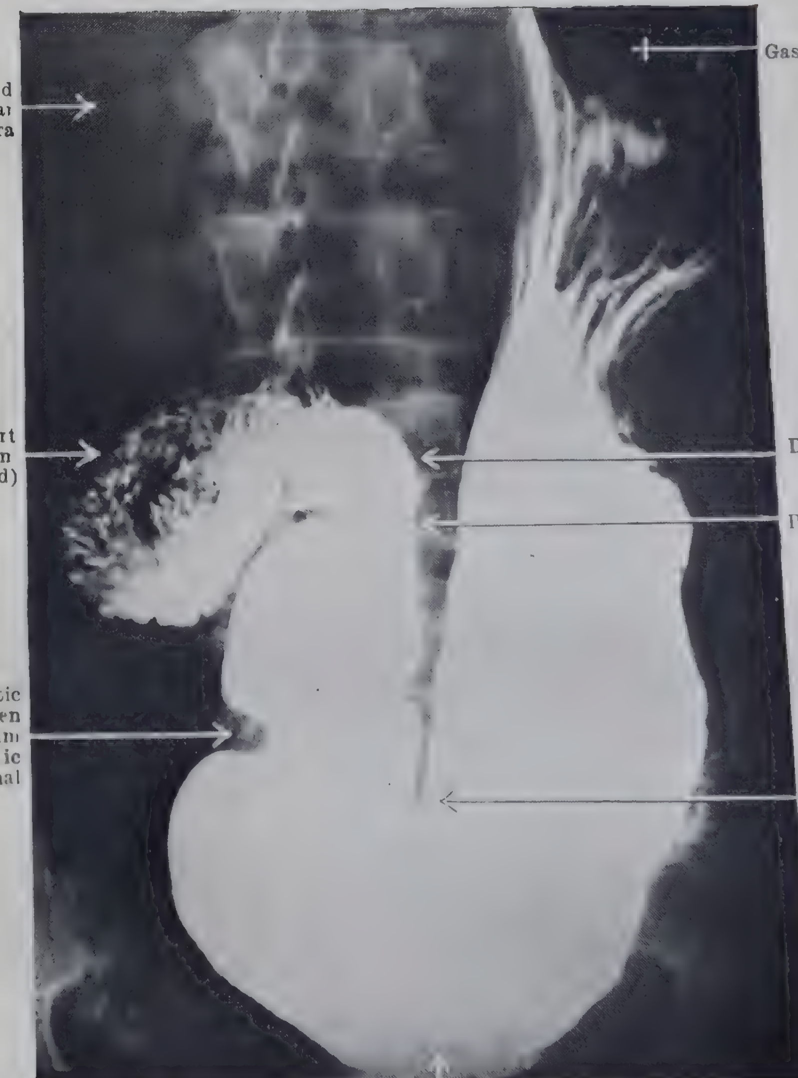

FIG. 2.—RADIOGRAPH OF STOMACH IN VISCEROPTOSIS.

The J-shape of the stomach is greatly exaggerated; the pylorus is at the level of the fourth lumbar vertebra; and the greater curvature descends into the pelvis.

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Surfaces and Chief Relations of Stomach.—The **anterior surface of the stomach** is more convex and more extensive than the posterior. When the stomach is distended, it is in contact with the inferior surface of the left lobe of the liver medially, the vault of the diaphragm laterally, and the anterior abdominal wall below. When the stomach is empty, on the other hand, the transverse colon may rise in front of it, and separate its anterior surface from the liver and diaphragm and abdominal wall.

The **posterior surface of the stomach** is more flattened than the anterior, owing to the contours of the structures upon which it rests. Towards the left, the body and fundus are in contact with the diaphragm and the spleen. To the right of the fundus the upper portion of the posterior surface is in contact with the left kidney, the left suprarenal gland and the diaphragm; and the lower portion, more horizontal, is in contact with the pancreas, with the splenic artery as it runs along the upper border of the pancreas, and with the transverse mesocolon and transverse colon below the pancreas. Those structures form what is known

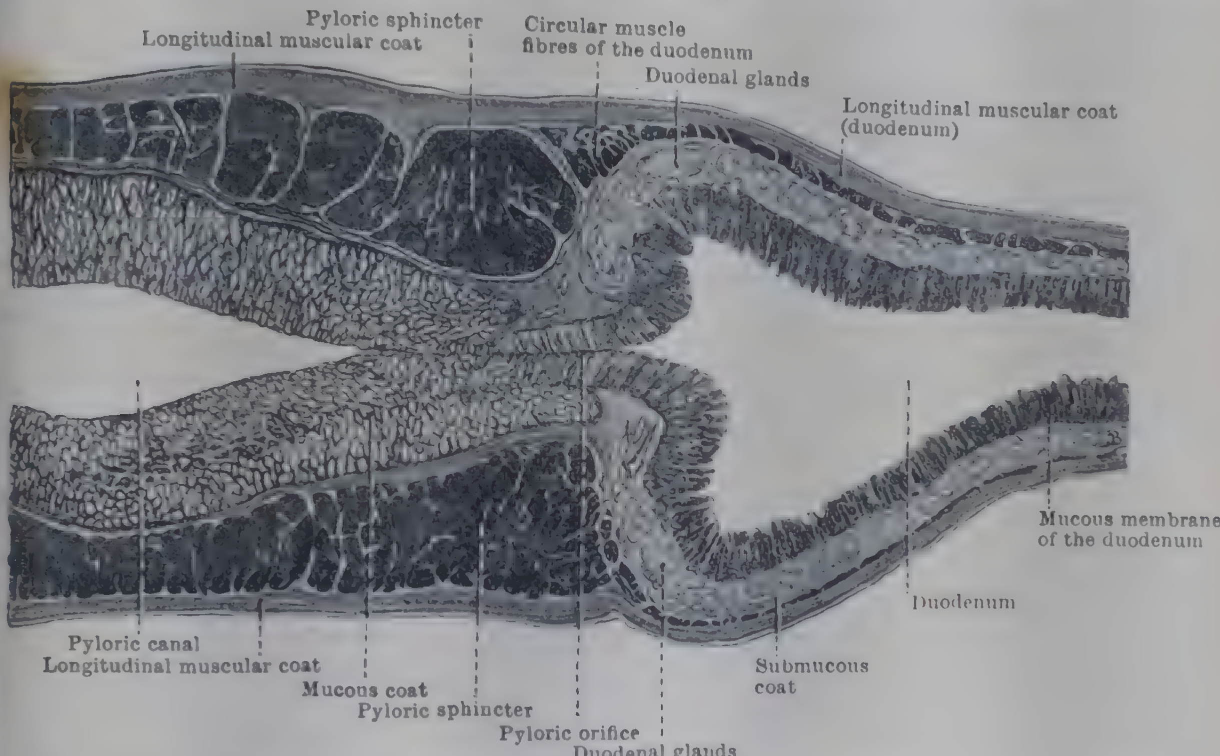

FIG. 521.—LONGITUDINAL SECTION THROUGH PYLORIC CANAL AND FIRST PART OF DUODENUM IN NEW-BORN CHILD.

as the **stomach-bed**, and, excepting the spleen, they lie immediately behind the posterior wall of the lesser sac of the peritoneum, which separates them from the stomach.

Curvatures of Stomach.—The **lesser curvature**, directed towards the liver, and attached to it by the lesser omentum, is on the whole concave. It consists of two portions which meet at the deepest part of the concavity to form a sharp angle called the **angular notch**. The upper or left portion, the longer of the two, is nearly vertical and continues the direction of the right margin of the œsophagus; the lower or right portion may be horizontal or even directed upwards to the pylorus. The angular notch is situated at the junction of the body with the pyloric portion of the stomach; and its position, its depth and the acuteness of its angle vary with the degree of distension of the stomach. When the pyloric portion of the stomach is full, the lower portion of the lesser curvature becomes convex in outline. The lesser curvature as a whole measures some three or four inches in length.

The **greater curvature** is convex, often with indentations upon it, and is usually over three times as long as the lesser curvature. But its length depends to a greater degree than that of the lesser curvature upon the physiological state of the stomach. It corresponds to a line drawn from the cardiac notch over the

summit of the fundus (Fig. 519) and along the most projecting part of the stomach as far as the pylorus. It is attached to the spleen by the gastro-splenic ligament and to the transverse colon by the greater omentum.

Divisions of Stomach.—The stomach may be divided into a *cardiac* and a *pyloric* portion. The cardiac portion, lying to the left side, is wider in diameter than the pyloric, and comprises the *fundus* and the *body* of the stomach.

The **fundus of the stomach** is the rounded or dome-shaped portion which lies above a horizontal plane drawn through the œsophageal opening. Its shape seldom alters, whatever the condition of the stomach may be, and it is usually filled with air.

The **body of the stomach** extends from the base of the fundus along the long axis of the stomach and merges into the pyloric portion. The junction of the

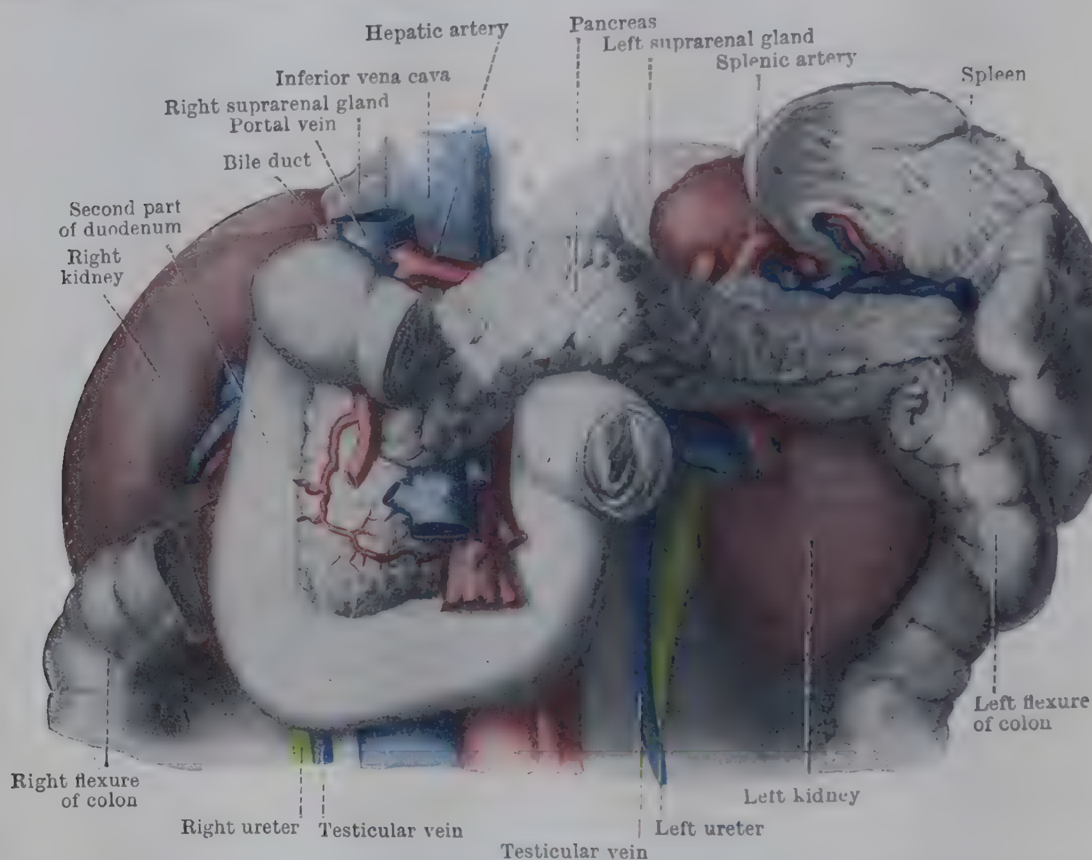

FIG. 522.—DISSECTION TO SHOW POSTERIOR RELATIONS OF STOMACH. The stomach has been cut close to the pylorus and removed. The transverse colon has been taken away, and the small intestine has been cut across close to the duodeno-jejunal flexure. (From a model by Birmingham.)

two parts is marked on the lesser curvature by the angular notch, but is not distinctly marked off on the greater curvature by any permanent notch. There is usually, however, on the greater curvature a slight notch due to a localized contraction of some of the circular muscular fibres which marks the junction of the two portions. The body of the stomach forms a rounded chamber, capable of great distension, but when the stomach is empty it contracts to a narrow tube-like structure. As the stomach is seldom completely empty, the body usually tapers from the fundus to the proximal end of the pyloric portion (Fig. 520).

The **pyloric portion of the stomach** extends from the angular notch in the lesser curvature, and a variable and inconstant notch on the greater curvature, as far as the pyloric orifice (Figs. 519, 520).

It differs from the body of the stomach in being more tubular in shape, and possessing thicker walls. It has been divided anatomically into the *pyloric antrum* and the *pyloric canal.*

The **pyloric canal** is the distal, short, more or less tubular portion which ends in the pyloric sphincter. The proximal portion, called the **pyloric antrum**, is more expanded. It is not clearly demarcated from the body of the stomach by any

constant line of division on the greater curvature. On the lesser curvature it extends from the angular notch to the pyloric canal.

Hour-Glass or Bilocular Stomach.—This is a condition of the stomach in which the organ is more or less completely separated into two divisions—a cardiac and a pyloric—the normal arrangement in certain rodents and other animals. As a rule the former division is the larger, but occasionally the two are nearly equal, or the pyloric portion may exceed the cardiac in size. Sometimes the condition is temporary, and the result of a vigorous contraction of the circular muscular fibres at the seat of constriction. In other cases it is permanent, and may be due to cicatricial contraction after gastric ulcer, or to some other pathological condition. The condition is more frequent in women than in men, and it is rarely found in the fœtus or child.

Size and Capacity of Stomach.—Probably no organ in the body varies more in size within the limits of health than the stomach. Moreover, as its tissues change so

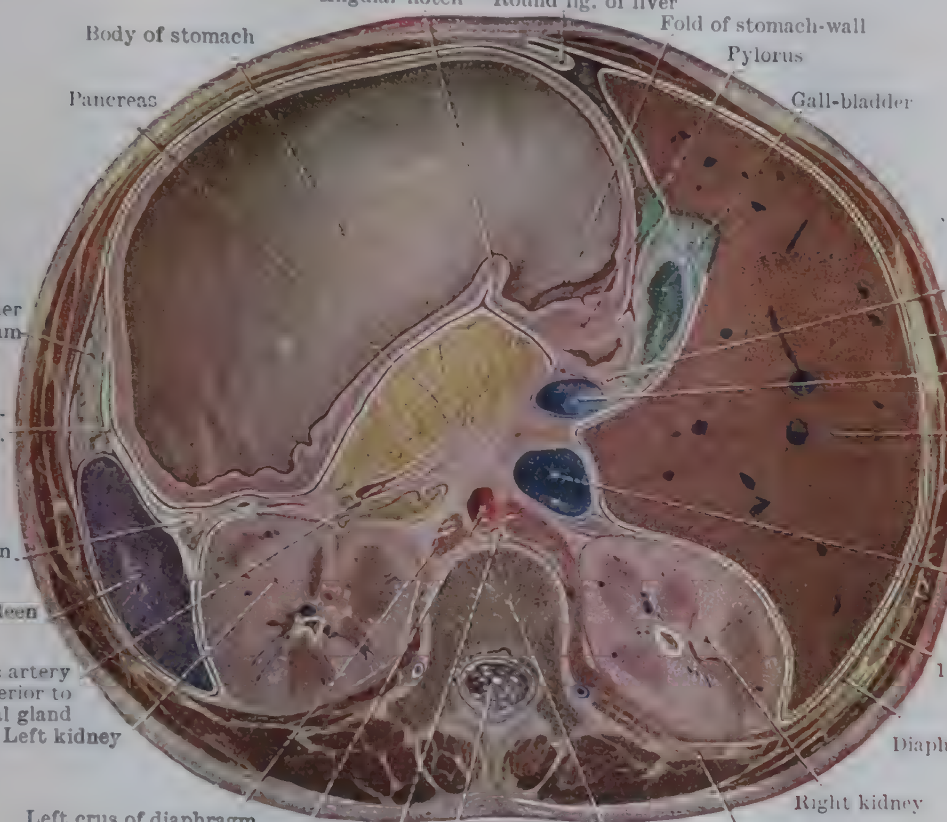

FIG. 523.—TRANSVERSE SECTION OF TRUNK AT LEVEL OF FIRST LUMBAR VERTEBRA.
Showing relations of stomach, pancreas, kidneys, etc. From a subject ten years old.

rapidly after death, measurements made on softened and relaxed organs are not only worthless but quite misleading.

The *length* of the stomach in the fully distended condition is about 10 to 11 inches (25 to 27·5 cm.), and its greatest *diameter* not more than 4 to 4½ inches (10 to 11·2 cm.); whilst its *capacity* in the average state rarely exceeds 40 ounces or 1 quart.

The distance in a direct line from the cardiac to the pyloric orifice varies from 3 to 5 inches (7·5 to 12·5 cm.), and that from the cardiac orifice to the summit of the fundus from 2½ to 4 inches (6 to 10·0 cm.).

As regards the *weight*, the average of twelve wet specimens freed from their omenta was found to be 4¾ oz. (135 grms.), with a maximum of 7 oz. (200 grms.) and a minimum of 3½ oz. (100 grms.).

In the **new-born child** the stomach is scarcely as large as a small hen's egg, and its capacity is about 1 oz. (28 c.cm.). In shape it corresponds fairly closely to that of the adult, and the fundus is well developed. It is vertical in position.

Position of Stomach.—*In the cadaver*, lying horizontally, the stomach, if empty or nearly so, is found in the upper left quadrant of the abdominal cavity, with its fundus in the hollow of the diaphragm, its long axis lying almost

horizontally and its pyloric part running to the right to join the duodenum. In that state the whole organ is narrow and tubular, particularly the pyloric part, which is contracted, and resembles a piece of thick-walled small intestine.

When the stomach is *distended*, both the cardiac and pyloric parts are full and rounded (Fig. 519). It extends down below the subcostal plane. As a result of the general increase in length which takes place during distension, the pylorus is moved a variable distance to the right beneath the quadrate lobe of the liver, and at the same time the long axis of the whole organ becomes much more vertical, running forwards, downwards, and to the right.

When the stomach has been removed, after the body has been hardened, a chamber or recess is exposed, known as the **stomach-chamber** (Figs. 522 and 524). It is a space in the upper and

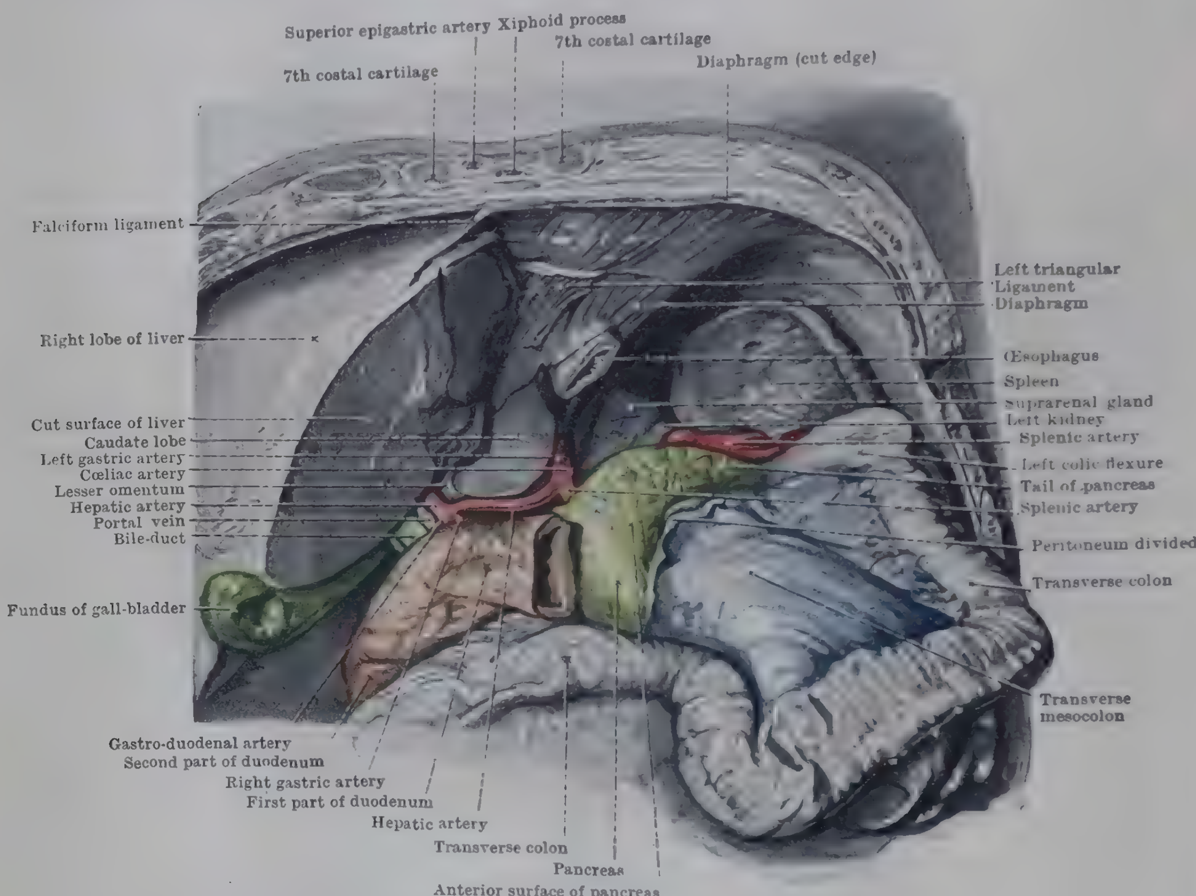

FIG. 524.—STOMACH-CHAMBER VIEWED FROM THE FRONT AND FROM BELOW.
From the specimen figured in Fig. 525, after removal of the stomach and lesser omentum.

left portion of the abdominal cavity with an arched roof, and an irregularly sloping floor. The *roof* is formed by the visceral surface of the left lobe of the liver and by the left cupola of the diaphragm.

The *floor* or "*stomach-bed*" (Fig. 524) is formed behind by the upper end of the left kidney (with the suprarenal gland) and the gastric surface of the spleen; and in front by the anterior surface of the pancreas and the transverse mesocolon.

Peritoneal Relations.—The stomach is almost completely covered with peritoneum—the anterior surface being clothed with that of the general peritoneal sac, and the posterior surface by the anterior wall of the lesser sac. The layers of peritoneum that clothe the front and the back of the stomach meet at the lesser curvature and extend to the liver as the two layers of the *lesser omentum.* They meet also along the greater curvature and pass away from the stomach as a wide fold, to different parts of which different names have been given—(1) the anterior two layers of the *greater omentum*, (2) the two layers of the *gastro-splenic ligament*, and (3) a small peritoneal fold, known as the *gastro-phrenic ligament*, which runs from the stomach up to the diaphragm along the left side of the œsophagus.

A small irregularly triangular area (about 2 inches wide and 1½ inches from above downwards during moderate distension of the stomach, on the posterior surface below and to the left of the cardia) is not covered with peritoneum, and over it the organ is in direct contact with the diaphragm, occasionally also with the upper end of the left kidney and the suprarenal gland (Fig. 538). From the left angle of that "bare area" the attachment of the gastro-splenic ligament starts; and at the right angle a fold begins through which the left gastric artery passes to the stomach. That fold is called the *left gastro-pancreatic* fold.

The *right gastro-pancreatic* fold of peritoneum passes from the right extremity of the upper border of the pancreas to the first part of the duodenum. It encloses the hepatic artery.

Structure of Stomach.—The wall of the stomach is composed of four coats—from without inwards: (1) serous, (2) muscular, (3) submucous, and (4) mucous (Fig. 526).

The **serous coat** is formed of the peritoneum, the relations of which to the stomach have already been described. It is closely attached to the subjacent muscular coat, except near the curvatures, where the connexion is more lax.

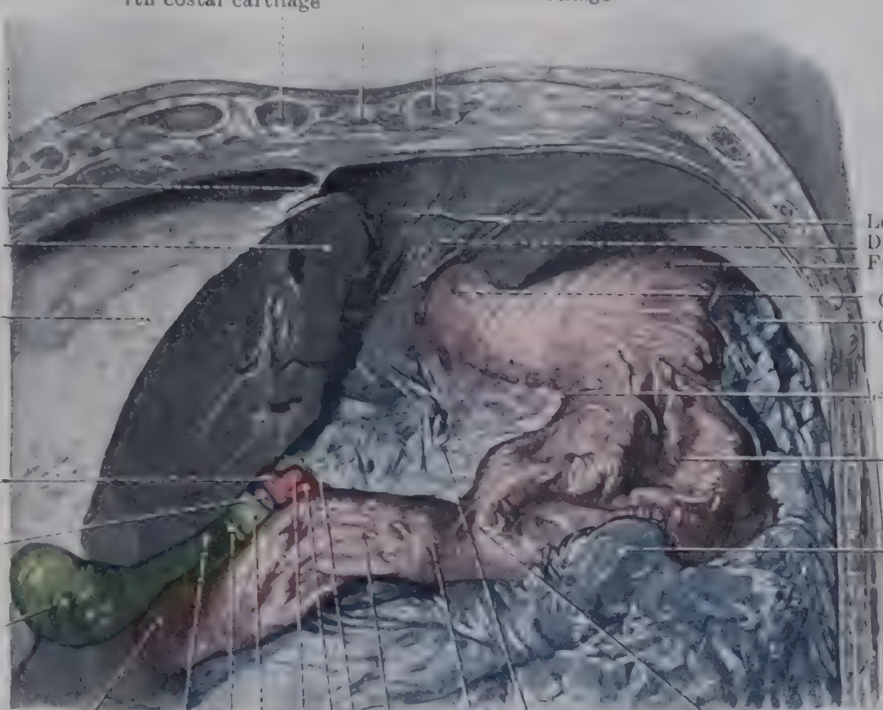

FIG. 525.—STOMACH WITH GREATER AND LESSER OMENTA *IN SITU*.

The left lobe of the liver has been removed, and also the anterior layer of the duodenal part of the lesser omentum. The view is taken looking upwards as well as backwards.

The **muscular coat**, composed of plain muscle, thinnest in the fundus and body, and thicker in the pyloric portion, is responsible for the production of the gastric movements in digestion. It is made up of three complete or almost complete layers:—an external longitudinal, a middle circular, and an internal oblique layer.

The *longitudinal layer*, continuous with the longitudinal fibres of the œsophagus, sweeps from the cardiac orifice along and on each side of the curvatures, particularly the lesser curvature, but is almost or entirely absent on the central parts of the anterior and posterior surfaces. On each side of the lesser curvature it forms two strong bands, many of whose marginal fibres turn aside and terminate, at intervals, in the deeper layers. Towards the pylorus the longitudinal fibres become much thicker, and also much tougher and more closely united, and they take part in the formation of the **pyloric sphincter** (see p. 610).

A specially condensed band of these can often be made out both on the front and back at the pyloric antrum, the form of which is said to be due to their presence. These bands are known as the *pyloric ligaments*.

The *circular layer*, continuous with the more superficial of the circular fibres of the œsophagus (Fig. 528), is a more complete layer; its fibres encircle the body from the

lesser to the greater curvature, and they are absent only from the fundus. In the wall of the pyloric canal they increase in thickness and pass into the pyloric sphincter. A marked thickening of the circular layer in this region is found in the condition known as congenital hypertrophic pyloric stenosis.

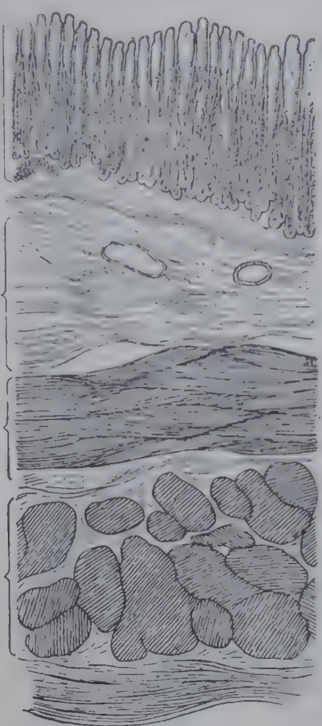

FIG. 526.—TRANSVERSE SECTION OF WALL OF HUMAN STOMACH IN REGION OF PYLORIC ANTRUM. (Diagrammatic.)

The *oblique fibres* form the inner layer and are continuous above with the deeper circular fibres of the œsophagus. They are arranged in U-shaped bundles which loop over the stomach immediately to the left of the cardia and run very obliquely downwards on both surfaces of the organ as far as the angular notch (Fig. 528). The looped fibres, as they pass to the left, gradually become less oblique, and they finally form circles around the wide end of the stomach as far as the fundus. These last fibres are sometimes ascribed to the circular layer.

The **submucous coat** is a layer of strong but loose areolar tissue which lies between the muscular and mucous coats and unites them (Fig. 526). It is more loosely attached to the muscular and more closely to the mucous coat, and it forms a bed in which the vessels and nerves break up before they enter the mucous membrane.

In the fresh state the **mucous coat** is of a reddish-grey colour and of moderate consistence. After death, the colour turns to a darker grey, and the whole membrane becomes softer and more pulpy. It is thicker (over 2 mm.) and firmer in the pyloric part than elsewhere, and it is thinnest at the fundus. When the stomach is empty the mucous coat is thrown into numerous prominent folds or *rugæ* which project into the interior. They are, in general, longitudinal in direction, with numerous cross branches.

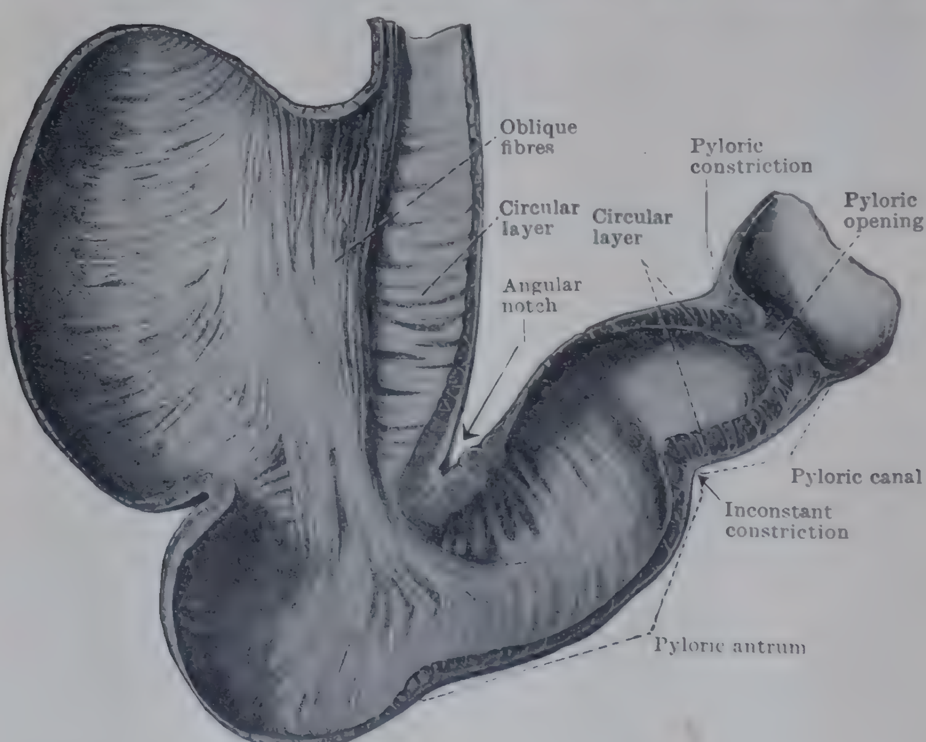

FIG. 527.—MUSCULAR COAT OF STOMACH, SEEN FROM WITHIN AFTER REMOVAL OF MUCOUS AND SUBMUCOUS COATS. (Cunningham, 1906.) The anterior half of the stomach is shown, viewed from behind.

They disappear when the stomach is distended. Along the lesser curvature there are three or four long, narrow, very constant ridges which pass without a break from the œsophageal orifice towards the pyloric part of the stomach (Fig. 520). They are parallel to one another, and are apparently never completely obliterated. Between them are deep

furrows which lead from the cardiac orifice to the pyloric portion of the stomach, and thus occupy the position of the 'gastric canal' of the foetus (Lewis, 1912). The view once held (Jefferson, 1915) that these mucosal gutters constitute a functional 'gastric canal', which is reinforced by the action of the oblique muscle fibres (Fig. 527), is no longer accepted (see p. 621).

When the surface of the mucous coat is examined in a *fresh* stomach, it is seen to be marked out into a number of small, slightly elevated polygonal areas by numerous linear depressions; the mucous membrane is consequently said to be mamillated (Fig. 529, A). These little areas, which measure from 1 to 6 mm. in diameter, show numerous small pits, about ·2 mm. wide, which are the mouths of the gastric glands, and they are so closely placed that the amount of surface separating them is reduced (particularly in the pyloric portion, where the gland-mouths are widest) to a series of elevated ridges that resemble villi on section. Although the gland-mouths cannot be seen with the naked eye, a very slight magnification is sufficient to show them clearly; it is also possible to see the gland-tubes leading off from the bottom of each (Fig. 529, B).

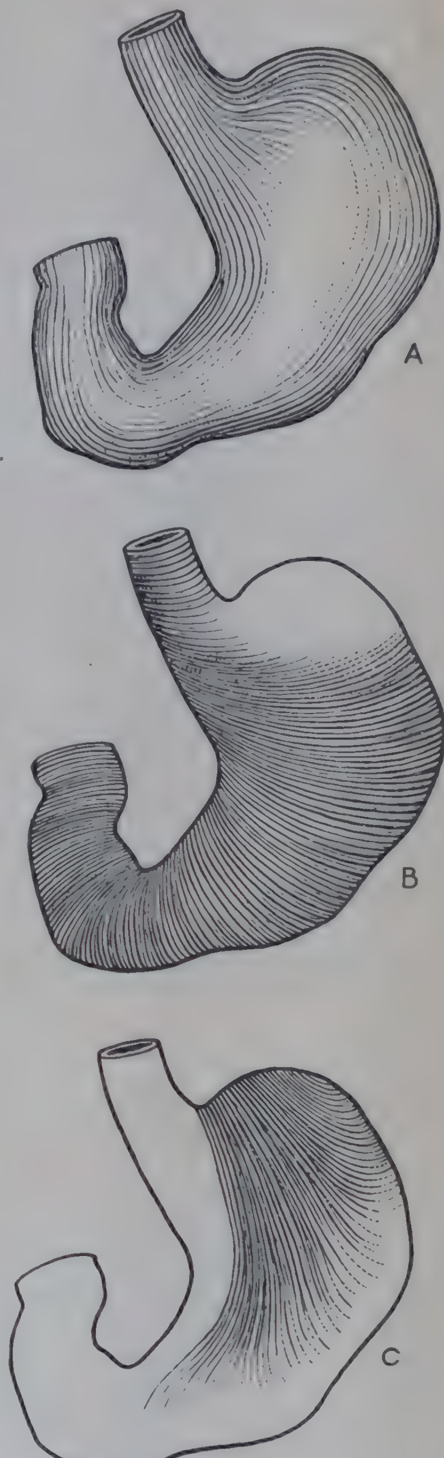

Fig. 528.—Three Diagrams of the Muscular Coats of the Stomach, to show Extent and Direction of Fibres composing them. A. Longitudinal layer whose fibres form an incomplete investment and are specially developed along the lines of the curvatures, especially the lesser. B. Middle circular layer, which forms a complete investment for the body and pyloric portion of the stomach. C. Oblique fibres which run obliquely to those of the other layers from the notch between the cardiac orifice and fundus on the anterior (and posterior) surfaces of the stomach and form an incomplete layer.

Minute Structure of Mucous Coat.—The mucous coat consists of an epithelial covering composed of long columnar cells, and of numerous tubular glands which are prolonged outwards and are enclosed in a delicate stroma of areolar tissue mingled with some small lymph-nodules. The bases of the glands reach outwards to the lamina muscularis mucosæ—a layer consisting of an external longitudinal and an internal circular layer of plain muscle-fibres.

Gastric Glands.—Each gastric gland consists of one or more secreting tubules which terminate in a duct. The duct is lined with columnar epithelial cells similar to those which cover the surface of the mucous membrane. Three varieties of glands are found in different regions of the stomach, and they are named from their position :—

(1) **Cardiac Glands** are situated close to the œsophageal opening. The duct of each ends in a single, long tubule lined with short columnar, granular cells.

(2) **Fundal Glands** are found in the fundus and body of the stomach. The duct of each ends in one or more tubules lined with polyhedral cells termed the *chief* or *central cells.* At intervals, between that layer of cells and the basement membrane, are placed large spheroidal cells, termed the *parietal* or *oxyntic* cells, which stain more deeply as a rule.

(3) **Pyloric glands** are found in the pyloric portion of the stomach. Each consists of a group of short but tortuous gland tubules which end in a short duct. The tubules are lined with short columnar or polyhedral cells similar to the central cells of the fundal glands.

Vessels and Nerves.—The **arteries** of the stomach are all derived ultimately from the *cœliac artery.* The *left gastric artery* arises from that trunk direct. Having reached the lesser curvature and given off an œsophageal branch, it divides into two branches which run along the front and the back of the lesser curvature and join with two similarly disposed arteries derived from the *right gastric* branch of the hepatic. From the two arches thus formed, four or five branches pass to each surface of the stomach and soon pierce the muscular coat. Along the greater curvature numerous branches reach the stomach from the *right and left gastro-epiploic arteries,* which are branches respectively of the gastroduodenal and the splenic; they run in the greater omentum close to its attachment to the

stomach. Finally, four or five *short gastric arteries*, branches of the splenic, are distributed to the fundus of the stomach, which they reach by passing forwards between the layers of the gastro-splenic ligament. At first the arteries lie beneath the peritoneum; very soon, however, they pierce the muscular coat, which they supply, and, reaching the submucosa, break up to form a close network of vessels. From these arise numerous small branches which enter the mucous membrane and form capillary plexuses around the glands as far as the surface.

The **veins** begin in the capillary plexuses around the glands; uniting, they form a network in the submucosa, from which branches arise that pierce the muscular coat and finally end in the following veins: the *right gastro-epiploic*, which joins the superior mesenteric; the *left gastro-epiploic* and four or five *short gastric veins*, which join the splenic; the *left gastric vein*, which runs along the lesser curvature from right to left, and ultimately joins the portal vein. These veins contain numerous valves which, though competent to prevent the return of blood in the child, are rarely so in the adult.

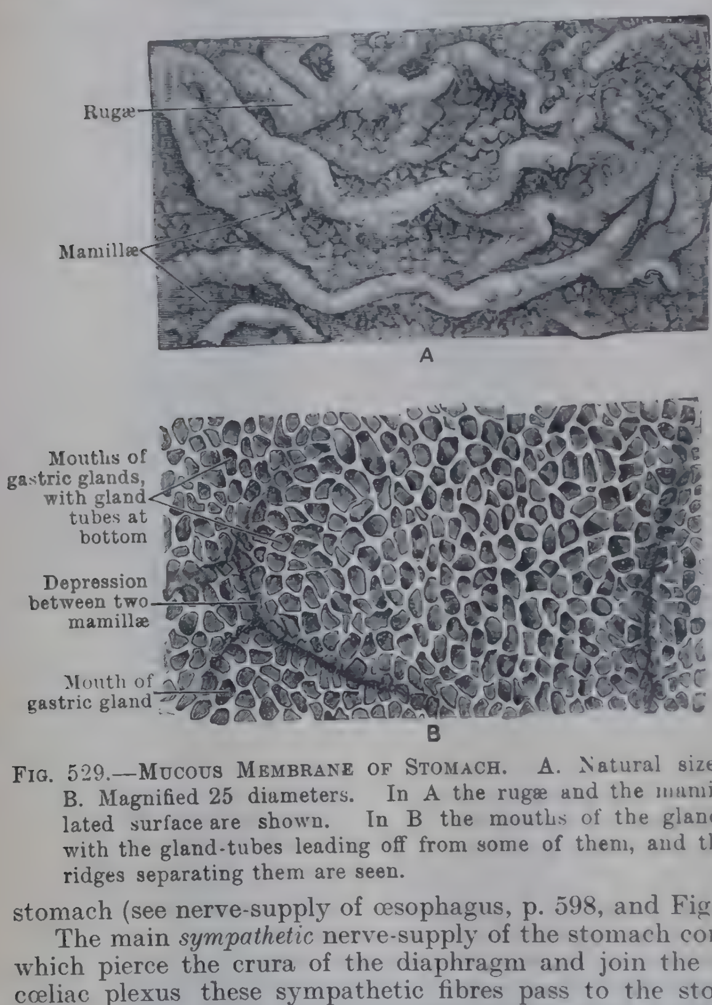

FIG. 529.—MUCOUS MEMBRANE OF STOMACH. A. Natural size; B. Magnified 25 diameters. In A the rugæ and the mamillated surface are shown. In B the mouths of the glands with the gland-tubes leading off from some of them, and the ridges separating them are seen.

The **lymph-vessels** of the stomach arise in an extensive plexus in the mucous membrane and join a subserous plexus from which efferent vessels arise. These are arranged in three main streams which pass to numerous glands situated on the branches of the cœliac artery.

The **nerves** are the *anterior* and *posterior gastric nerves*, which are distributed for the most part to the front and back of the stomach respectively. These nerves are derived from the œsophageal plexus, and the great majority of the fibres composing each of them are *parasympathetic* and come from both the right and left vagus nerves. A small number of *sympathetic* fibres also may come through the œsophageal plexus to the cardiac end of the stomach (see nerve-supply of œsophagus, p. 598, and Fig. 965, p. 1135).

The main *sympathetic* nerve-supply of the stomach comes through thoracic splanchnic nerves, which pierce the crura of the diaphragm and join the cœliac ganglia and plexus. From the cœliac plexus these sympathetic fibres pass to the stomach through finer extensions of this plexus which accompany the branches of the cœliac artery. These *left gastric, hepatic* and *splenic plexuses* also contain *parasympathetic* fibres which take a variety of routes to reach them (Dos Santos, 1931), but come for the most part from a branch of the posterior gastric nerve. This branch comes off the posterior gastric nerve soon after that nerve has entered the abdomen, and it runs down on the diaphragm to be distributed through the cœliac plexus.

For the manner in which the parasympathetic fibres are relayed in the *myenteric* and *submucous plexuses*, and for the terminal distribution of the sympathetic fibres see nerve-supply of the intestine, p. 624.

Radiographic Examination of Stomach.—Examination of the stomach by X-rays after a "barium meal" throws light upon its form and position and also upon the action of its muscular coats. This kind of examination has shown that there are permanent differences in the form and position of the stomach—especially in the level and direction of its pyloric portion—which seem to depend on the "bodily habitus" of the individual, as well as factors such as race, age, and sex. In addition, the stomach in its form reacts to the amount and character of an ingested meal, and to emotional and general health conditions. Fatigue and mental strain produce 'hypotony'—the greater curvature of the stomach showing a low position and less peristalsis (Wingate Todd, 1930). The form and position of the stomach are greatly influenced by the posture also, and are not the same when the person is standing or sitting up as when he is lying down, either supine or prone (Fig. 530).

The normal empty stomach is a contracted tubular organ with its walls in apposition except at the fundus, which always contains a bubble of air.

When a "barium meal" is taken, the barium first accumulates in the pyloric portion of the stomach and then the body becomes filled. With only a little barium the stomach appears

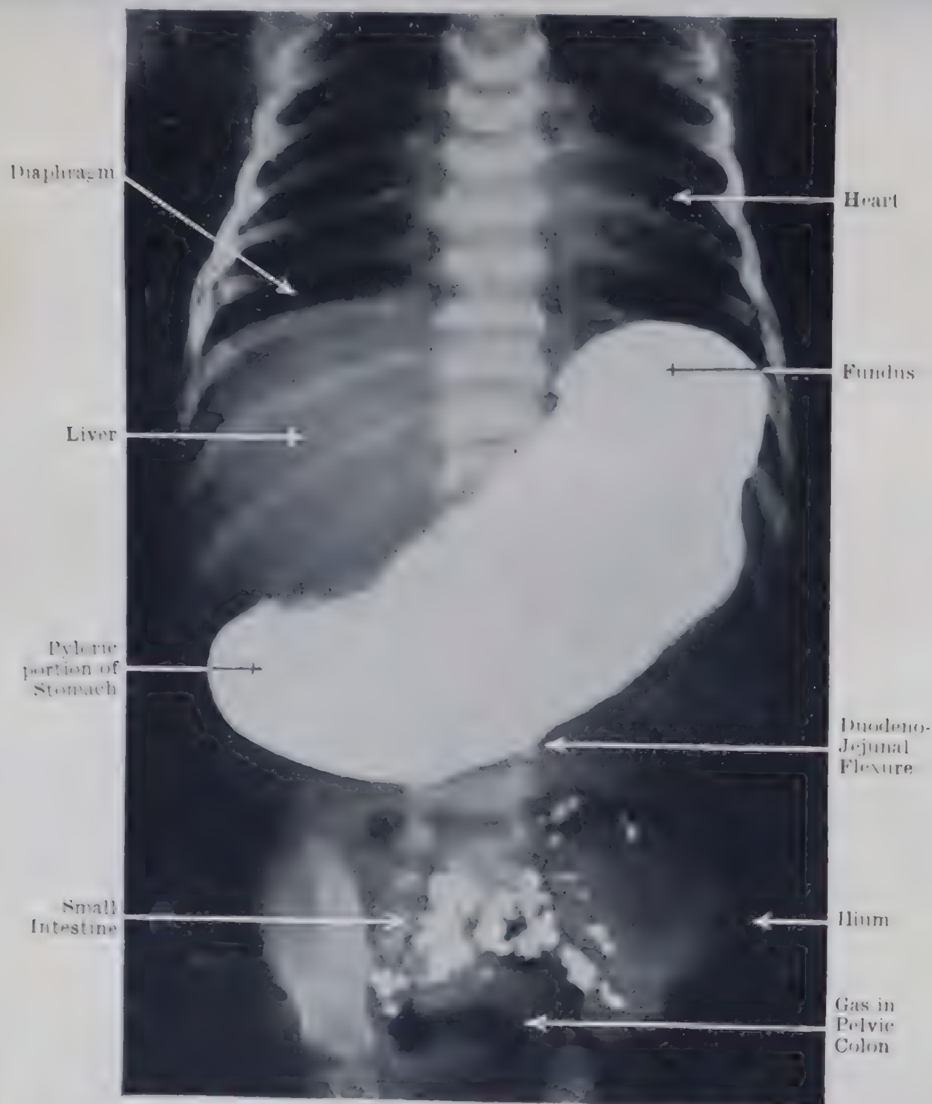

FIG. 1.—RADIOGRAPH OF STOMACH, FILLED WITH BARIUM, OF INFANT FIVE WEEKS OLD, SHOWING THE CHARACTERISTIC "STEER-HORN" FORM. (DR. G. G. ALLAN.) Compare with Fig. 2 and Plate LIV, Fig. 1, p. 613.

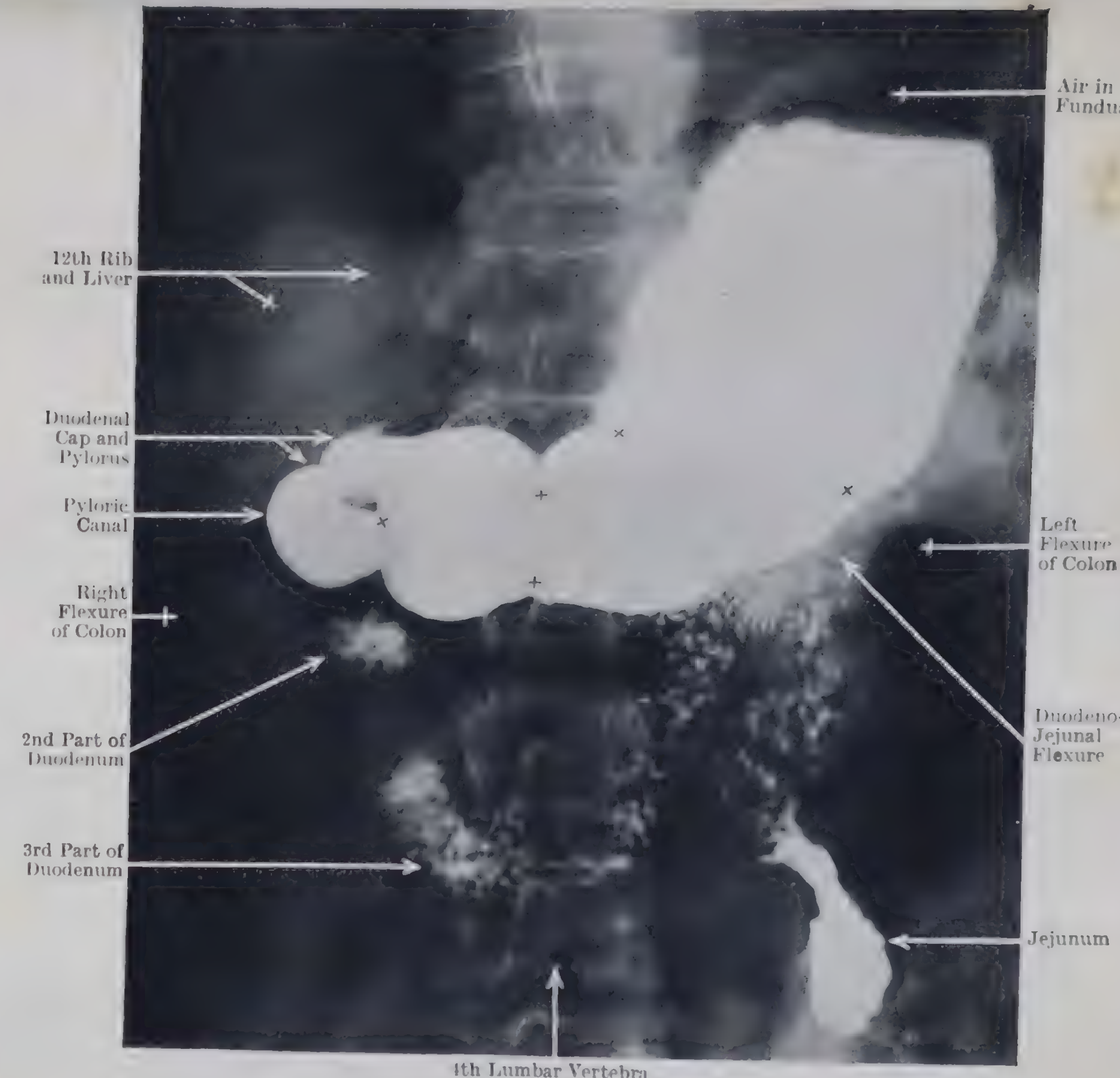

FIG. 2.—RADIOGRAPH OF "STEER-HORN" STOMACH (MAN, AGED 51), FILLED WITH BARIUM, SHOWING A SERIES OF PERISTALTIC WAVES (x).

Note the mucosal folds in the Duodenum and Jejunum and the outlining of the Large Intestine by gas.

[*Facing p.* 620

PLATE LVI

FIG. 1.—RADIOGRAPH OF J-SHAPED STOMACH (MAN, AGED 33), FILLED WITH BARIUM, SHOWING TWO PERISTALTIC WAVES (x) AND THE PASSAGE OF BARIUM THROUGH THE PYLORUS.

FIG. 2.—RADIOGRAPH OF THE SAME STOMACH AS IN FIG. 1 AT A LATER STAGE OF EMPTYING, WITH SHALLOWER PERISTALTIC WAVES (x).

More barium has passed into the small intestine and the pylorus is temporarily closed.

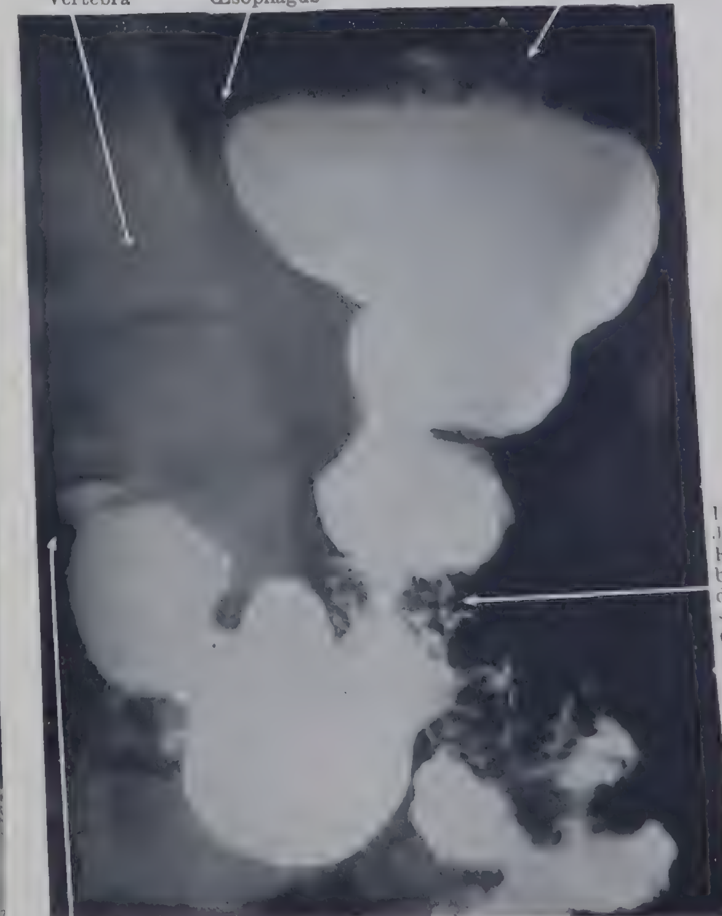

FIG. 3.—RADIOGRAPH OF J-SHAPED STOMACH (MAN, AGED 48), FILLED WITH BARIUM, SHOWING HYPERPERISTALSIS.

The series of peristaltic waves is marked with crosses.

PLATE LVI. RADIOGRAPHS SHOWING STAGES OF PERISTALSIS AND HYPERPERISTALSIS IN J-SHAPED STOMACHS.

narrow and tubular, but as more barium is taken the whole organ becomes wider. If there is any secretion present, it forms in a layer above the barium. Above that again is the air-bubble, which is nearly always larger than before the meal because some air is usually swallowed with it. The air-bubble does not absorb X-rays, so that it appears black on the film.

If a patient with the usual J-shaped stomach is examined in the erect posture during the taking of the meal, the barium is seen to pass directly to the pyloric portion along the lesser curvature. It was believed at one time that this path taken by the barium is determined by the "gastric canal" mentioned on p. 619; but it is now accepted that it is due to gravity and that the musculo-mucosal arrangement in a longitudinal direction is functionally unimportant. If the stomach is moderately filled with water before the barium is taken, the barium still follows the lesser curvature while the patient remains in the erect posture. But if he inclines his body to the left, the barium is then seen to drop through the water—a proof that under these circumstances gravity determines its path.

In the barium-filled stomach peristaltic waves are clearly visible (Pls. LII, p. 609, LVI). They begin as shallow indentations of the greater curvature in the lower part of the body. They gradually deepen and involve the lesser curvature as they pass over the pyloric antrum and canal towards the pylorus. Preceding the ring of contraction there is a zone of relaxation; and, as peristalsis goes on, the pyloric orifice opens from time to time. Not every peristaltic wave forces barium through the pylorus, for the function of peristalsis is not merely to empty the stomach—it also serves to mix the digestive secretions with the food. The pyloric sphincter usually relaxes with every third or fourth peristaltic wave. The first sign that the pylorus is opening is the characteristic appearance of opaque material in the first part of the duodenum, known as the *duodenal cap* (Pl. LII).

In addition to the examination of the form and of the outline of the stomach, the mucosal folds or *rugæ* may be made evident by spreading a thin layer of barium over the mucous coat (Pl. LI, p. 608). In the fundus the rugæ form an irregular pattern, but in the body they run parallel to one another. Some of the folds pass from the posterior wall on to the anterior wall; and, as they turn over the greater curvature, they produce some irregularity of the outline of the stomach, especially if they are prominent.

The form and position of three well-recognized "types of stomach", as seen in the erect posture, may be studied in Plates LII, LIII, and LIV.

Plate LII represents the J-shaped stomach, by far the commonest "type of stomach" seen on the X-ray screen. On the lesser curvature, the angular notch is distinct, and on the opposite part of the greater curvature there is a wide, shallow temporary constriction produced by contraction of the circular muscle-fibres. Nearer the pylorus a peristaltic contraction is indicated by deep indentations opposite each other on the two curvatures. The position of the pyloric sphincter is shown by an abrupt interruption of the shadow of the barium. A thin streak passes through the sphincter and leads to a shadow, higher up, produced by opaque material in the first part of the duodenum —the *duodenal cap*.

Plates LIII and LIV, p. 612, represent two other "types of stomach" which are much less common but equally characteristic as seen on the X-ray screen. In both of them the body and the pyloric portion exhibit a more continuous curvature, and the pyloric canal is horizontal rather than vertical. Plate LIV, Fig. **1** is a radiograph of a stomach that lies almost transversely in the abdomen even in the erect posture: it is the so-called "steer-horn" type—see also Pl. LV, Fig. 2. In children, the stomach is characteristically of this type (Fig. **1**, Pl. LV). Plate LIII exhibits an intermediate form.

The lowest point of the body, the pylorus and the first part of the duodenum are at a much lower level in the J-shaped than in the other types of stomach. In the J-shaped the pylorus is often as low as the third lumbar vertebra and may be lower still; whereas in the intermediate and steer-horn types the pylorus is frequently in the "transpyloric plane" opposite the body of the first lumbar vertebra or the disc between the bodies of the first and second.

In the horizontal posture, the form and the position of the stomach are altered. The J-shaped stomach hangs less vertically, the lowest part of the greater curvature moves upwards, and the stomach comes to resemble the other types which even in the erect posture are more in the position shown in the cadaver (Fig. 525). The duodenal cap may be hidden by the rise of the pyloric portion of the stomach, which ascends in front of it, and the first part of the duodenum is horizontal instead of almost vertical as it is in the erect posture.

X-Ray examination shows that the position of the stomach is influenced also by the condition of the abdominal muscles. Contraction of these muscles can elevate the stomach as a whole and the change from the horizontal to the erect posture alters

the height of the inferior border. The sinking which occurs in the alteration from the horizontal to the erect posture accounts partly for the differences between the stomach seen in the post-mortem room or on the operating table and the stomach displayed by means of X-rays in the living person standing erect.

That the position of the digestive organs in healthy living persons is much more variable than might be supposed from their examination in the horizontal cadaver is illustrated by the observations made by Moody, van Nuys & Kidder (1929) on students in California

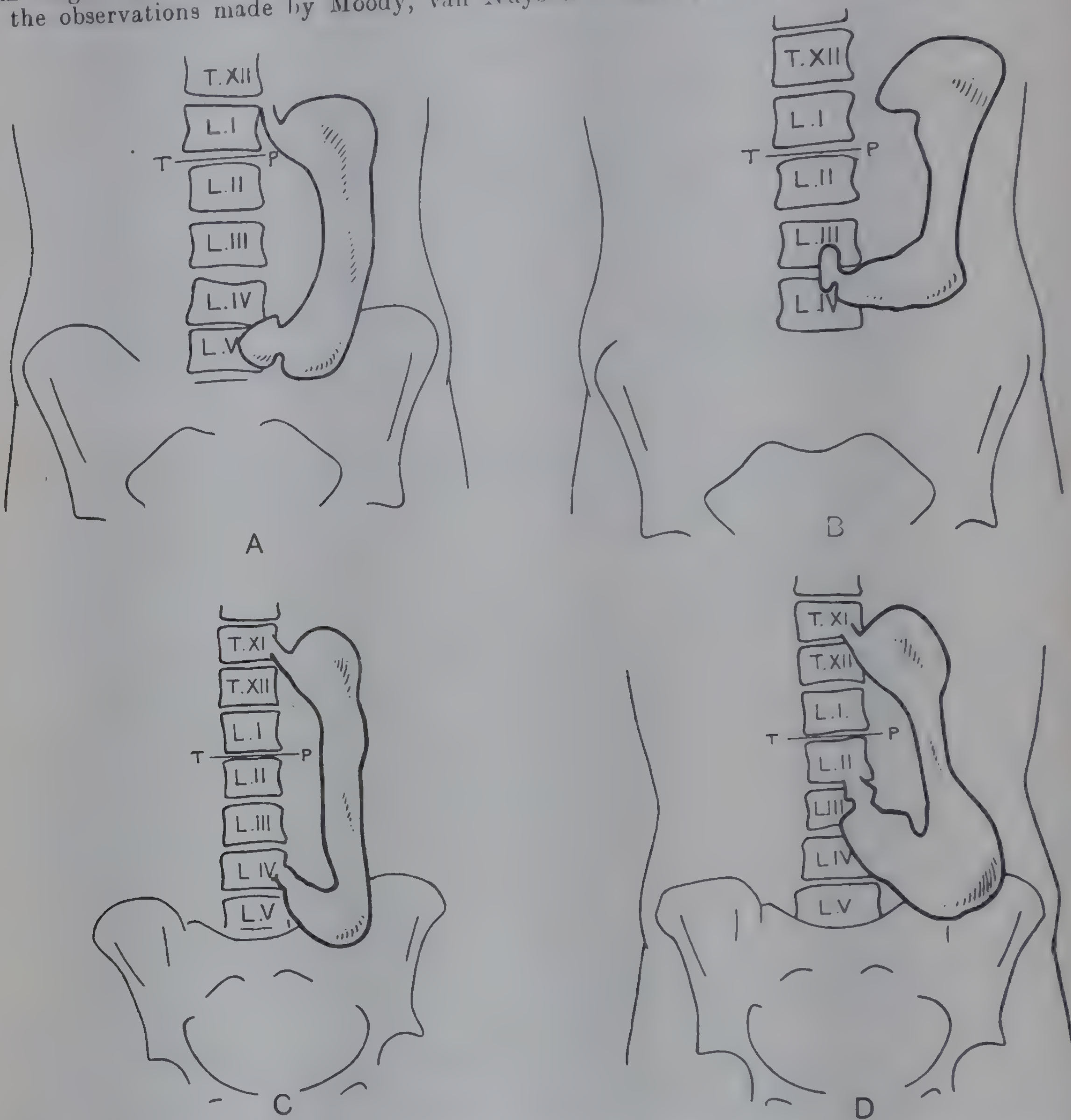

FIG. 530.—TRACINGS OF OUTLINES OF STOMACH AS DEFINED BY X-RAY EXAMINATION. (After Moody, Van Nuys, & Kidder, 1929.) A. Empty stomach, subject erect, the form of the stomach a 'reverse L', with short horizontal arm; lowest part of the greater curvature 5 cm. below the plane of the iliac crests opposite the upper half of the first sacral vertebra. B. Same stomach, subject prone. C. Empty stomach, subject erect, pylorus opposite the fourth lumbar vertebra. D. Same stomach, subject prone, pylorus opposite the third lumbar vertebra. (From the *Anatomical Record*, by permission of the Wistar Institute.)

and London. They confirm the view that in the living the form and position of the stomach vary in different people and in the same person with changes in posture, and that the individual variations which may occur are of wide range. The observations may be briefly summarized as follows:—The pylorus, for example, may lie as high as the upper half of the twelfth thoracic vertebra or as low as the upper half of the fifth lumbar vertebra, and it may lie below the 'inter-iliac line' or plane of the iliac crests, when the subject is erect, supine, or prone. It may lie in the median plane, or to the right or to the left of it, though the position to the left (as shown in Fig. 530) is uncommon. Similarly, the position of the greater curvature of the stomach varies widely, and it may be seen even in the pelvis (Pl. LIV, Fig. 2, p. 613).

Associated with those different positions of the pylorus there is a difference in the position of the first part of the duodenum and in its relation to the head of the pancreas.

Moody has found also that in the living subject standing erect, "the common position of the cæcum is not in the iliac fossa, but in the cavity of the true pelvis".

He finds a similar difference in the position and form of the liver in the living person, and

that its lower border extends below the inter-iliac plane in 50 per cent of males and in 34 per cent of females. Its position and vertical dimensions are greatly influenced by posture; the "excursion" or range of movement of the lower margin with change of posture is usually from 2 to 3 cm. but may be as much as 9 cm. He finds also that "there seems to be no definite relation between the position of the liver and that of the stomach; the liver may be low and the stomach high, or the liver high and the stomach low". (See also Barclay, 1936.)

INTESTINES

The remaining portions of the alimentary canal—from the stomach to the anus—are called the *intestines*, and are divided into two main parts called the small intestine and the large intestine. The **small intestine** succeeds the stomach and is disposed in coiled loops throughout the abdomen proper and the pelvis. It is divided into three parts: the *duodenum*, which is continuous with the pylorus, the *jejunum*, and the *ileum*, which joins the large intestine in the right iliac fossa. The **large intestine** begins in that fossa, takes an arched course round the coils of the small intestine, passes over the left side of the pelvic brim into the pelvis, and ends at the anus. Its commencement is called the *cæcum*, to which a small worm-like structure called the *vermiform appendix* is attached; the cæcum is succeeded by the *colon*, which is by far the longest part of the large intestine and is itself divided; it passes into the pelvis to become continuous with the *rectum*, which is succeeded by the *anal canal*—the terminal inch and a half of the bowel.

Though they have the contrasted designations of "small" and "large" because the small intestine is usually of narrower calibre than the large intestine, yet it is not invariably narrower, and it is very much longer. They have the same general structure of serous, muscular, submucous and mucous coats (see below), but there are certain obvious differences between them. The small intestine is uniformly smooth and, with the exception of the duodenum, has a complete coat of peritoneum. Its longitudinal muscular coat is uniformly distributed around its circumference. The greater part of the large intestine—in fact, the whole colon—is puckered and sacculated, and, excepting the cæcum and the middle and terminal parts of the colon, it has only a partial coat of peritoneum. Another obvious and characteristic difference from the small intestine is that all over the colon little pockets of peritoneum filled with fat hang from its surfaces; these are called *appendices epiploicæ*, and their significance is obscure.

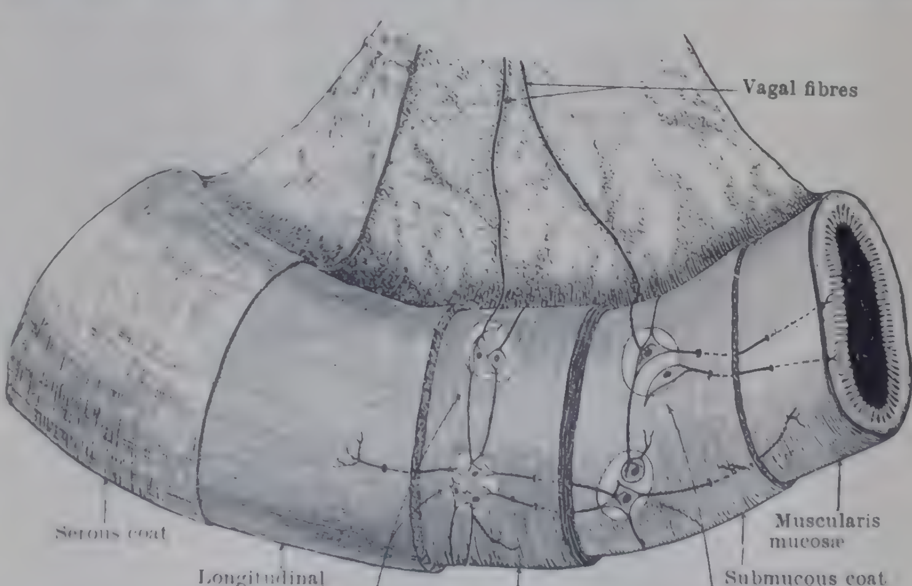

Fig. 531.—Diagram of Connexions and Distribution of the Enteric Plexuses. (After C. J. Hill, 1927.)

Characteristic of the large intestine, as far down as the rectum, is the arrangement of the bundles of longitudinal muscle. They are grouped into three obvious bands, termed the *tæniæ coli*, but in the intervals between these bands, according to Hamilton (1946), the longitudinal muscular coat is present as a definite layer "a little less than one-half the thickness of the circular coat".

The sacculated appearance is often well seen in radiographs of the abdomen, when the gut is filled with material opaque to X-rays (Pls. XLVIII, LVII, LVIII, LIX, LX, pp. 559, 648, 649).

Structure.—Both small and large intestines have four coats—serous, muscular, submucous, and mucous. The external *serous coat* forms a complete or a partial covering in different parts. The underlying *muscular coat*, formed of two layers of plain muscle—an outer longitudinal, and an inner, whose fibres are circular or ring-like—is separated by the submucous coat from the mucous coat, which lines the interior of the canal. It has been stated (Carey, 1921) that in the small intestine of many mammals the muscular layers are not truly circular or longitudinal, but are both spiral, the inner coat forming a close spiral and the outer a long one. In the inner coat one complete turn is made in every 0·5 to 1 mm. or less, while those of the outer coat which are spiral make a complete turn in every 200 to 500 mm. or more. The *submucous coat* consists of a layer of loosely arranged but strong areolar tissue. The *mucous coat* shows three layers of component tissue, viz., internally a layer of columnar epithelium, which may be more than one layer of cells in thickness and rests on a thin layer of loose areolar tissue, external to which there is a thin sheet of plain muscle called the *lamina muscularis mucosæ*. The internal surface of the mucous coat shows the openings of an enormous number of *intestinal glands*—small straight tubular glands—whose closed ends lie in the deeper part of the mucous coat. The internal surfaces of the small and large intestines differ from one another in many respects, and especially in that the mucous coat of the

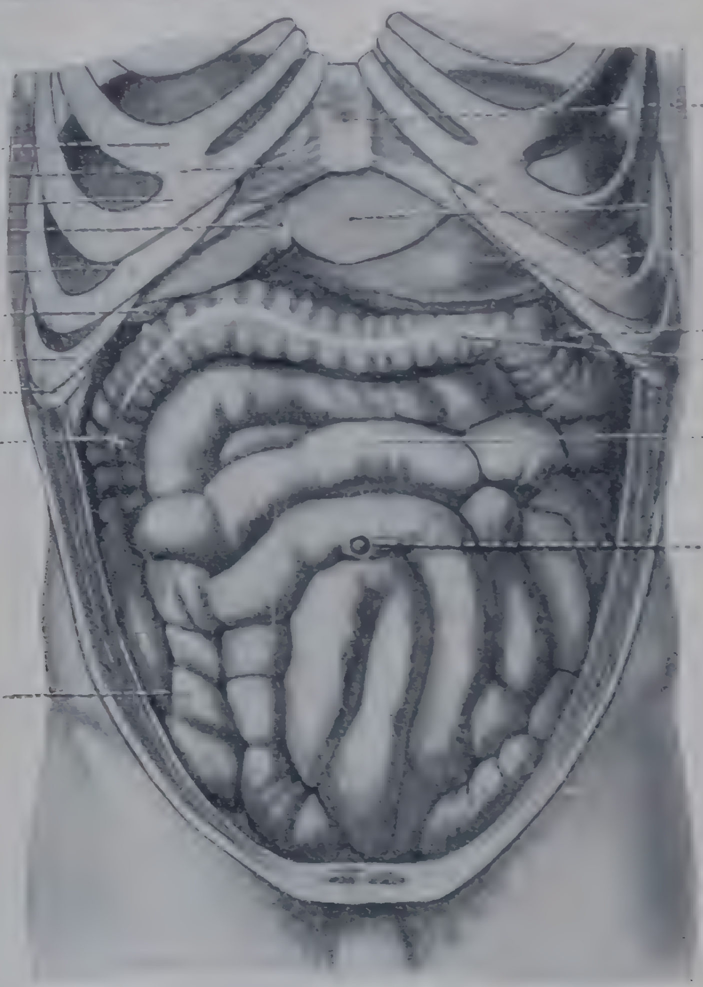

FIG. 532.—ABDOMINAL VISCERA, AFTER REMOVAL OF GREATER OMENTUM.
The oblique position of the stomach and the high position of the transverse colon are largely due to the fact that the subject was fixed in the horizontal position.

small intestine is covered with villi, is thrown into permanent folds, and has in its substance aggregated as well as solitary lymphatic nodules.

Nerves.—The intestine has a rich supply of nerves belonging to the sympathetic and parasympathetic systems. *Sympathetic* fibres are distributed to the whole of the intestine as far as the rectum through the cœliac, the superior and the inferior mesenteric plexuses, and along finer extensions from these major networks which accompany the branches of the blood-vessels. The source of the sympathetic fibres which run through the cœliac and superior mesenteric plexuses, namely the thoracic splanchnic nerves, is supplemented for the lower part of the colon mainly by splanchnic branches from the upper two lumbar ganglia of both sides. These run downwards and forwards to join the inferior mesenteric plexus, and they are probably more important than other fibres which may reach the inferior mesenteric plexus through the hypogastric and pelvic plexuses from ganglia of the sympathetic trunks at a lower level (Telford and Stopford, 1934).

The sympathetic fibres are accompanied in their course through the plexuses by *parasympathetic* vagal fibres which pass to the cœliac plexus from the posterior gastric nerve (see nerve-

upply of stomach p. 620). Other parasympathetic fibres reach the inferior mesenteric plexus rom the pelvic splanchnic nerves (S. 2 and 3, or 3 and 4) by ascending through the pelvic and ıypogastric plexuses.

The nerves to the intestine thus constituted do not all follow the blood-vessels slavishly, nd Mitchell (1935) has described, in particular, a number of branches from the pelvic and hypogastric plexuses which take an upward, independent course across the lower left colic vessels o the descending and pelvic colons. These nerves communicate with the perivascular plexuses, nd he considers that they are probably important parasympathetic pathways to the distal colon.

On reaching the intestine the *parasympathetic fibres*, which are preganglionic and of uniform liameter, pierce the longitudinal muscle coat and some of the fibres end by synapsing round he cells of the ganglia of the *myenteric plexus*, whilst other fibres continue onwards and form imilar connexions in the *submucous plexus*. From the cells of the myenteric plexus postganglionic fibres run through the network and eventually end on the muscle-fibres of both the ongitudinal and the circular muscle coats (Fig. 531). From the cells of the submucous plexus ostganglionic fibres reach the lamina muscularis mucosæ and muscle-fibres in the villi; some f these vagal fibres also reach the intestinal glands.

The *sympathetic fibres*, on the other hand, are postganglionic when they reach the intestine, ıaving been relayed in the cœliac and other ganglia of the plexuses, and they are varicose and hinner than the vagal fibres. According to Hill (1927), whose work was done on rabbit and uinea-pig material, the majority of the sympathetic fibres are distributed to the blood-vessels f the intestinal walls. In the case of the stomach and colon, a few fibres pass to a special plexus mmediately internal to the myenteric plexus; and, in the case of the small intestine, some join the ıyenteric plexus itself, where they become indistinguishable from the postganglionic vagal fibres.

Other sympathetic fibres form fine, scattered plexuses in the subserous and submucous layers, eaching from the latter into the subepithelial layer of the villi (Fig. 533). These are probably ensory in nature. The stimuli to which they respond are stretching of the gut, strong musclecontraction, and probably also the toxins and tensions of inflammation. These stimuli may xcite reflexes, or they may give rise to painful sensations, referred for the most part to that egion of the abdominal wall which has a somatic nerve-supply corresponding segmentally to hat of the part of the intestine affected by the stimulus. The whole of the intestine, however, xcept the anal canal, is quite insensitive to other stimuli which, when applied to most of the ther parts of the body, give rise to pain.

SMALL INTESTINE

The **small intestine** (intestinum tenue) commences at the pylorus and ends at he ileo-colic valve by joining the large intestine. It occupies the greater portion f the abdominal cavity below the liver and stomach (Fig. 479), and part of it ies in the pelvic cavity.

In *length*, the small intestine usually measures some 20 to 22 feet. In form it s cylindrical, with a *diameter* that varies from nearly two inches (47 mm.) in the uodenum to a little over an inch (27 mm.) at the end of the ileum; there is thus gradual diminution in its size from the pylorus to the ileo-colic valve.

The small intestine is relatively longer in the child than in the adult; at birth it is to the total eight of the child as 7 to 1, whilst in the adult the proportion is as 4 to 1. It is generally eld that the small gut is relatively longer in the male than the female.

While the entire length of the intestine in its most extended form after death, when muscular onus has disappeared, may be 20 to 22 feet as stated, it is probable that during life the length s not so great. The muscular coats, both longitudinal and circular, are more or less contracted, nd probably the total length during life may be estimated as 15 to 17 feet.

In formalin-hardened bodies the small bowel rarely measures more than 12 or 13 feet in ength. Similarly its diameter is often reduced in places to ½ or ¾ inch (12 to 18 mm.), lthough the greater part of the gut may retain its usual width: these narrow parts have pparently been fixed in a state of contraction.

The small intestine is divided into three parts—(1) the **duodenum** (Fig. 537), onstituting the first ten inches, distinctly marked off from the rest by its xation and the absence of a mesentery; (2) the **jejunum**, which comprises the pper two-fifths of the remainder, and (3) the **ileum**, the lower three-fifths. The ejunum and ileum pass imperceptibly into each other, and the line of division etween them is artificial. Typical parts of the two—namely, the beginning of he jejunum and the end of the ileum—differ in size and in the appearance resented by their lining mucous membrane, and they can be distinguished from ach other without difficulty (see p. 635).

The characteristic features of the small intestine are found on its inner surface n special developments of its mucous coat: they are (1) intestinal villi; (2) ircular folds; and (3) aggregated lymphatic nodules.

Intestinal Villi.—The mucous coat of all parts of the small intestine has a soft, velvety appearance (Fig. 534, B) which is due to the presence of an enormous number of minute processes known as villi.

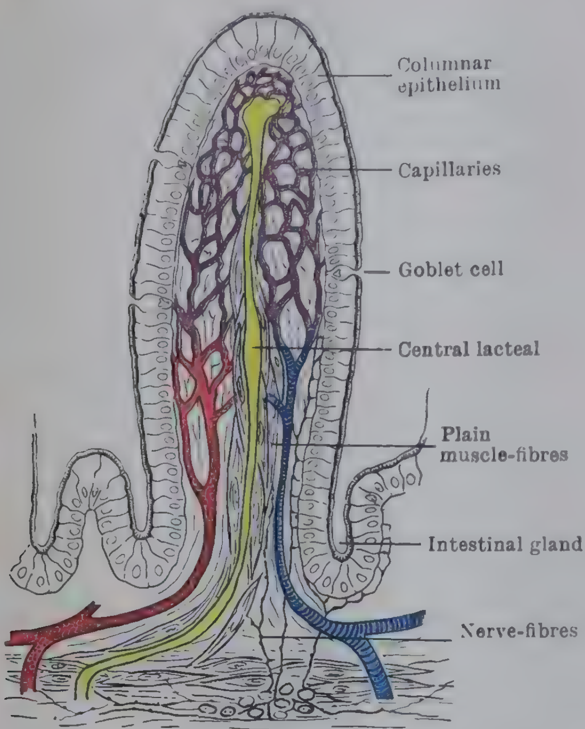

FIG. 533.—STRUCTURE OF AN INTESTINAL VILLUS. (Diagrammatic.)

They are minute, cylindrical or finger-like projections of the mucous coat (Fig. 535) about $\frac{1}{20}$th to $\frac{1}{50}$th of an inch (1·2 to 0·5 mm.) in height, barely visible to the naked eye. They begin at the edge of the pyloric orifice and are broad and short in the duodenum, but grow narrower as they are followed down through the intestine to the ileo-colic valve, at the edge of which they cease. They are found not only on the general surface of the mucous membrane but also on the circular folds, and, while they are not present over the solitary lymphatic nodules, they are found on the surface of the aggregated nodules.

Structure of Villi.—Each villus is covered by a layer of columnar cells set upon a basement membrane. These cells have a finely striated border, and goblet cells are interspersed amongst them. The core of a villus has a fine reticulum of connective tissue cells and fibres, with strands of smooth muscle-fibres that run parallel to the axis of the villus and have their origins in the muscularis mucosæ (Fig. 533).

In the centre of each villus there is a channel lined with flattened endothelium, known as the *central lacteal*, which drains into the lymph-vessels of the mucosa ; there may be several lacteal vessels within the larger villi. One or more arteries enter the base of the villus and break up into a dense capillary network which lies under the epithelium and surrounds the whole surface of the structure. The venous drainage is into the submucous plexus. A subepithelial nerve-plexus and nerve-fibres running from the submucous plexus to the muscle-cells have been described by Hill (1927).

Dilatation of the blood-vessels causes enlargement of the villus, while contraction of the muscle-layer diminishes its height and serves to assist in emptying the lacteal into the lymph-vessels. The villi thus play an important part in the absorption of the products of digestion. According to Spanner (1931) there is an arterio-venous anastomosis in each villus which acts as a by-pass when absorption is not active.

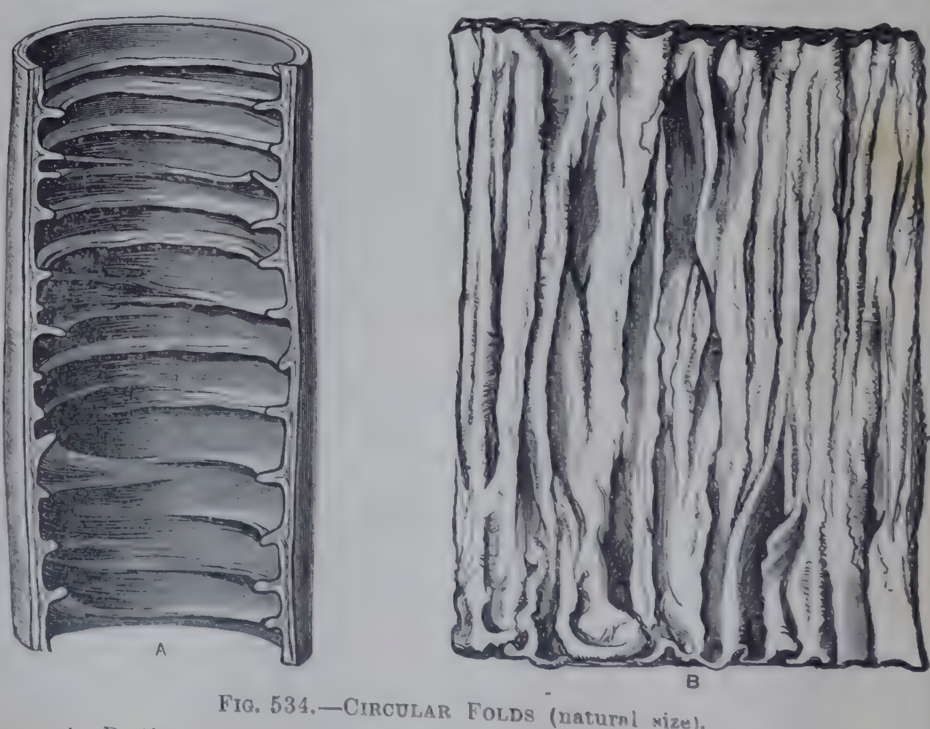

FIG. 534.—CIRCULAR FOLDS (natural size).
A. Portion of jejunum which has been filled with alcohol and hardened ;
B. Portion of fresh intestine spread out under water.

Circular Folds.—When the intestine is empty and contracted, its mucous membrane is thrown into folds which disappear on distension. In addition to

these, there are in certain portions of the small intestine a series of large, permanent folds, known as circular folds (Fig. 534). They are usually more or less crescentic folds of the mucous coat, with a prolongation from the submucous coat, and resemble a series of closely placed shelves running transversely around the gut. They rarely form more than two-thirds of a circle; sometimes, however, they present a spiral arrangement, the spiral extending little more than once round the tube, as a rule. Occasionally they bifurcate at one or both ends; sometimes, too, short irregularly directed branches pass off from them. They are usually about 2 to 3 inches (5 to 7·5 cm.) in length, and their height, that is, their projection into the cavity, may be as much as $\frac{1}{3}$ of an inch (8 mm.), whilst in thickness they measure about $\frac{1}{8}$ inch (3 mm.).

They increase the amount of surface available for secretion and absorption.

Circular folds begin at a distance of from 1 to 2 inches (2·5 to 5 cm.) beyond the pylorus. At first they are small, irregular, and scattered; but they are larger lower down, and at the opening of the bile-duct (4 inches from the pylorus) they are distinct and prominent. In the rest of the duodenum, and in the upper half of the jejunum, they are highly developed, being large, broad, and closely set. In the lower half of the jejunum they become gradually smaller and fewer. In the ileum they become still smaller and more irregular, and, as a rule, they practically cease a little below its middle, but though much reduced in size they can be traced to within a short distance of the ileo-colic valve.

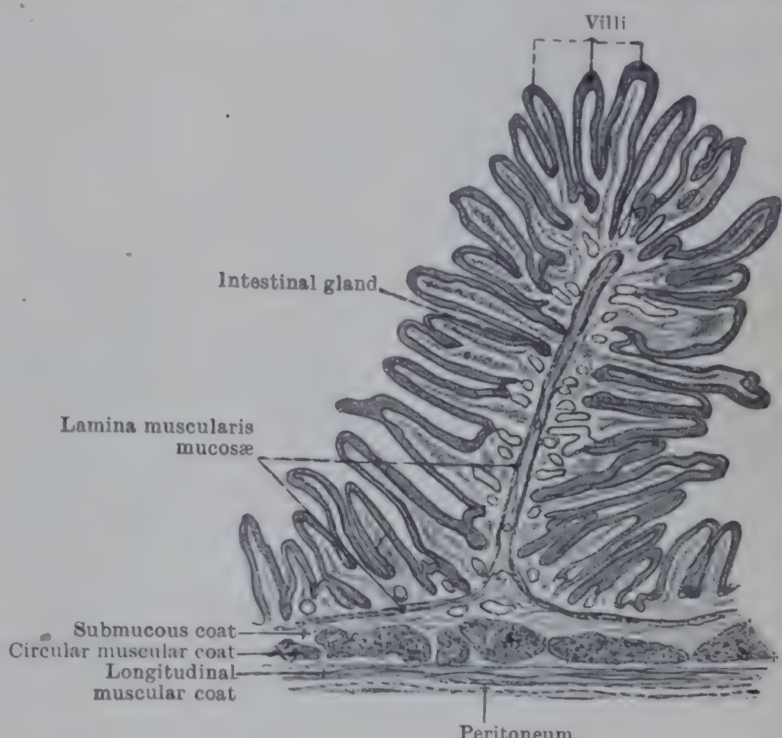

Fig. 535.—Longitudinal Section of Wall of Small Intestine passing transversely through a Circular Fold.

Lymphatic Nodules.—The **solitary lymphatic nodules** are minute masses of lymphoid tissue, opaque and of a whitish colour, which project on the surface of the mucous membrane throughout the whole length of both the small and the large intestine.

Isolated lymph-cells are found in abundance scattered through the areolar tissue layer of the intestinal mucous membrane generally; in places these cells are gathered together to form little nodules, supported by a framework of reticular tissue and surrounded by a lymph-space which communicates externally with the lymph-vessels of the submucous coat. Such a collection of lymph-cells constitutes a solitary nodule. They are usually of a rounded or oval shape (Fig. 536), the deep surface resting in the submucous coat, the nodule itself piercing the lamina muscularis mucosæ, and the free surface projecting slightly above the general surface of the mucous membrane. In size they vary from $\frac{1}{40}$th to $\frac{1}{8}$th of an inch (0·6 to 3·0 mm.), but their average bulk is about that of a small grain of sago, to which they bear some resemblance. They are particularly abundant in the vermiform appendix and the cæcum.

The **aggregated lymphatic nodules** consist of a large number of minute lymphatic nodules grouped closely together and forming a slightly elevated area, usually of an oblong form, on the surface of the mucous membrane (Fig. 536). In length they vary from half an inch (12 mm.), or less, to three or four inches (100 mm.), and in width they commonly measure from a third to half an inch (8 to 12 mm.). Their number is variable, but in the average condition about

20 or 30 are found. They are best marked in young subjects, where they form considerable elevations above the general surface and may be as many as 45 in number. After middle life they atrophy, and in old age, although usually present, they are indistinct. Occasionally their positions are marked by little more than a dark discoloration of the mucous membrane. They are situated along the surface of the intestine opposite the line of mesenteric attachment, with their long axis corresponding to that of the bowel.

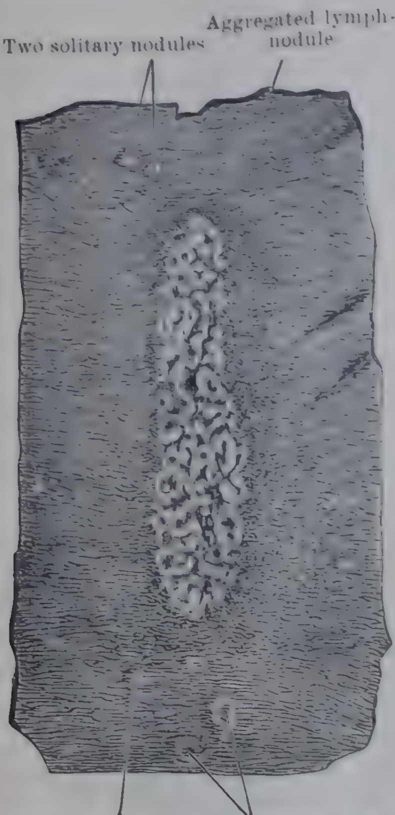

FIG. 536.—SOLITARY and AGGREGATED LYMPHATIC NODULES FROM ILEUM OF CHILD TWO YEARS OLD (natural size).

Near the lower border are seen a few small patches made up of two or three lymphatic nodules; they are marked "intermediate form".

The aggregated nodules are confined to the small intestine, being largest and most numerous in the ileum, particularly in its distal part, where they usually assume an oblong shape; in the distal half of the jejunum they are small, circular, and few in number; in its proximal part they are much less numerous: and in the duodenum only a few can be found.

The circular folds stop at the margins of the aggregated nodules, and are not continued across them; but villi are found on the surface of the aggregated nodules, in the intervals between the individual nodules.

The chief bowel lesion in typhoid (enteric) fever is found in the nodules—both aggregated and solitary.

When the surface of one of those nodules from a child's intestine (in which these structures are particularly well developed) is carefully examined, it is seen to be made up, not of a series of separate, rounded nodules grouped together but rather of a number of wavy, irregular, and branching ridges connected with one another by cross-branches, the whole recalling in miniature the appearance of a relief map of a very mountainous district in which the chief chains run irregular courses and are joined to one another by connecting ridges.

Small patches, intermediate in form between solitary and aggregated nodules, and consisting of two or three lymphatic nodules, are also found.

DUODENUM

The **duodenum** is the first part of the small intestine, and it differs from the rest of the tube in that, having no mesentery, it is fixed to the posterior abdominal wall. The ducts of the liver and pancreas open into it, and some distinctive glands, termed the *duodenal glands*, are found in its wall.

Position, Shape, and Dimensions.—The duodenum begins at the pylorus about the level of the first lumbar vertebra, and it ends at the **duodeno-jejunal flexure** on the left side of the second lumbar vertebra (Fig. 537). It lies on the posterior wall of the abdomen opposite the upper three lumbar vertebræ, and, with the exception of its terminal part, it lies to the right of the median plane.

It forms an irregular horseshoe-shaped curve, with the opening directed upwards and to the left, and the ends reaching to within about two inches of each other. Within the concavity of the curve lies the head and neck of the pancreas.

The duodenum is about 10 inches (25·0 cm.) in length, and it has a diameter of from $1\frac{1}{2}$ to 2 inches (3·5-5·0 cm.).

Various Forms of Duodenum.—Three different types of duodenum have been described—(1) the **annular,** in which the curves separating the various parts are open, and the two extremities come fairly close to one another; (2) the **U-shaped,** in which the third part is very long, and the fourth part is nearly vertical; and (3) the **V-shaped** duodenum, in which the third part is very short or absent.

Divisions and Relations.—For descriptive purposes the duodenum is divided into four parts, viz. :—(1) A *first* part, which passes from the pylorus obliquely backwards, to the right and slightly upwards. (2) A *second* part, which descends vertically. (3) A *third* part, which is directed horizontally from right to left. (4) A *fourth* part, which ascends vertically or with a slight obliquity to the left to end in the duodeno-jejunal flexure.

First Part.—The first part is about 2 inches (5·0 cm.) long, and it has a considerable degree of mobility. Its commencement is sometimes indicated by a slight groove, and there is always a sudden transition that can be felt between the thick walls of the pylorus and the thin walls of the duodenum. For the first inch of its course, the first part of the duodenum has the same peritoneal relationships as the pyloric part of the stomach. Thus, it is suspended from the liver by the lesser omentum, whilst from its

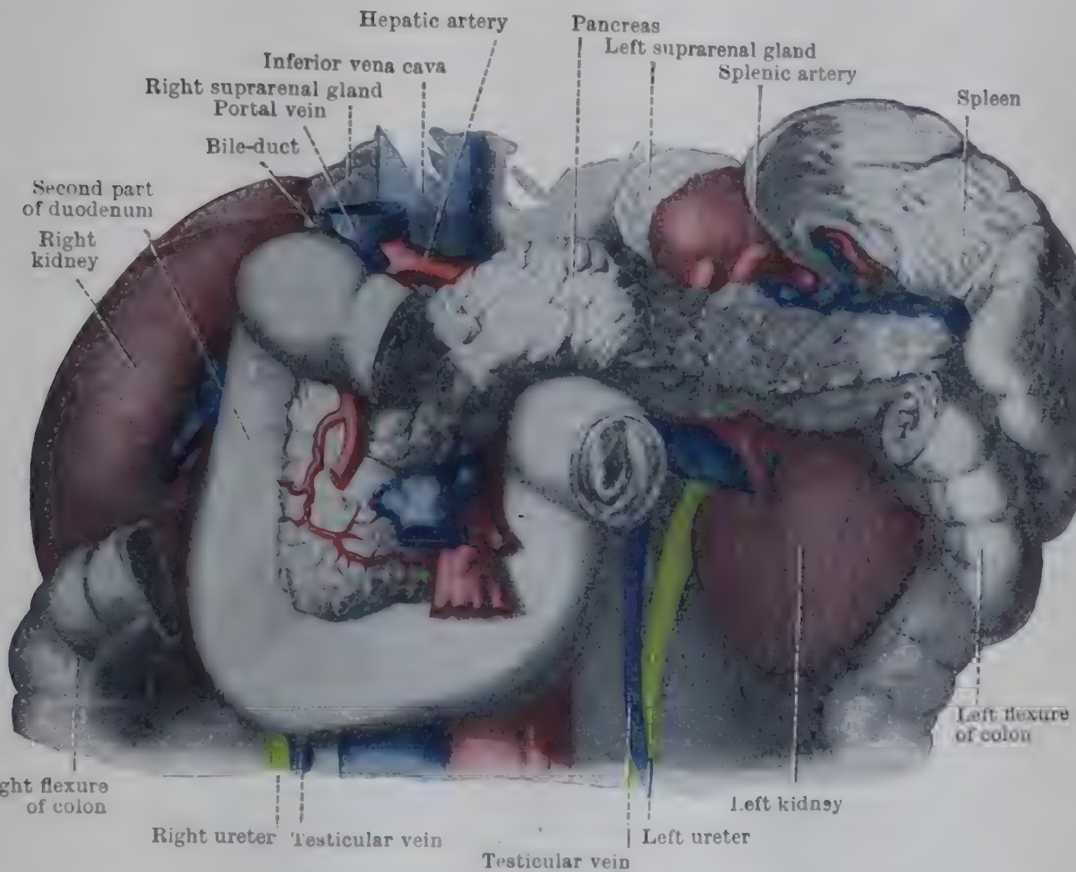

FIG. 537.—DISSECTION TO SHOW RELATIONS OF DUODENUM. The stomach has been cut and removed close to the pylorus. The transverse colon has been taken away, and the small intestine has been cut across close to the duodeno-jejunal flexure. (From a model by Birmingham.)

lower border hangs the right edge of the greater omentum. The *anterior surface* is covered with peritoneum and looks into the greater sac, where it comes into relation with the quadrate lobe of the liver and the body of the gall-bladder. The closeness of this contact is often indicated in the cadaver by a staining of the duodenum with bile which has escaped through the walls of the gall-bladder. The *posterior surface* of the first inch also is covered with peritoneum, and it looks backwards into the lesser sac, which separates it from the neck of the pancreas.

The second inch or so of the first part of the duodenum curves backwards and is covered with peritoneum on its superior and lateral surfaces only. Its medial surface is directly related to the portal vein, bile-duct, and gastro-duodenal artery (Fig. 537), and its inferior surface rests on the head of the pancreas. The lateral surface is related to the neck of the gall-bladder and the superior surface is the lower boundary of the opening into the lesser sac, which separates it from the caudate process of the liver. In order to enter the attachment of the right border of the lesser omentum the hepatic artery runs horizontally forwards above the pancreas but below the opening into the lesser sac and on the medial side of the duodenum. As the hepatic artery enters the lesser omentum it gives off the right gastric artery, which runs forwards and to the left along the upper border of the first part of the duodenum in the lower attachment of the lesser omentum. The gastro-duodenal artery on the other hand, descends vertically behind and to the left of this part of the duodenum.

Here it is accompanied by the bile-duct on its right and by the portal vein behind it. On reaching the lower border of the duodenum the gastro-duodenal artery gives off the right gastro-epiploic branch which runs forwards along the lower border of the duodenum in the attachment of the greater omentum.

Second Part.—The second part measures about 3 inches (7·5 cm.) in length, and it descends from the region of the neck of the gall-bladder opposite the upper part of the first lumbar vertebra to the level of the third lumbar vertebra. In its descent it lies on the posterior abdominal wall to the right of the vertebral column and the inferior vena cava, and it is crossed in front by the transverse colon.

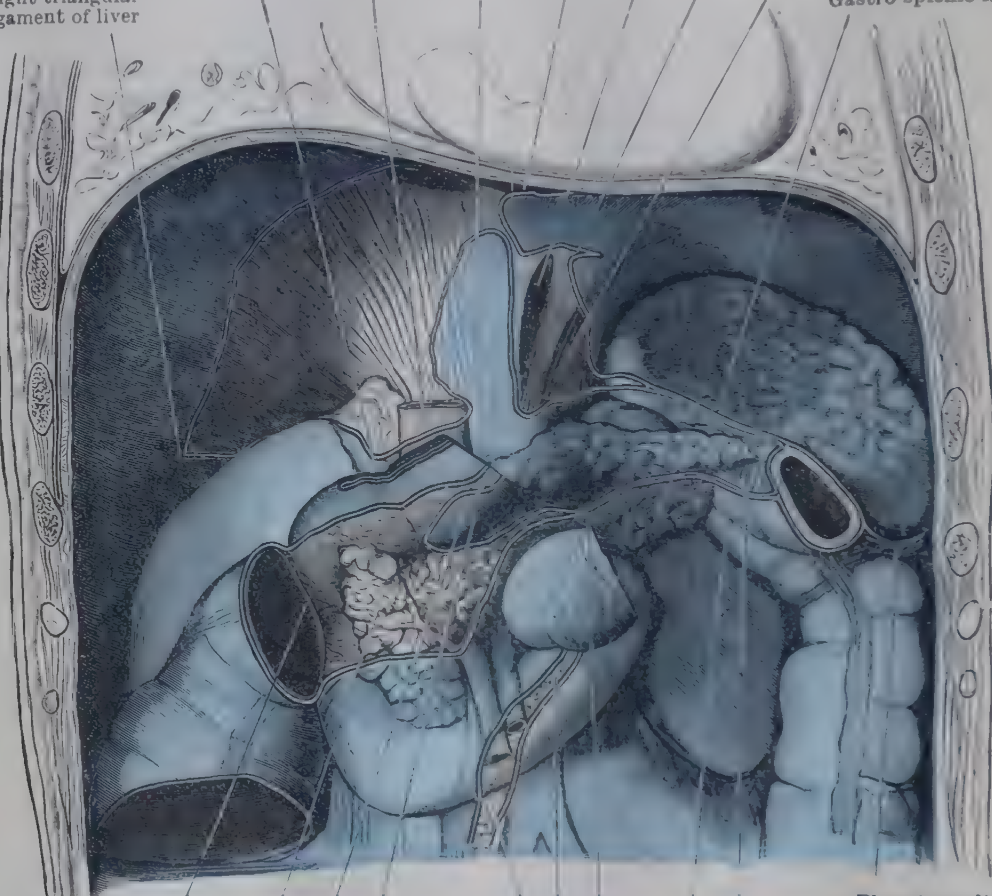

FIG. 538.—PERITONEAL RELATIONS OF DUODENUM, PANCREAS, SPLEEN, KIDNEYS, ETC.
From a body hardened by injections of formalin. When the liver, stomach, and intestines were removed the lines of the peritoneal reflexions were carefully preserved. The peritoneum is coloured blue.

At its commencement it is related *posteriorly* to the right suprarenal gland, and below this to the right kidney near its hilum, to the right renal vessels, to the pelvis of the right ureter, and to the right psoas major muscle.

The *anterior* and *lateral surfaces*, above and below the transverse colon, are covered with peritoneum. Above the colon, these surfaces of the duodenum look into the upper compartment of the general peritoneal cavity and form a bulging which accounts for the duodenal impression on the right lobe of the liver. Below the colon they look into the lower compartment of the cavity and are related to coils of the jejunum. These two peritoneal-covered areas are separated by the attachment of the root of the transverse mesocolon or by the transverse colon itself when the layers of the right part of the mesocolon shorten and separate to leave the back of that part of the colon bare.

The *medial surface* of the second part is in contact with the head of the pancreas, which

occasionally overlaps it anteriorly and posteriorly; and the anastomosis formed by the superior and inferior pancreatico-duodenal arteries is between the duodenum and pancreas.

The bile-duct, after passing down behind the first part of the duodenum, descends between the head of the pancreas (usually embedded in its substance) and the second part, nearly as far as its middle. There, it is joined by the pancreatic duct, and the two, piercing the wall of the duodenum obliquely, open into it by a common orifice $3\frac{1}{2}$ or 4 inches (8·5 to 10 cm.) beyond the pylorus.

Third Part.—This part runs more or less transversely to the left for a distance of about 3 inches (7·5 cm.). As it crosses the posterior abdominal wall it is separated from the vertebral column by the right ureter, the right psoas major, the right testicular or ovarian vessels, the inferior vena cava, and the aorta.

The *anterior* and *inferior surfaces* are covered with peritoneum and are in relation to coils of the jejunum. Near its termination the superior mesenteric vessels pass in front of it in the root of the mesentery. The *superior surface* is in close relation to the head of the pancreas.

Fourth Part.—The fourth part of the duodenum is about 2 inches (5·0 cm.) in length, and it ascends along the left side of the aorta to the level of the second lumbar vertebra to terminate by bending abruptly forwards into the duodeno-jejunal flexure.

As it ascends it lies in front of the left sympathetic trunk, the left psoas major, and the left testicular or ovarian artery.

The root of the mesentery begins on the front of this part of the duodenum at the duodeno-jejunal flexure; thence, it runs obliquely down to the right, and finally leaves the third part of the duodenum near its union with the fourth part. The *front* and *lateral side* of the fourth part are covered with peritoneum and are in contact with some coils of the jejunum; the *medial side* is closely applied to the uncinate process of the pancreas and the aorta.

Duodenal Peritoneal Recesses.—In the neighbourhood of the fourth part of the duodenum there may be four peritoneal pockets—the superior and inferior duodenal, the paraduodenal, and the retroduodenal recesses (Fig. 539). These fossæ and the peritoneal folds guarding them are of considerable interest, because they are situated in a region where developmental failures may occur that require surgical interference. Thus one or other of the recesses may present itself as the sac of an 'internal' or retroperitoneal hernia (p. 1502). These herniæ are now regarded as essentially congenital in nature, and the result of defects in the normal developmental rotation of the intestine and its mesentery around the axis of the superior mesenteric artery as described on page 677. In such cases the greater part of the small intestine may be found imprisoned behind the mesentery of the colon, and the neck of the sac may or may not have large mesenteric vessels constricting it according to its position. For a more detailed account of the anatomy and mechanism of production of these recesses and herniæ see Treves (1885), Moynihan (1906), Andrews (1923) and Longacre (1934).

When the fourth part of the duodenum is drawn medially, two triangular folds of peritoneum will generally be found passing from the duodenum to the abdominal wall (Fig. 539). Each fold is attached by one border to the duodenum and by another to the parietal peritoneum at the left side of the duodenum, whilst the third margin is free and bounds the opening of a small pouch which lies behind the fold. Of these folds, the *upper* is situated near the termination of the duodenum with its free margin directed down. It sometimes contains a portion of the inferior mesenteric vein. Behind it lies the **superior duodenal recess**, whose opening looks downwards and will usually admit

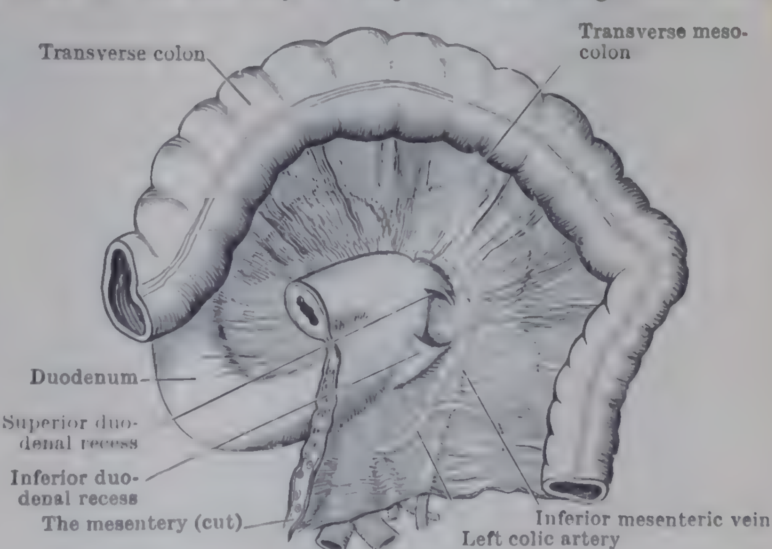

Fig. 539.—Duodenal Folds and Recesses.

The transverse colon and mesocolon have been thrown up, and the mesentery has been turned to the right and cut. The paraduodenal fossa is situated to the medial side of the inferior mesenteric vein, between it and the terminal part of the duodenum. It is not shown in the illustration.

the tip of a finger (Fig. 539). The second fold is placed lower down. Its free border is directed upwards, as is the mouth of the **inferior duodenal recess**, which lies behind it. The inferior recess is larger and more constant than the superior; it is present in 75 per cent of bodies, whilst the superior is present in 50 per cent (Jonnesco, 1895).

Paraduodenal Recess.—This recess, which is seen best in the infant, is placed to the left of the fourth part of the duodenum. It is produced by the inferior mesenteric vein raising up a fold of peritoneum termed the **paraduodenal fold** as it runs along the lateral side of the recess and then above it (see Fig. 539, where the vein, but not the fold or recess is shown). According to Moynihan (1906), this is the only recess to the left of the duodenum capable of developing into the sac of a hernia; and, when that occurs, the inferior mesenteric vein always lies in the anterior margin of the orifice of the sac (accompanied for some distance by the ascending branch of the superior left colic artery).

The **retroduodenal recess** is a small pocket that passes behind the fourth part of the duodenum from its left margin.

Interior of Duodenum.—No circular folds are found in the duodenum for an inch or two beyond the pylorus. They begin as low, scattered, and irregular folds which gradually become larger, more regular, and more numerous, and at the middle of the second part are of considerable size. In the third and fourth part of the duodenum the folds are large, prominent, and closely set.

Fig. 540.—Interior of Second Part of Duodenum (viewed from the Front) showing Duodenal Papilla and Opening of Accessory Pancreatic Duct.

On the postero-medial wall of the second part, about its middle—*i.e.*, 3½ or 4 inches (8·5 to 10 cm.) beyond the pylorus—there is a small papilla on which the bile-duct and pancreatic duct open by a common orifice (Fig. 567, p. 666); it is known as the **duodenal papilla**.

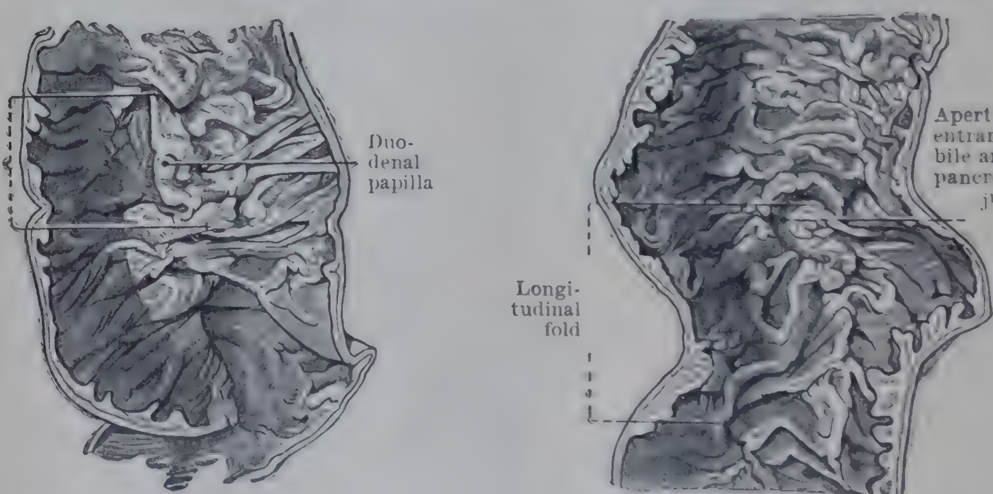

Fig. 541.—Variation of Duodenal Papilla.

A. At middle of longitudinal fold. B. Absent; the opening of the ducts is on the upper part of posterior face of longitudinal fold.

The papilla is placed beneath, and protected by, a hood-like circular fold. From its lower margin a ridge of the mucous membrane, called the *longitudinal fold of the duodenum*, descends for a considerable distance and acts as a frenum which fixes the papilla and directs its apex slightly downwards (Fig. 540). The common orifice of the bile-duct and pancreatic duct on the summit of the papilla is so narrow that it can admit only the point of a pencil.

The position of the papilla in relation to the longitudinal fold varies, and the papilla may even be absent (Fig. 541). For variations of the opening of the bile-duct, see p. 667.

Nearly an inch higher up, and on a slightly more ventral plane, there is a second and smaller papilla on whose summit the accessory pancreatic duct opens by a very small orifice. The second papilla seems to be constantly present, although sometimes so small that it may easily

escape detection unless carefully sought for. When well developed it may have a hood-like fold and a little frenulum like those of the duodenal papilla.

Structure of Duodenum.—The serous coat has been described with the several parts of the duodenum.

The **muscular coat** is well developed, and is pierced by the bile-duct and pancreatic duct. As these united ducts traverse the muscular wall they are surrounded by a sphincter-like group of fibres which extends into the papilla.

The **submucous coat** differs from that of the rest of the small intestine in that it contains, especially in the upper half of the duodenum, the **duodenal glands**. They are small acino-tubular glands that closely resemble the pyloric glands of the stomach; they lie in the submucous coat and send their ducts through the lamina muscularis mucosæ to open on the surface between the intestinal glands or, sometimes, into these glands themselves (Fig. 542). To naked-eye examination they are small, round or flattened masses of a reddish-grey colour, and vary in size from $\frac{1}{50}$th to $\frac{1}{12}$th of an inch in diameter (0·5 to 2·0 mm.). They form an almost continuous layer as far as the opening of the bile-duct; beyond that they diminish progressively, and they completely disappear near the duodeno-jejunal flexure.

The **mucous coat** is thicker in the duodenum than in any other part of the small intestine, and it is covered throughout with broad, short villi.

Vessels and Nerves.—The main **arteries** are the superior and inferior pancreatico-duodenal—branches of the gastro-duodenal and superior mesenteric arteries respectively; but the first part receives also a small branch from the right gastric artery, which is said to have little or no anastomoses with the others. The blood is returned by the **pancreatico-duodenal veins**, of which some pass downwards and to the left on the front of the head of pancreas and join the superior mesenteric vein (Fig. 568, p. 669); while others cross the back of the head of pancreas and open into the portal vein or the superior mesenteric vein.

The **lymph-vessels** for the most part follow the course of the blood-vessels and end in adjacent groups of lymph-glands.

The **nerves** come from the *cœliac* and *superior mesenteric plexuses* of the sympathetic.

Duodenal Diverticula.—Occasional diverticula are found passing from the duodenal wall in different directions. Such diverticula may be hernial protrusions of the mucous and submucous coats through the muscular wall, termed "false" diverticula, or they may be "true" diverticula, in which all the coats are represented, and they may contain pancreatic tissue in their wall. They are usually situated on the aspect of the duodenum which is in contact with the pancreas, and frequently in the neighbourhood of the orifice of the bile-duct. Some of them appear to be due to pressure from the interior of the duodenum, while others, including most of the true diverticula, are congenital in origin and are possibly associated with the diverticula which give rise to the liver and pancreas. The foregoing is a summary of the standard account of this condition by Baldwin (1911); for a later discussion and description of a case, see Maclean (1923).

Duodeno-Jejunal Flexure.—When the fourth part of the duodenum reaches the inferior surface of the body of the pancreas, at a point opposite the left side of the second lumbar vertebra, it turns abruptly forwards, downwards, and to the left, and passes into the jejunum. The abrupt bend is known as the **duodeno-jejunal flexure.** Unlike the rest of the duodenum, which is subject to considerable variations in position in different individuals, the duodeno-jejunal flexure is fixed by a thin band of muscle called the *suspensory muscle of the duodenum* (Treitz, 1853), which blends, at the flexure, with the muscular coat of the duodenum. Thence, it passes upwards behind the pancreas, is connected with the fibrous tunic around the cœliac artery, and is continued above into the right crus of the diaphragm (p. 452). For more details about this so-called *muscle of Treitz*, see Lockwood (1889), Low (1907), and Crymble (1910).

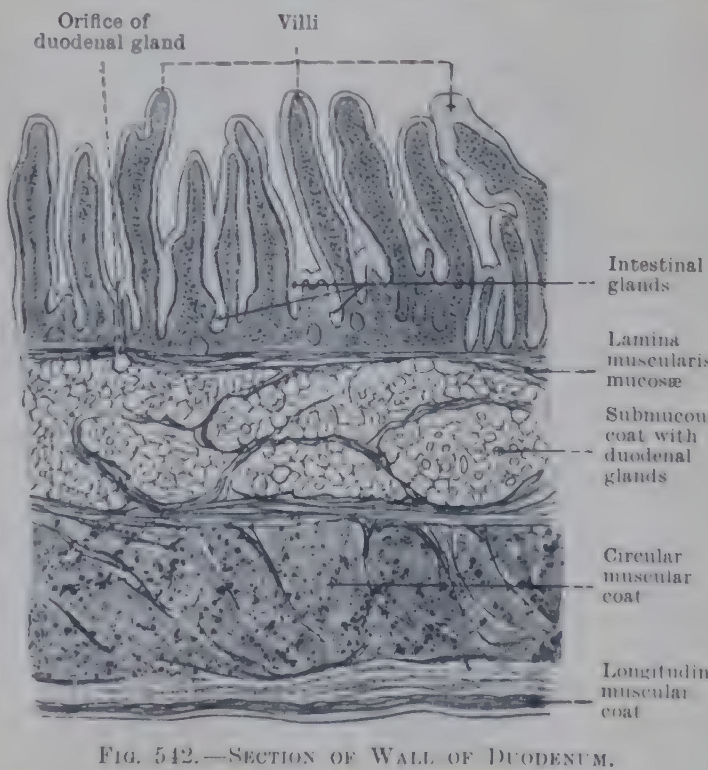

FIG. 542.—SECTION OF WALL OF DUODENUM.

The duodeno-jejunal flexure is occasionally directed to the right, and it lies at a variable distance from the root of the transverse mesocolon; when the attachment of the mesocolon is low, the duodeno-jejunal flexure is in contact with it.

Jejunum and Ileum

The **jejunum** and **ileum** are attached to the posterior wall of the abdomen by *the mesentery*, which is a lamina of fibro-areolar tissue covered on each side with peritoneum, and containing blood-vessels, lymph-vessels, lymph-glands, and nerves.

The part of the tube to which the mesentery is connected is known as the mesenteric or attached border; the opposite side is the free border.

The **mesentery** is a broad, fan-shaped fold which connects the small intestine to the posterior wall of the abdomen. The long, free border of the fold contains the intestine within it. The other (or attached) border, called the **root of the mesentery**, is comparatively short, being only 6 or 7 inches long; but it is much thicker than the part near the gut, for it contains between its layers a considerable

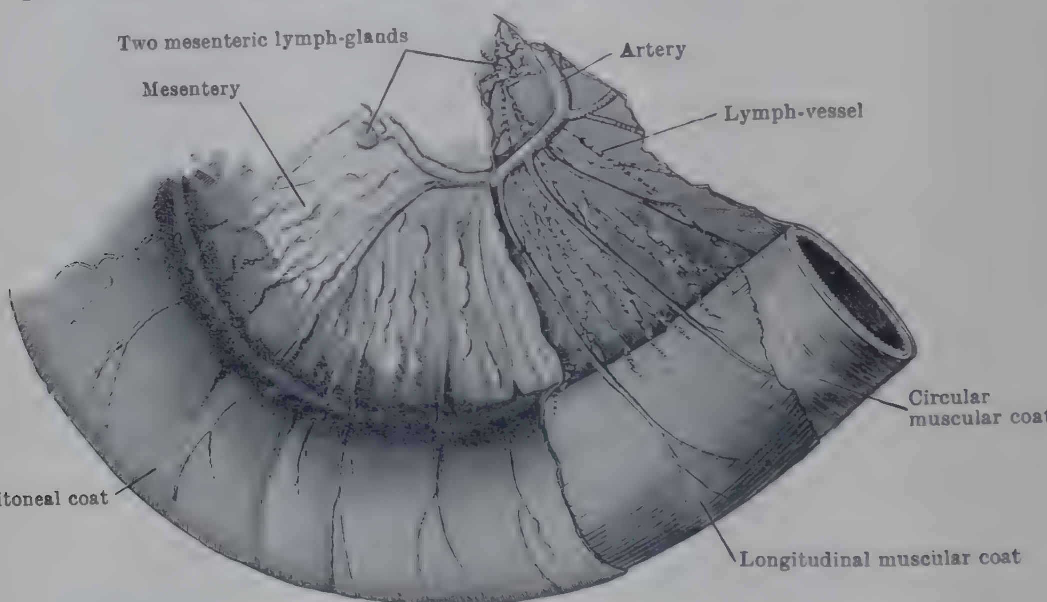

Fig. 543.—Portion of Small Intestine, with Mesentery and Vessels.
The peritoneal coat has been removed from the right half, and the two layers of the muscular coat exposed.

amount of fatty extraperitoneal tissue and the large vascular trunks that supply the intestine. **The root is attached to the posterior abdominal wall** along an oblique line which extends approximately from the left side of the second lumbar vertebra to the right sacro-iliac joint (Fig. 552). In that course the line of attachment passes from the duodeno-jejunal flexure down over the front of the third part of the duodenum, then obliquely across the aorta, the inferior vena cava, the right ureter, and psoas major muscle, to the right iliac region.

The unattached border of the mesentery is frilled out to an enormous degree, so that, while the root measures but 6 or 7 inches, the free border is extended to some 20 feet. The length of the mesentery, measured from its root to the attached edge of the intestine directly opposite, usually measures at its longest part about 6 inches (8 or 9 inches, Treves, 1885; and Lockwood, 1889). Its longest part goes to the portion of the small intestine situated between two points, one six feet, the other eleven feet from the duodenum (Treves, 1885).

Between the two layers of the mesentery (Fig. 543) there are:—(*a*) The jejunal and ileal branches of the superior mesenteric vessels, accompanied by nerve-plexuses and lymph-vessels; the nerves of the mesentery terminate, some in the intestinal wall, others in blood-vessels in the mesentery, and others form terminal plexuses with free nerve-endings; lamellated corpuscles also are occasionally present. (*b*) The mesenteric lymph-glands—between 100 and 200 in number. (*c*) A considerable amount of fatty fibro-areolar tissue, continuous with the extra-peritoneal areolar tissue. (*d*) The intestine itself.

The portion of the mesentery connected to the jejunum contains less fat than that of the ileum, and near the border of the jejunum there are oval or circular areas ("windows") where fat is absent and which are translucent. The mesentery attached to the ileum is usually fat-laden and opaque up to the margin of the intestine.

As a means of deciding which is the proximal and which the distal part of any particular loop of small intestine, it is helpful to note that the peritoneum from the right side of the mesentery is reflected laterally on the posterior abdominal wall to clothe the ascending colon. That of the left side, similarly, passes across the parietes to the descending colon.

The mesentery is of such a length that the coils are able to move about freely in the abdominal cavity, and consequently the position occupied by any portion of the tube, with the exception of the beginning of the jejunum and the ending of the ileum, can never be stated with certainty. Nevertheless, it may be said that, in general, the jejunum occupies the superior and left portions of the cavity below the stomach, the ileum the inferior and right divisions, its terminal part almost always lying in the pelvis just before it joins the large gut.

According to Mall (1898), the most usual arrangement is that the upper coils of the jejunum are on the left side and high up. The tube then crosses the vertebral column below the duodenum, and a few coils are placed on the right side. It then crosses to the left side again, and several coils are formed, some of which may descend into the true pelvis. Thence, it passes again to the right side, where it is coiled up, and then finally descends into the true pelvis.

The root of the mesentery pursues at its attachment an almost straight line from one end to the other, but, if cut across a very short distance from the posterior abdominal wall, it will there be found to form a wavy line. Farther away still, that condition becomes more and more marked; and, finally, if the mesentery is cut close to its attachment to the intestinal wall, it will be seen that its free edge is not only undulating but is frilled or goffered to an extreme degree. When shown in that way, it is found that the folding is not quite indiscriminate but that the main folds, of which there are usually six, run alternately to the right and left. As a rule, the first fold runs to the left from the duodeno-jejunal flexure and goes to a coil of jejunum which lies under the transverse mesocolon and helps to support the stomach. The second fold passes to the right, the third to the left, and so on up to the fifth and sixth, which are usually small. From the margins of the primary folds secondary folds project in all directions, and from those again even a third series may be formed.

The order is of course by no means constant, but if the intestine is removed from a hardened body without disturbing the mesentery, the mesentery will be found to be arranged with more or less regularity on some such plan as that indicated.

Structure (Fig. 531).—The **muscular coat** is thicker in the jejunum, and grows gradually thinner as it is traced down along the ileum. The **submucous coat** contains the bases of the solitary nodules, but otherwise calls for no special remark. The **mucous coat** is thicker and redder in the jejunum than in the ileum. It is covered throughout with villi, which are shorter and broader in the jejunum than in the ileum. In its whole extent it is closely set with intestinal glands, and numerous solitary nodules are seen projecting on its surface. Aggregated lymphatic nodules are particularly large and numerous in the ileum; they are fewer, smaller, and usually circular in the jejunum. Finally, the mucous membrane is thrown into *circular folds*, which are fully described on p. 626.

Vessels.—The **arteries**, on reaching the intestine, pass to one or other side of it and only occasionally bifurcate to give a branch to each side of the gut. They are at first under the peritoneal coat; soon, however, they pierce the muscular coat and form a plexus in the submucous coat from which numerous branches pass to the mucous coat, where some form plexuses around the intestinal glands whilst others pass to the villi. The **veins** are similarly disposed, and the blood from the whole of the small intestine beyond the duodenum is returned by the *superior mesenteric vein*, which joins with the splenic to form the portal vein.

The **lymph-vessels** of the small intestine (known as *lacteals*) begin in the villi, and also as lymph-sinuses around the bases of the solitary nodules; a large plexus is formed in the submucosa, a second between the two layers of the muscular coat, and a third beneath the peritoneum. The vessels from all these pass up in the mesentery, being connected on the way with the numerous *lymph-glands of the mesentery* and finally join the *gastro-intestinal trunk*, which opens into the cisterna chyli.

Differences between Jejunum and Ileum.—If the small intestine is followed down from the duodenum to the cæcum no noticeable change in appearance will be found at any one part of its course to indicate the transition from jejunum to ileum, for the one passes insensibly into the other. Nevertheless, a gradual change takes place, and if typical parts of the two, namely, the upper portion of the jejunum and the lower portion of the ileum, are examined, they will be found to present characteristic differences, which are set forth in the following table.

Jejunum.	Ileum.
Wider, $1\frac{1}{2}$ to $1\frac{1}{4}$ inches in diameter. Wall, thicker and heavier. Redder and more vascular. Circular folds, well developed. Villi, short and broad. Aggregated lymphatic nodules, few and small. Less fat in its mesentery and translucent areas present near the gut.	Narrower, $1\frac{1}{4}$ to 1 inch in diameter. Wall, thinner and lighter. Paler and less vascular. Circular folds, very small or absent. Villi, slender and filiform. Aggregated lymphatic nodules, large and numerous. Mesentery, fat-laden and opaque.

Diverticulum Ilei.—This is a short protrusion which springs from the lower part of the ileum in a little over 2 per cent of bodies. It is usually about 2 inches long and of the same width as the intestine. Most commonly it is found about $2\frac{3}{4}$ feet from the ileo-colic orifice and opposite the original termination of the superior mesenteric artery. As a rule, its end is free; but occasionally it is adherent either to the abdominal wall, the adjacent viscera, or the mesentery; and in such cases it may be the cause of strangulation of the intestine. This curious abnormality attracted the attention of earlier anatomists, but the younger J. F. Meckel (1808, 1812) was the first to explain it in terms of the normal development of the intestine; and it is still currently known as *Meckel's diverticulum.*

The diverticulum is due to the persistence of the proximal portion of the vitello-intestinal duct, which connects the primitive intestine of the embryo with the yolk-sac. In shape it may be cylindrical, conical, or cord-like, and it may present secondary diverticula near its tip in which, on microscopic examination, pancreatic tissue may sometimes be found. It arises most frequently from the free border of the intestine, but it sometimes comes off from the side. It runs at right angles to the gut most commonly, but it may assume any direction, and it is often provided with a mesentery. In 3302 bodies specially examined with reference to its existence, it was present in 73, or 2·2 per cent, and it appeared to be more common in the male than in the female. In 59 out of the 73 cases its position with reference to the end of the ileum was examined: its average distance from the ileo-colic valve was $32\frac{1}{2}$ inches measured along the gut, the greatest distance being 12 feet, and the smallest 6 inches. In 52 specimens the average length was 2·1 inches, the longest being $5\frac{1}{4}$ inches, the shortest $\frac{1}{2}$ inch. The diameter usually equals that of the intestine; but occasionally it is cord-like, or pervious only for a short way; on the other hand, it may attain a diameter of $3\frac{3}{4}$ inches. These data have been compiled from Thomson (Collective Investigation, 1891), Kelynack (1892), Mitchell (1898) and other sources.

Radiographic Examination of Small Intestine.—The small intestine, examined by X-rays after a "barium meal", has a characteristic appearance owing to the presence of the circular folds of its mucous coat. In the lower half of the duodenum and in the **jejunum**, where the folds are numerous and closely set, the barium is broken up into irregular transverse streaks and may be finely fragmented so that the intestine resembles an old-fashioned fur-boa; but in the **ileum** the shadow is more or less continuous (Pls. LIII, LIV, p. 620). This difference is sufficiently great to enable at least the upper coils of the jejunum to be distinguished easily from the ileum. The position of the coils is, of course, another help in identification (see p. 635).

The passage of the barium through the jejunum is rapid, but in the ileum the rate of progress is much slower; barium enters the cæcum usually about three hours after the meal has been taken.

The form and position of the **duodenum**, as seen in X-ray examination after a "barium meal", are shown in Pl. LIII, p. 620. With variations in the position of the pylorus, mentioned on p. 622, there is a corresponding alteration in the position of the first part of the duodenum. The characteristic appearance of the "duodenal cap", as barium begins to leave the stomach (p. 621), is well shown in Pl. LII, p. 609.

LARGE INTESTINE

The ileum is succeeded by the **large intestine** (intestinum crassum), which begins on the right side about $2\frac{1}{2}$ inches below the end of the small intestine. It comprises the following parts: **cæcum and vermiform appendix, ascending colon, right flexure of colon, transverse colon, left flexure of colon, descending colon, pelvic colon, rectum, and anal canal.** In its course the large bowel is arranged in an arched manner around the small intestine (Fig. 532 and Pl. LVII, p. 648).

In *length*, the large intestine measures about one-fifth of the whole intestinal canal, that is, 5 to $5\frac{1}{2}$ feet (1·5 m.). Its *breadth* is greatest at the cæcum, which

measures about 3 inches (75 mm.) in diameter when distended; and from there —with the exception of a dilatation at the rectum—it decreases to the anus. Functionally, there is a distinct difference between the ascending colon and transverse colon together and the descending colon; the descending colon is often found firmly contracted after death and measures only $1\frac{1}{2}$ inches or less in diameter.

The external appearances by which the large intestine, with the exception of the vermiform appendix and the rectum, may be distinguished from the small intestine are stated on p. 623. Two structures peculiar to the large intestine and visible on its external surface require further description.

The **tæniæ coli** are about $\frac{1}{4}$ inch (6 mm.) wide, begin at the root of the vermiform appendix, and run along the surface of the large intestine at nearly equal distances from one another as far as to the rectum. There, they spread out and form a layer of longitudinal muscular fibres which is continuous all round the tube (see p. 653). The tæniæ are about one-sixth shorter than the colon;

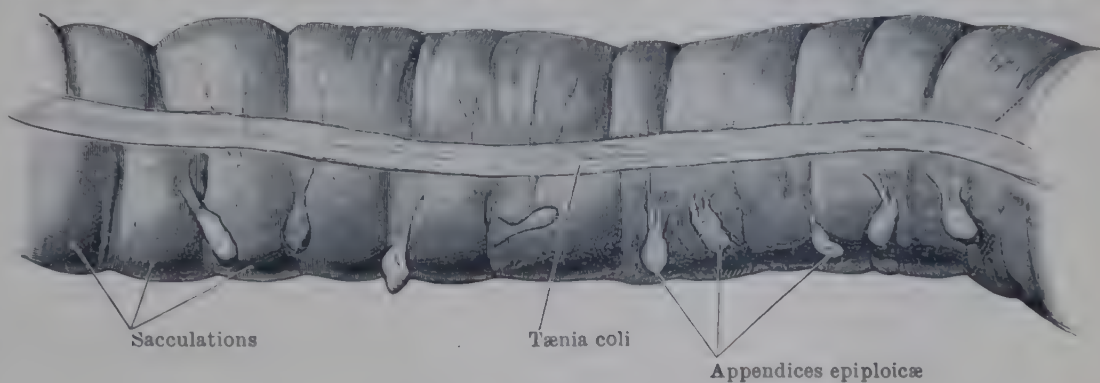

FIG. 544.—LARGE INTESTINE.

A piece of transverse colon from a child two years old. The three chief characteristics of the large intestine—appendices epiploicæ, tæniæ, and sacculations—are shown.

consequently, in order to accommodate it to the length of the tæniæ, the colon is puckered (Fig. 544), and three rows of **sacculations** are produced, along the length of the tube, between the tæniæ. If the tæniæ are dissected off, the sacculations largely disappear, the intestine becomes cylindrical, and at the same time about one-sixth longer.

The position of the three tæniæ on the colon is as follows: On the ascending and descending colon one tænia lies on the front of the gut and two on the back--one to the lateral side (postero-lateral) the other to the medial side (postero-medial). It is chiefly along the first of them (the anterior) that the appendices epiploicæ are found. On the transverse colon in the natural position, the anterior tænia of the ascending and descending colon becomes the posterior (or postero-inferior), the postero-lateral becomes anterior and the postero-medial becomes superior in position. The anterior and postero-lateral tæniæ of the descending colon pass on to the front of the pelvic colon and the longitudinal muscular coat, increasing in total bulk (Hamilton, 1946), forms two wide bands, one on the front and the other on the back of the rectum (p. 649).

When the interior of a piece of distended and dried large intestine is examined, its sacculations appear as rounded pouches separated by crescentic folds that correspond to the creases on the exterior. These folds are made up of mucous membrane containing the muscular coats of the intestine as well as areolar tissue, and each extends over only one-third of the circumference of the intestine, between the tæniæ.

The **appendices epiploicæ** are little pouches of peritoneum, generally more or less distended with fat, which project from the serous coat along the whole length of the large intestine, with the exception of the rectum. They are rudimentary in the appendix. The appendices epiploicæ can be seen as early as the seventh month in the fœtus, but at that time they contain no fat.

In formalin-hardened bodies portions of the large intestine, but particularly of the descending colon, are often found fixed in what appears to be a state of contraction, when they are reduced to a diameter of about $\frac{5}{8}$ or $\frac{3}{4}$ of an inch (16 to 19 mm.). Under similar conditions parts of the small intestine are found correspondingly reduced.

Structure of Large Intestine.—The **serous coat** is complete on the vermiform appendix, cæcum, transverse colon, and pelvic colon; incomplete on the ascending and descending colon and on the rectum. It will be described in detail with each of these portions of the intestine.

The **mucous coat** is of a pale or yellowish ash-colour in the colon, but becomes much

redder in the rectum. Unlike that of the small intestine, its surface is smooth, owing to the absence of villi, but it is closely studded with the orifices of numerous large intestinal glands. Solitary lymphatic nodules also are numerous, particularly in the vermiform appendix (Fig. 550).

Vessels and Nerves.—The arteries are derived from the *mesenteric arteries.* Branches of the superior mesenteric supply the large intestine as far as the left flexure of the colon, and branches of the inferior supply the remainder as far as the lower part of the rectum. The cæcum and vermiform appendix receive their blood from the *ileo-colic artery*; the ascending colon from the *right colic artery*; and the transverse colon from the *middle colic artery.* The descending colon is supplied by the *superior* and *inferior left colic*, and the pelvic colon by the *inferior left colic arteries.* The rectum derives its blood from the three *rectal arteries.*

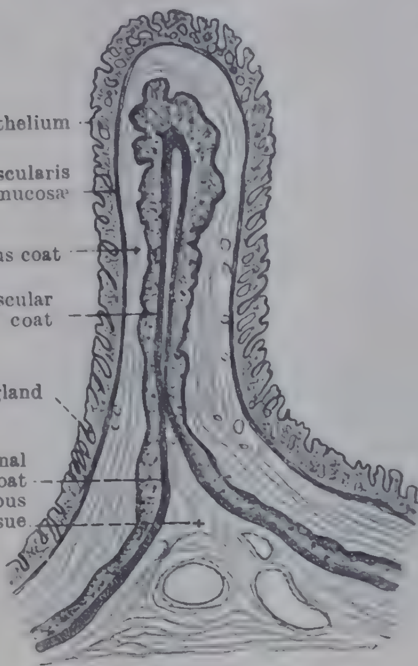

Fig. 545.—Transverse Section of a Crescentic Fold of the Colon.

The **veins** correspond largely to the arteries, and join the *inferior* and *superior mesenteric veins*, which send their blood into the portal vein.

The **lymph-vessels** of the large intestine arise from plexuses in the submucous and subperitoneal coats, as in other parts of the alimentary canal. Those from the cæcum and vermiform appendix run to the *ileo-colic glands.* The deeper vessels of the colon escape chiefly along the entering blood-vessels, those from the lateral aspects passing behind the intestine. The vessels pass first to a series of "*paracolic*" *glands* that lie along the medial border of the intestine; thence, they pass along the lines of the main arteries to *intermediate* and *main glands* disposed at intervals around those vessels (p. 1415).

The **nerves** come from the *superior and inferior mesenteric plexuses.* Their arrangement is described on p. 624.

CÆCUM AND VERMIFORM APPENDIX

Cæcum.—After leaving the pelvic cavity, as already described, the terminal portion of the ileum passes upwards, backwards, and to the right, in close contact with the cæcum, and opens very obliquely, by the ileo-colic orifice, into the large intestine some $2\frac{1}{2}$ inches from its lower end. The portion of the large gut which lies below the level of this orifice is known as the cæcum. *In shape* (Fig. 549) it is a wide, asymmetrical cul-de-sac furnished with tæniæ and sacculations. Its lower end is directed downwards and medially, and usually rests on the right psoas major muscle close to the brim of the true pelvis; whilst the opposite end is directed upwards and laterally and is continued into the ascending colon.

Fig. 546.—Cæcum and Vermiform Appendix from Front.

Its asymmetrical form is due to the fact that the lateral and medial portions of the organ undergo an unequal development in the child. The medial (or medial and posterior) section lags behind, while the lateral (or lateral and anterior) division grows much more rapidly, and, extending downwards, soon comes to form the lower end of the

cæcum. As a result the original extremity of the gut, with the vermiform appendix springing from it, is hidden on the back of the cæcum.

In *length* the distended cæcum usually measures about 2½ inches (60 mm.); whilst its *breadth* is usually more and averages about 3 inches (75 mm.).

Position.—It is usually situated in the right iliac fossa immediately above the lateral half or third of the inguinal ligament, but its lower end bulges medially to overlap the psoas major (Fig. 546). On the other hand, it is sometimes found high up near the liver (owing to the persistence of the fœtal position), or hanging over the pelvic brim and dipping into the pelvic cavity to a varying extent.

In most bodies the cæcum is completely covered with peritoneum on all aspects and lies quite free in the abdominal cavity; but in 6 or 7 per cent. of bodies, the posterior surface (probably as a result of adhesions) is not completely covered and over a greater or less portion of its extent is bound down to the posterior abdominal wall by fibro-areolar tissue.

Relations.—*Posteriorly*, the cæcum rests on the ilio-psoas muscle and the femoral nerve; generally, too, on the vermiform appendix. *Anteriorly*, it usually lies in contact with the greater omentum and anterior abdominal wall; but when the cæcum is empty the small intestine intervenes. Its *lateral side* is placed immediately above the lateral half or third of the inguinal ligament (Fig. 546), whilst the *medial side* has the terminal part of the ileum lying in contact with it. On the medial and posterior aspects, but more on the former than the latter, the small intestine joins the cæcum. On the same aspect, and usually from 1 to 1½ inches (25 to 35 mm.) lower down, the vermiform appendix springs from the cæcum.

Types of Cæcum.—Three chief types of cæcum may be distinguished—the *fœtal type*, conical in shape and nearly symmetrical, with the inferior end gradually passing into the vermiform appendix; the *infantile*, in which the passage from the cæcum to the vermiform appendix becomes more abrupt, the lateral wall more prominent, and the whole sac more asymmetrical; and the lop-sided *adult form*, which is the condition found in 93 or 94 per cent of adults.

Structure.—Nothing in the arrangement of the mucous and submucous coats calls for special notice. The tæniæ all spring from the root of the vermiform appendix (Fig. 549); the anterior runs up on the front, medial to the main prominence of the cæcum; the postero-lateral runs up behind this prominence; whilst the postero-medial passes directly upwards behind the ileum (Fig. 549). The longitudinal fibres on the superior aspect of the ileum partly join the postero-medial tænia; those on the anterior and posterior aspects join the circular fibres of the large gut.

The *interior* of the cæcum corresponds in general appearance to that of the large intestine; but it presents two special features on the posterior part of its medial wall, namely, the **ileo-colic orifice**, guarded by the **ileo-colic valve**, and below that a smaller orifice—the opening of the **vermiform appendix**.

The **position of the ileo-colic valve**, in the average condition, may be indicated on the surface of the body by the point of intersection of the intertubercular and right vertical planes. A point 1 to 1½ inches (2·5 to 3·8 cm.) lower down would correspond to the **orifice of the vermiform appendix**.

Ileo-Colic Valve.—Where the ileum enters the large intestine, the end of the small gut is, as it were, thrust through the wall of the large bowel carrying with it certain layers of that wall; these layers project into the cæcum in the form of two folds which lie one above and one below its orifice and constitute the two segments of the valve (Fig. 548). The peritoneum and longitudinal muscular fibres of the bowel take no part in this infolding; on the contrary, they are stretched tightly across the crease produced on the exterior by the inversion, and thus serve to preserve the folds and the formation of the valve.

As seen from the interior, in specimens which have been distended and dried (Fig. 548), the valve is made up of two crescentic segments—a superior, in a more or less horizontal plane, and an inferior, which is larger, placed in an oblique plane, and sloping upwards and inwards (*i.e.*, towards the cavity of the cæcum). Between the two segments is situated the slit-shaped opening, which runs in an almost antero-posterior direction, with a rounded anterior and a pointed posterior extremity. At each end of the orifice the two segments of the valve unite and are then prolonged around the wall of the cavity as a prominent fold—the **frenulum**. It is thought that when the cæcum is distended, and its

circumference thereby increased, the frenula are put on the stretch, and, pulling upon the two segments of the valve, they bring them into apposition and effect the closure of the orifice.

In bodies hardened with formalin the ileo-colic valve and orifice present a different appearance (see Fig. 547), suggesting, much more closely than in the dried state, the appearance of telescoping or inversion. The two segments of the valve are much thicker and shorter, but they can always be distinguished and have the same relation to each other as in the dried condition, although this may be obscured by foldings or rugæ. The aperture may be slit-like or may be rounded with sloping or funnel-shaped edges; the frenula are not so prominent in some; but the whole valve projects much more abruptly into the cavity of the cæcum than in the distended and dried specimen.

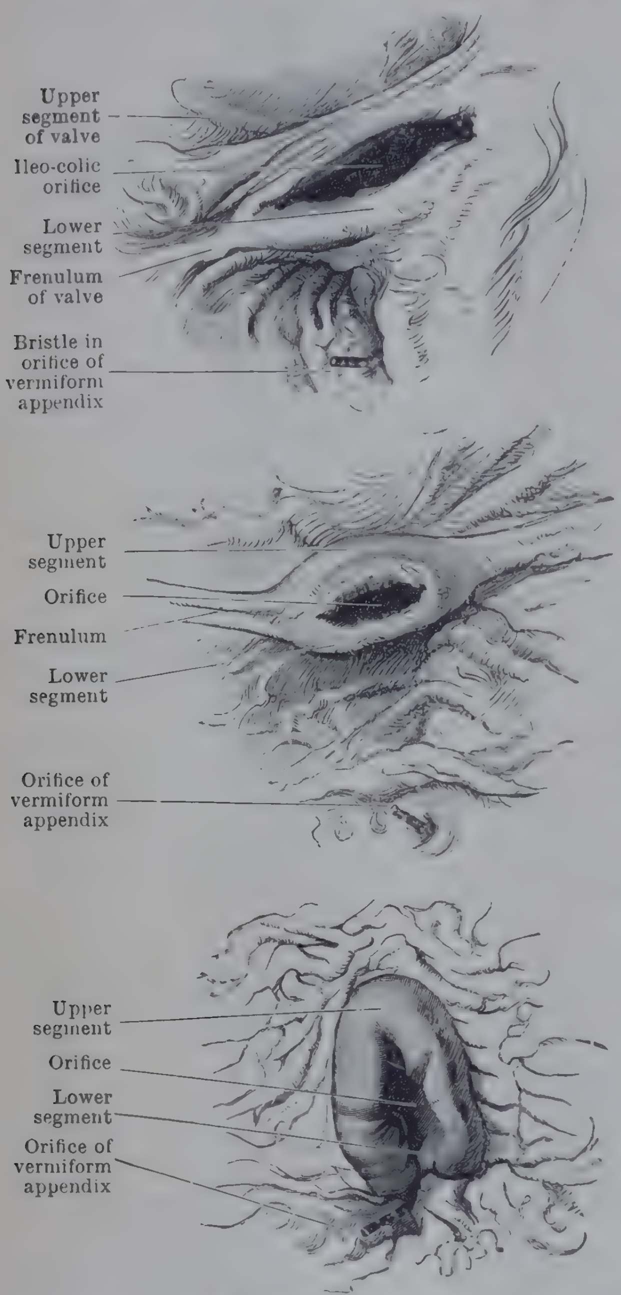

FIG. 547.—THREE FORMS OF ILEO-COLIC VALVE FROM BODIES HARDENED BY FORMALIN.

The hardening was not so complete in the highest of the three valves represented.

Form in the Living Body.—The ileo-colic valve has been observed, in the course of surgical operations, during life. It appears as a "hemispherical mamillary eminence, about 1·8 cm. in diameter, scarlet in appearance, smooth and glistening" (Rutherford, 1914). The summit is truncated, and the orifice is stellate, with lobulated elevations between the rays of the star. It is said also that no frenula are to be seen during life.

Structure of Ileo-Colic Valve.—Each segment of the valve consists of two layers of mucous membrane, with the submucosa and the circular muscular fibres between, all of which are continuous with those of the ileum on the one hand and of the large intestine on the other. The surface of each segment turned towards the small intestine is covered with villi and conforms in the structure of its mucous coat to that of the ileum; whilst the mucous coat of the opposite surface resembles the mucous coat of the large bowel.

The efficiency of the valve is partly due to the oblique manner in which the ileum enters or invaginates the large intestine and partly to muscular contraction.

Vermiform Appendix (Fig. 549).—The vermiform appendix is a worm-like tubular structure which springs from the postero-medial aspect of the cæcum about 1 to $1\frac{1}{2}$ inches (2·5 to 3·5 cm.) below the ileo-colic orifice. From that relatively fixed point the appendix may radiate in almost any direction. This it usually does with the degree of freedom permitted by its mesentery (p. 604), but this mobility may be more or less restricted by adhesions. In a considerable number of cases, however, the appendix is found in a fixed, somewhat buried position due to a retardation of its developmental migration in association with the cæcum (see p. 677). The most reliable guide to the vermiform appendix in all cases of difficulty is provided by the anterior tænia of the cæcum. When this band is traced to the back of the cæcum its fibres continue on to the root of the appendix, which is thus located with a good deal of certainty.

Wakeley (1933), from an analysis of 10,000 cases, has found that the relative frequency of the different positions of the appendix is approximately as follows:—

(1) Behind the cæcum and colon (65%). In this situation the appendix may either (*a*) lie free in a recess, (*b*) have a short mesentery which holds it in contact with the posterior surface of the cæcum or colon, (*c*) be adherent to the cæcum or colon, (*d*) lie extra-peritoneally, the peritoneal recess having been obliterated, or (*e*) be adherent to the posterior abdominal wall.

(2) Directed downwards (33%). In this variety the appendix may be long enough to curve below the level of the cæcum, and it is frequently of sufficient length to reach over the brim into the true pelvis.

(3) In a small percentage ($1\frac{1}{2}$%) of cases the appendix may be found directed upwards and medially in front of and more rarely behind the terminal part of the ileum.

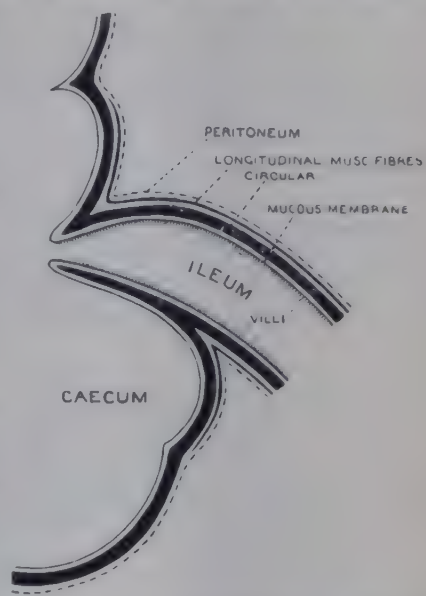

Fig. 548.—Diagrammatic Section through Junction of Ileum with Cæcum, to show Formation of Ileo-Colic Valve.

In addition to the positions mentioned above, the appendix has been found in almost every possible position consistent with its developmental history (see p. 677). In the rare condition of complete transposition of the abdominal viscera, the appendix lies naturally on the left side of the body.

Its *size* is almost as variable as its position. Its length, according to Berry (1895), may be given as about $3\frac{1}{2}$ inches (92 mm.), and its breadth as $\frac{1}{4}$ inch (6 mm.). On the other hand, it has been found as long as 9 inches (230 mm.), and as short as $\frac{3}{4}$ inch (18 mm.). Congenital absence has been recorded, but this must be looked upon as an extremely rare occurrence.

Its *lumen* or *cavity* is variable in size, and is found to be totally or partially occluded in at least one-fourth of all adult and old bodies examined. It opens on

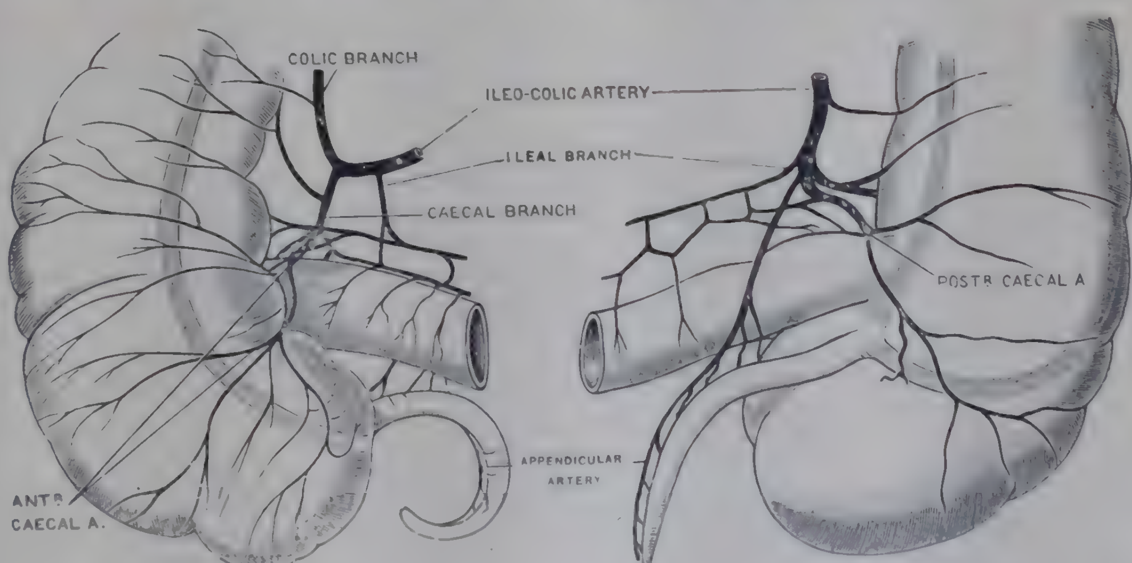

Fig. 549.—Blood-Supply of Cæcum and Vermiform Appendix. (Modified from Jonnesco, 1895.)
The left illustration is from the front, the right from behind. In the latter the appendicular artery and the three tæniæ coli springing from the root of the appendix should be specially noted.

the postero-medial wall of the cavity of the cæcum (Fig. 547), at a point 1 to $1\frac{1}{2}$ inches below the ileo-colic orifice and slightly farther back. These are the relative positions of the two orifices as seen from the interior of the cæcum; viewed from the exterior, the root of the vermiform process is within $\frac{3}{4}$ inch of the lower border of the ileum. The apparent difference is due to the fact that the ileum adheres to the medial side of the cæcum for a distance of nearly an inch before it opens into it. The *orifice* has a crescentic fold placed at its upper border; but the fold is probably of very little functional importance.

The vermiform appendix is completely covered with peritoneum and has a

considerable **mesentery**, which extends to its tip, as a rule, and connects the appendix to the inferior surface of that part of the mesentery proper which goes to the distal end of the ileum.

The vermiform appendix is longer, relative to the rest of the large intestine, in the child at birth than in the adult, the proportion being about 1 to 16 or 17 at birth and 1 to 19 or 20 in the adult. It attains its greatest length and diameter during adult and middle age, and it atrophies slowly after that time. It is said to be slightly longer in the male than in the female.

Total occlusion of its cavity is found in 3 or 4 per cent of bodies; it is then converted into a fibrous cord. Partial occlusion is present in 25 per cent of adults and in more than 50 per cent of those over 60 years old, but it is unknown in the child. The frequency of occlusion, the physiological atrophy which takes place after middle life, the great variations in length, and other signs of instability, have been considered to point to the retrogressive character of the appendix.

A vermiform appendix is found only in Man, the higher apes, and the wombat, although in certain rodents a similar arrangement exists. In carnivorous animals the cæcum is very

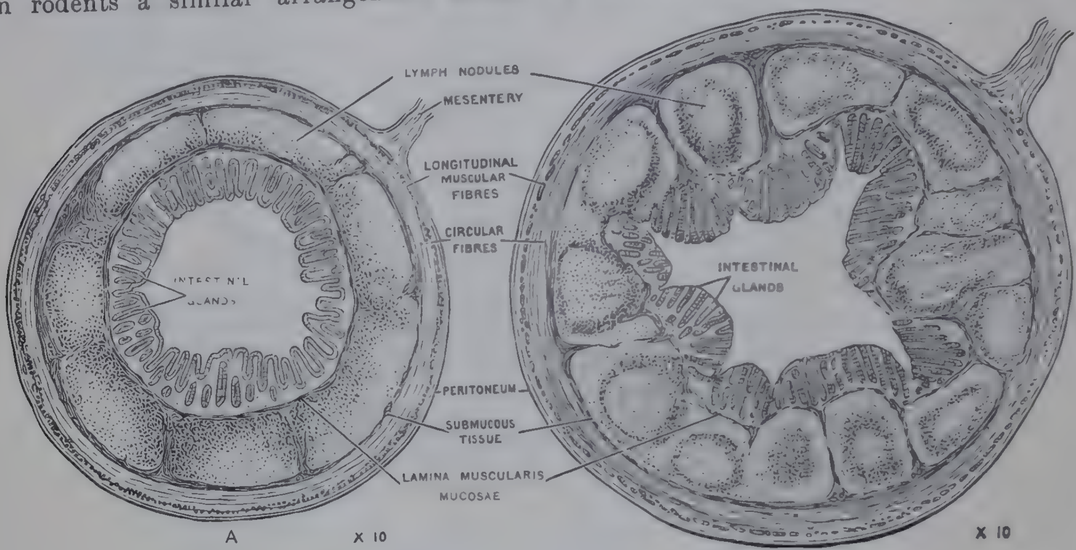

Fig. 550.—Structure of Vermiform Appendix.

A. From a child two years old. B. From a male, aged 56.

It will be observed that the submucous coat is almost entirely occupied by lymphatic nodules. The lamina muscularis mucosæ is very faint, and lies quite close to the bases of the intestinal glands. The longitudinal layer of muscular fibres forms a continuous sheet.

slightly developed; in herbivorous animals (with a simple stomach) it is, as a rule, extremely large. It has been suggested that the vermiform appendix in Man is the degenerated remains of the herbivorous cæcum, which has been replaced by the carnivorous form. Another and perhaps more probable view regards the appendix as a lymph-organ, having the same functions as lymphatic nodules, and, like these, undergoing degeneration after middle life (Berry, 1895).

In the fœtus and child, as well as in the adult with the infantile type of cæcum, the vermiform appendix springs from the apex, not from the postero-medial wall of the cæcum.

Foreign bodies, although reputed to find their way very easily into the appendix, are rarely found there after death. On the other hand, concretions or calculi, formed of mucus, fæces, and various salts, are often present (Berry, 1895).

Structure (Fig 550).—The **serous coat** forms a perfect investment for the appendix. The **muscular coat**, unlike that of the rest of the large intestine, has a continuous and thick layer of longitudinal fibres which passes at the root of the appendix into the three tæniæ coli (Fig. 549). The layer of circular fibres is well developed. The **submucous coat** is almost entirely occupied by large masses of lymphoid tissue surrounded by sinus-like lymph-spaces. Owing to the large size of the lymphatic nodules, the areolar tissue of the submucosa is compressed against the inner surface of the muscular coat and forms a well-marked fibrous tube which sends processes at intervals between the lymphoid masses towards the mucous membrane. The lymphatic nodules correspond to solitary lymphatic nodules, which, owing to their great number, have been almost completely crushed out of the mucous coat (in which they chiefly lie in the intestine) into the submucosa.

The **mucous coat** corresponds to that of the large intestine in its general characters, but the intestinal glands are fewer and are irregular in their direction; the lamina muscularis mucosæ is thin and ill-defined; it lies immediately internal to the lymphatic nodules of the submucosa and immediately outside the base of the intestinal glands. Some few lymphatic nodules lie in the mucous coat also.

Peritoneal Folds and Recesses.—In the neighbourhood of the cæcum there are several peritoneal recesses, of which the most important are the superior and the inferior ileo-cæcal recesses and the retrocæcal recess (Berry, 1897).

If the vermiform appendix is drawn down and the finger passed towards the cæcum along the inferior border of the terminal part of the ileum, it will enter a recess between the ileum and the cæcum known as the **inferior ileo-cæcal recess**. A peritoneal fold which bounds it in front is the **ileo-cæcal fold.** It extends between the terminal part of the ileum and the front of the mesentery of the vermiform appendix. The fold contains some plain muscle-fibres continuous with the longitudinal muscle coat of the cæcum, and some fat, especially at its free margin. The inferior ileo-cæcal recess is bounded above by the lower end of the ileum, laterally by the cæcum, in front by the ileo-cæcal fold, behind by the root of the mesentery of the vermiform appendix; and it is open medially.

Similarly, if the finger is run along the superior border of the ileum towards the cæcum, it will usually lodge in a smaller recess—the **superior ileo-cæcal recess**—which is bounded in front by a small peritoneal fold, called the **vascular fold of the cæcum**

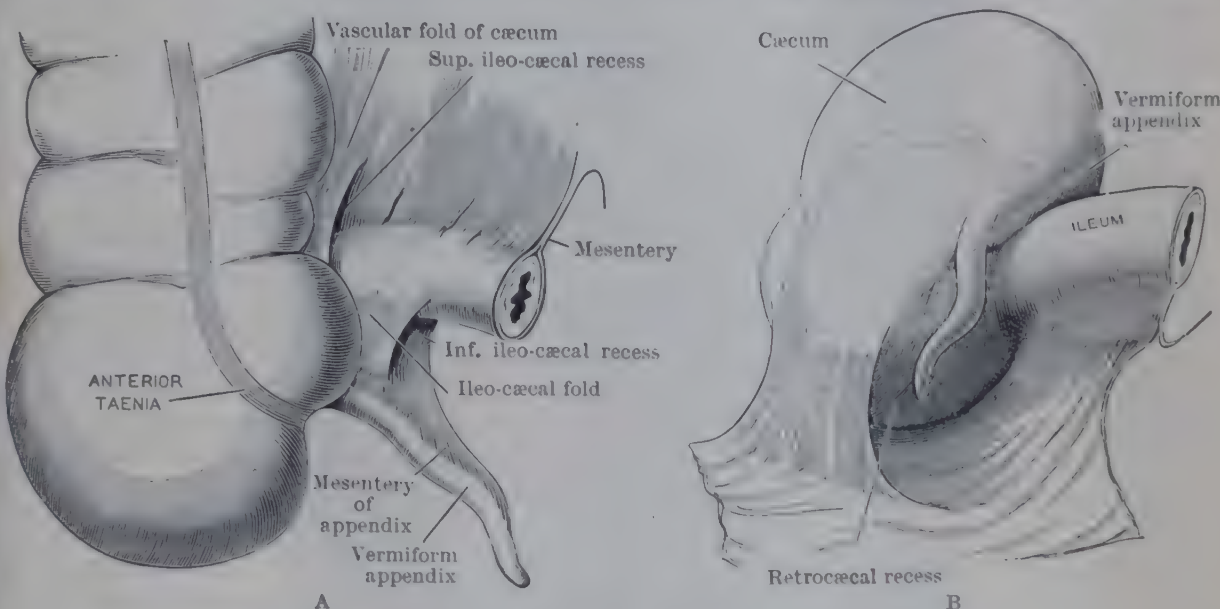

FIG. 551.—FOLDS AND RECESSES IN THE ILEO-CÆCAL REGION.

In A, the cæcum is viewed from the front; the mesentery of the vermiform appendix is distinct. In B, the cæcum is turned upwards to show a retrocæcal recess which lies behind it and behind the beginning of the ascending colon.

(Fig. 551, A), which contains the anterior cæcal artery. The superior ileo-cæcal recess lies at the upper margin of the junction of the ileum with the colon; it is bounded behind by the ileum and laterally by the cæcum.

The **retrocæcal recess** is an occasional pouch which passes upwards between the cæcum and the posterior abdominal wall. Its orifice looks downwards or medially, and it is bounded on each side by peritoneal folds termed the **cæcal folds**. It often contains the appendix.

COLON

Ascending Colon.—The ascending colon begins about the level of the intertubercular plane, opposite the ileo-colic orifice, where it is continuous with the cæcum. From there it runs upwards and slightly backwards, with a slight medial concavity, until it reaches the inferior surface of the liver, where it bends forwards and medially and passes into the right flexure of the colon (Fig. 552). In its course it lies in the angle between the quadratus lumborum and the psoas major.

Its *length* is extremely variable, depending upon the extent to which the cæcum has descended from the position it occupied during development, viz., in contact with the under surface of the liver. It is from 5 to 8 inches long, and it is wider and more prominent than the descending colon. It generally presents several minor curves or flexures, and it often has the appearance of being pushed into a space which is too short to accommodate it.

Relations.—*Anteriorly* it is usually in contact with the abdominal wall, but the small intestine frequently intervenes, particularly above. To its *medial side* lie the coils of the small bowel and the psoas major; to the *lateral side* is the side-wall of

the abdomen. Its *posterior surface*, which is free from peritoneum as a rule, is connected by areolar tissue to the iliacus muscle as far up as the iliac crest, to the quadratus lumborum and psoas major above that, and, finally, to the lower part of the right kidney.

In a small proportion of bodies the ascending colon is provided with a complete peritoneal coat and a mesentery, but the mesentery is so short that it allows only a slight amount of movement of the gut. Lateral to the cæcum and colon the peritoneum forms a gutter, termed the *paracolic groove*, which is usually divided by peritoneal folds into small recesses.

Like the cæcum, the ascending colon is frequently found distended with gas or fæces after death—hence, in part, its large size and prominence as compared with the descending colon, which is generally empty.

Right Flexure of Colon.—When the ascending colon reaches the inferior surface of the liver, it bends—usually acutely, sometimes obtusely—forwards and to the left on the anterior surface of the right kidney to form the flexure, and, on reaching the front of the second part of the duodenum, it passes into the transverse colon.

The flexure is placed between the duodenum medially and the anterior margin of the liver or the side-wall of the abdomen, laterally; above, it corresponds to the colic impression on the liver, and posteriorly it rests on the kidney. Its peritoneal relations are similar to those of the ascending colon.

Transverse Colon.—The transverse colon is the long and looped portion of the large intestine which lies between the right and left flexures. It begins at the right flexure, and, for the first few inches, it runs transversely and is comparatively fixed, being united to the front of the second part of the duodenum and the head of the pancreas either by a very short part of the mesocolon or by areolar tissue. Immediately to the left of the head of the pancreas, the mesocolon lengthens and allows the colon to hang down in front of the small intestine at a considerable distance from the posterior abdominal wall. The portion of the colon so suspended is therefore very movable; its position is consequently very variable and is influenced by posture and by the condition of the other viscera. Towards its left extremity the mesocolon shortens again, thus bringing the gut towards the body of the pancreas (Fig. 538), along which it runs towards the left and upwards under cover of the stomach, as far as the lateral end of the spleen, where it passes into the left flexure (Fig. 538). Its two ends lie in or above the transpyloric plane whilst its middle portion reaches down to the level of the umbilicus or even lower.

Its average *length* is about 19 or 20 inches (47·5 to 50·0 cm.), that is, more than twice the distance, in a direct line, between its two extremities. This great length is accounted for by the curved and somewhat irregular course which the bowel pursues.

Relations.—The greater part of the transverse colon lies behind the greater omentum, which must consequently be turned upwards in order to expose it. *Above*, it is in contact, from right to left (Fig. 552), with the liver and gall-bladder (which are also in front of it), the stomach, and near its left end, with the body of the pancreas and the spleen (Fig. 537). *Anteriorly* are placed the omentum and the anterior abdominal wall; towards its termination the stomach also is anterior. *Posteriorly* it first lies in contact with the second part of the duodenum and head of the pancreas; farther to the left, where it hangs down, the small intestine is placed below and behind it, and it is connected to the posterior abdominal wall by the transverse mesocolon. The transverse mesocolon is described with the peritoneum, p. 604.

The transverse colon is completely covered with peritoneum, with the exception of the first few inches of its posterior surface, which are often, if not usually, uncovered.

The state of the peritoneal covering on the posterior surface of the first part of the transverse colon would seem to depend, in some degree, on the extent to which the liver passes downwards on the right side. With a small, high liver no mesentery is present, and the posterior surface is devoid of peritoneum. On the other hand, when the liver is enlarged in the vertical direction, it pushes the colon downwards before it, and the peritoneum attached to the colon is drawn out to form a mesentery. In the fœtus of three or four months every part of the colon is supplied with a long mesentery.

Left Flexure of Colon.—The terminal portion of the transverse colon runs upwards (also backwards and to the left) until the spleen is reached; there it

bends sharply, forming the left flexure, and becomes the descending colon. The flexure is placed deeply behind the stomach, and in contact with the lower part of the spleen. It lies at a slightly higher level than the right colic flexure, and is connected to the abdominal parietes by the phrenico-colic ligament, which helps to maintain it in this position on the posterior abdominal wall.

The **phrenico-colic ligament** (Fig. 538) is a triangular fold of peritoneum, with

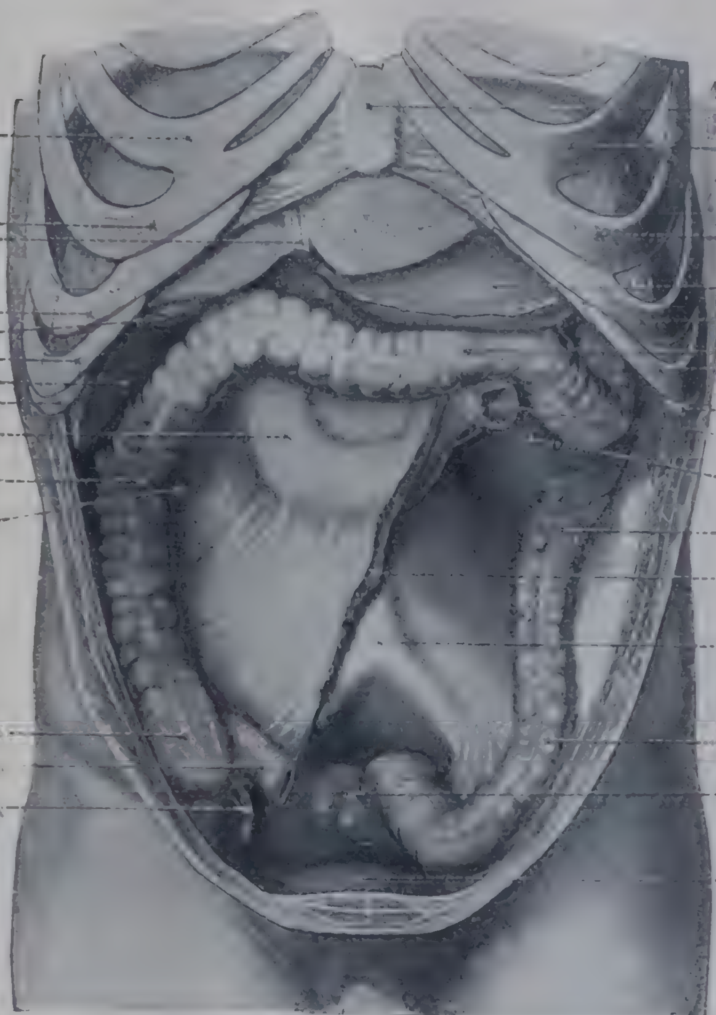

FIG. 552.—ABDOMINAL VISCERA AFTER REMOVAL OF JEJUNUM AND ILEUM. (From a photograph of the same body as depicted in Fig. 532.) The transverse colon is much more regular than usual.

a free anterior border, which is attached medially to the left flexure and laterally to the diaphragm opposite the eleventh rib.

The phrenico-colic ligament is formed in the fœtus from the left margin of the greater omentum (Jonnesco, 1895).

Descending Colon.—The descending colon is much narrower and less obtrusive than the ascending colon: indeed, in a large number of cases it is found firmly contracted. It begins at the left flexure, passes down on the left side of the abdomen, and terminates by passing into the pelvic colon at the inlet of the pelvis on the medial side of the left psoas muscle. Its course is not quite straight, for it first curves downwards and medially along the lateral border of the left kidney and then descends almost vertically to the iliac crest (Fig. 552). It then passes downwards and slightly medially in the iliac fossa, lying in front of the iliacus muscle. A little way above the inguinal ligament it turns medially over the psoas major and ends at its medial border by dipping into the true pelvis and becoming the pelvic colon (Fig. 552).

Its *length* is usually from 9 to 12 inches (22 to 30 cm.), and its *width*, which is less than that of the ascending colon, about 1½ inches.

The portion of the colon formerly described as a special segment, termed the *iliac colon*, is in structure and function a part of the descending colon and is here included with it.

Relations.—The upper part of the descending colon first lies in contact with the lateral border of the left kidney; below that it is placed, like the ascending colon, in the angle between the psoas major and quadratus lumborum muscles. Posteriorly it rests upon the lower part of the diaphragm above, and on the quadratus lumborum below. Anteriorly (and somewhat laterally also, except when the bowel is distended) are placed numerous coils of small intestine, which hide the colon completely from view, and compress it against the posterior abdominal wall. The lower part of the descending colon lies on the front of the ilio-psoas muscle. It also crosses the femoral and genito-femoral nerves, the left testicular (or ovarian) vessels, and the left external iliac vessels. Anteriorly it is usually covered by coils of small intestine, which hide it from view; but when distended, or when it occupies a lower position than usual, it comes into direct contact with the anterior abdominal wall.

In the great majority of bodies only the front and sides of the descending colon are covered with peritoneum; the posterior surface is connected to the posterior wall of the

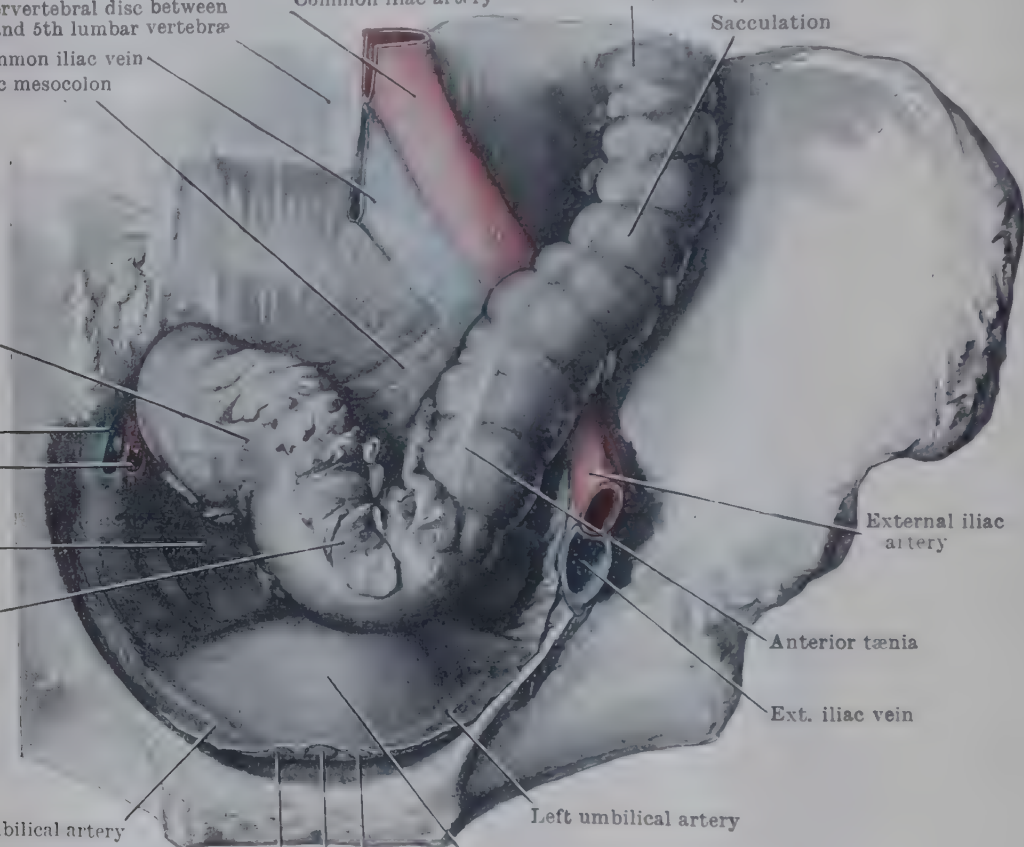

Fig. 553.—Pelvic Colon *in situ*.

abdomen by areolar tissue. In a small proportion of cases, on the other hand, the serous coat is complete, and the colon is furnished with a short mesentery.

Up to the fourth or fifth month of fœtal life the descending colon has a complete investment of peritoneum and a long mesentery. After the fifth month the mesentery adheres to, and soon blends with, the parietal peritoneum on the posterior abdominal wall, and is completely lost as a rule. The persistence of the mesentery, in a greater or less degree, explains the occasional presence of a *descending mesocolon* in the adult.

Pelvic Colon.—The pelvic colon begins at the medial border of the left psoas major muscle, where it is continuous with the descending colon, and it ends at the level of the third sacral vertebra by passing into the rectum. It is covered with peritoneum and has a well-developed mesentery which permits considerable movement. It forms a large and variously shaped coil which usually lies in the cavity of the true pelvis (93 per cent).

Whilst the loop of the pelvic colon is very irregular in form, the following may be given as perhaps its most common arrangement. Beginning at the medial margin of the left psoas major, it first descends into the true pelvis, and crosses that

cavity from left to right; it next bends backwards and then returns along the posterior wall of the pelvis towards the median plane, where it turns down and passes into the rectum (Figs. 552 and 553).

In *length* the pelvic colon generally measures about 16 inches (40 to 42·5 cm.), but it may be as short as 5 inches (12 cm.), or as long as 35 inches (84 cm.).

Relations.—As it passes from left to right across the cavity of the pelvis, it rests on the bladder or the uterus, according to the sex, and the coils of the small intestine lie above it.

When the pelvic colon is unusually long, in returning from the right side of the true pelvis it crosses the median plane, going even as far as the left wall, and then turns back a second time towards the middle of the sacrum, where it joins the rectum at the usual level, thus making an S-shaped curve within the pelvis. On the other hand, when the loop is short (a not infrequent occurrence), all its curves are abridged, and it fails to pass over to the right side, but runs more or less directly backwards after entering the pelvis.

From what has been said it will be seen that the loop of the pelvic colon is subject to considerable variations, which are dependent chiefly upon its length and that of its mesentery, and also upon the state of emptiness or distension of itself and of the other pelvic viscera. When the intestine is long the loop is more complex; when short, more simple. When the bladder and rectum are distended, or when the pelvic colon itself is much distended, it is unable to find accommodation in the pelvis and consequently it passes up into the abdomen proper, almost any part of the lower half of which it may occupy. But, as already stated, in the great majority of cases (92 per cent, according to Jonnesco, 1895) it is found after death lying entirely within the pelvis.

The **pelvic mesocolon** is a fan-shaped fold, short at each extremity and long in its middle portion (Figs. 552 and 553). Its root is attached along an inverted V-shaped line, one limb of which runs up close to the medial border of the left psoas major as high as the bifurcation of the common iliac artery (or often higher); there, it bends at an acute angle, and the second limb descends over the front of the sacrum to the middle of its third piece, where the mesentery ceases and the pelvic colon passes into the rectum. When the pelvic colon ascends into the abdomen proper, this mesentery is doubled up on itself, the side which was naturally posterior becoming anterior.

Recess of pelvic mesocolon.—When the pelvic colon with its mesentery is raised upwards, a small orifice will usually be found beneath the mesocolon, corresponding to the apex of the Λ-shaped attachment of its root to the posterior abdominal wall. This orifice leads into a recess which is directed upwards and will often admit the little finger. It is known as the recess of the pelvic mesocolon, and is due to the imperfect blending of the mesentery of the descending colon of the fœtus with the parietal peritoneum. The ureter is found lying behind the apex of the recess. In the fœtus the mesentery of the descending colon is well developed and extends from the region of the vertebral column towards the descending colon. After a time it begins to unite with the underlying parietal peritoneum; but in the line of the ureter the union is rarely perfect—hence the presence of the recess. The recess may occasionally be the seat of an internal hernia (p. 1505).

In the **child at birth** only the terminal part of the pelvic colon lies in the pelvis. That is chiefly owing to the small size of the pelvic cavity in the infant. Beginning at the end of the descending colon, the pelvic colon generally arches upwards and to the right across the abdomen towards the right iliac fossa, where it forms one or two coils, and then passes down over the right side of the pelvic brim into the pelvis.

Structure of Pelvic Colon.—Only the arrangement of the muscular coat need be referred to. As the tæniæ of the descending colon are followed down, it will be found that the postero-lateral band gradually passes on to the front and unites with the anterior tænia to form a broad band which occupies nearly the whole width of this bowel in its lower portion. The postero-medial tænia spreads out in a similar manner on the back; so that, in the lower half of the pelvic colon, the longitudinal layer of the muscular coat is complete, with the exception of a narrow part on each side; there the circular fibres come to the surface, and the intestine presents a series of small sacculations. As the rectum is approached, the sacculations disappear, and the longitudinal fibres, although thicker in front and behind, form a continuous layer all round.

Radiographic Examination of Large Intestine.—The large intestine may be examined by X-rays after a "barium meal" or after an opaque enema.

About three hours after a "meal" has been taken, the barium begins to pass through the ileo-colic valve and to fill the cæcum and ascending colon. The general progress of the barium in the **colon**, apart from sudden mass-movements of the contents, is so slow that it is difficult to detect by screen-examination. It reaches the pelvic colon from 18 to 24 hours after the taking of the meal, but traces of the barium are often to be seen in the colon after 48 hours or longer. The shadow of the colon is distinguished easily from that of other parts of the intestine by the undulating outline due to the sacculations (Pl. XLVIII, p. 559).

The enema method, by which the whole of the large intestine may be filled (Pl. LVIII, p. 648), is preferable for the detection of disease and is therefore the one usually employed

clinically. The enema, however, not only distends the colon but also appears to produce some increase in its length. Accordingly, radiographs taken after an enema always suggest that the colon, and in particular the pelvic colon, is markedly redundant; and, in addition, the sacculations are much less evident than in radiographs taken after filling the colon by a "meal" (Cf. Pls. XLVIII, p. 559, and LVIII, p. 648).

The presence of gas in the colon makes it, like the fundus of the stomach, radio-translucent so that any part of it may appear as a dark area in a radiograph (Pl. LIV, p. 613); the left flexure, where gas tends to collect, is usually easily distinguished from the air-bubble in the fundus of the stomach. The radio-translucency of the gas-filled colon is taken advantage of in the "double contrast" method of examination. The bowel is evacuated after a barium enema and then air is injected with the result that the mucous coat is very clearly defined (Pl. LIX, p. 649). This method is of special value in the detection of disease.

The length, shape, and position of the different parts of the colon show a wide range of variation (Pls. XLVIII, LVII, and LVIII); but typically they approximate to those shown in Fig. 552, p. 645.

The form and position of the **cæcum** vary with its activity and the posture of the subject. Some of the barium may enter the **appendix** after a "meal", or it may be filled with the rest of the large intestine by an enema, so that its position and direction may be demonstrated (Pl. LVII, p. 648).

RECTUM

The **rectum** is the portion of the intestine between the pelvic colon and the anal canal.

Unlike the pelvic colon the rectum has but a partial covering of peritoneum, and has no mesentery; sacculations, too, such as are characteristic of the colon, cannot be said to be present.

The rectum begins about the level of the third sacral vertebra, and ends, in the male, opposite the apex of the prostate, or, in both sexes, at a point $1\frac{1}{2}$ inches (3·5 cm.) in front of and slightly below the tip of the coccyx. It first descends along the front of the sacrum and coccyx; it then rests for about $1\frac{1}{2}$ inches on the posterior part of the pelvic floor, formed by the union of the two levatores ani; and, finally, it bends abruptly backwards and downwards to become the anal canal (Fig. 620, p. 740).

Curvatures.—The rectum is curved in both the antero-posterior and the transverse planes. Viewed *from the side* it forms a gentle curve, convex backwards, from the beginning of the rectum to the back of the prostate, and fits into the hollow of the sacrum and coccyx. At the back of the prostate a second curve is formed where the rectum joins the anal canal. The convexity of the second curve is directed forwards, and its concavity embraces the **ano-coccygeal body**—the mass of muscular and fibrous tissue which lies between the tip of the coccyx and the anal canal.

When *viewed from the front* the rectum is seen to be folded from side to side in a zigzag fashion, the folding being slightly marked when the rectum is empty, but becoming much more distinct with distension (Figs. 554 and 555). There are three more or less distinct lateral flexures. Of these the upper and lower have their concavities directed to the left as a rule; the third flexure, which is the best-marked, lies between the other two, but on the right side. Not infrequently, however, two are found on the right and one on the left side. The flexures are marked on the exterior by creases which appear in the interior as three prominent crescentic shelves known as the **horizontal folds of the rectum** (Fig. 557).

The folds are produced by an infolding of the mucous and submucous coats and the greater part of the circular muscular coat, and their form is preserved by the relative shortness of the anterior and posterior bands of longitudinal muscular fibres. Three are usually present (there may be four, five, or, it is said, even more), but often the lowest of the three is small or absent; or all the folds may be ill-developed and indistinct. They are most evident in a distended rectum which has been

PLATE LVII

PLATE LVII.—RADIOGRAPH SHOWING ALL THE PARTS OF THE LARGE INTESTINE. MOST OF THE BARIUM HAS ACCUMULATED IN THE LOWER PART OF THE DESCENDING COLON, THE PELVIC COLON AND THE RECTUM.

Note the residue of radio-opaque material in the Cæcum and Appendix, and the contraction of the Descending Colon. Compare this radiograph with Plate XLVIII, p. 559, which shows an earlier stage in the filling of the Cæcum and Colon.

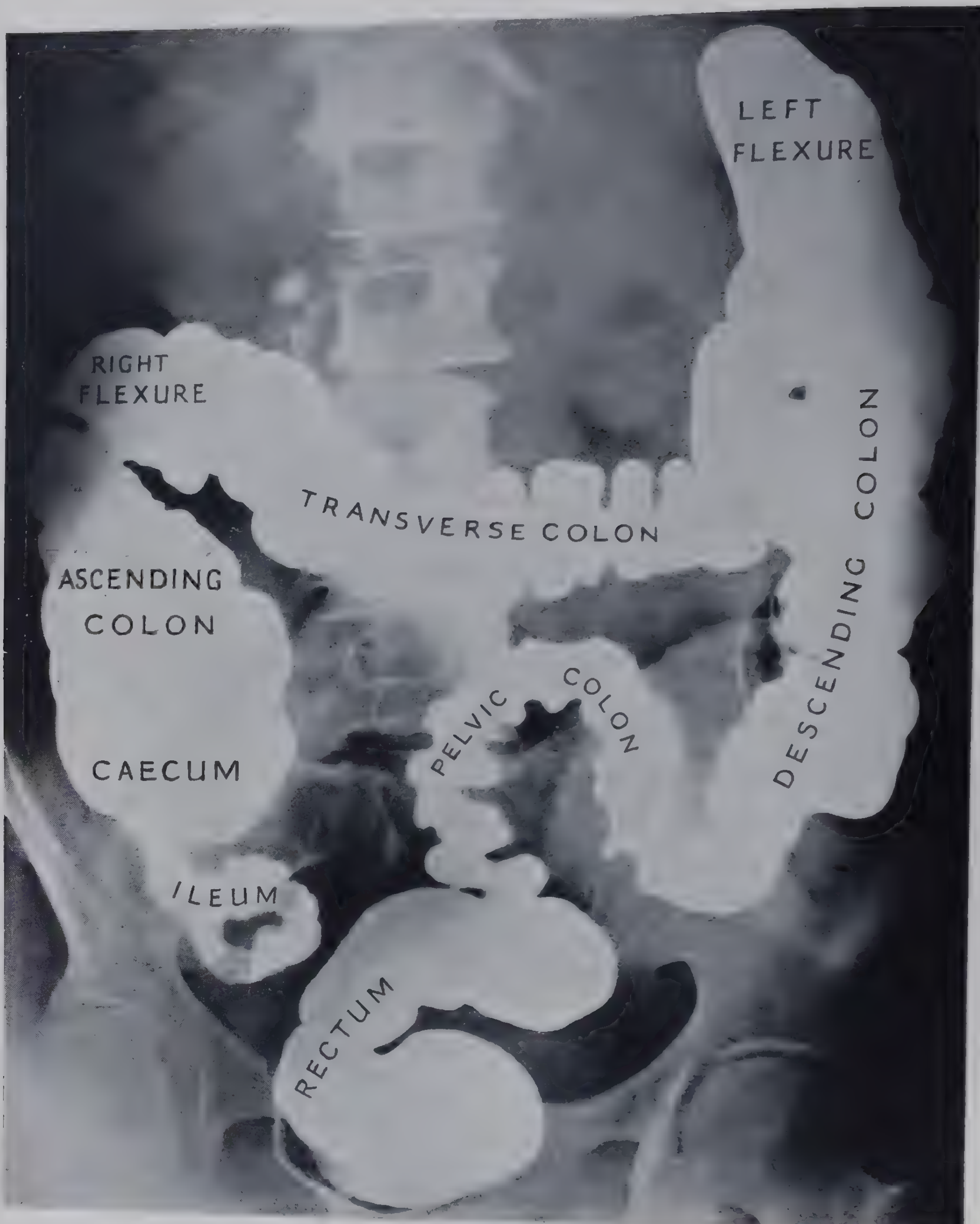

PLATE LVIII.—RADIOGRAPH OF LARGE INTESTINE FILLED ENTIRELY (WITH THE EXCEPTION OF VERMIFORM APPENDIX) BY BARIUM-ENEMA.

The position of the several parts of the Large Intestine is well shown. Note the loop of the Pelvic Colon, and that some of the barium injection has passed into the terminal part of the Ileum. Cf. Plate LVII, p. 648.

PLATE LIX

PLATE LIX.—RADIOGRAPH OF LARGE INTESTINE (MAN, AGED 26) SHOWN BY "DOUBLE-CONTRAST" ENEMA.

Note the definition of the sacculations (cf. Plate LVIII) and for details of the method employed see pp. 648 and 1555.

PLATE LX

FIG. 1.—SERIAL RADIOGRAPHS OF GALL-BLADDER (WOMAN, AGED 44) SHOWING PHYSIOLOGICAL CHANGES AFTER ADMINISTRATION OF SODIUM-TETRA-IODO-PHENOL-PHTHALEIN. (See pp. 667 and 1556.)

A. 16 hours after administration of S.T.I.P.P., showing concentration of bile; fatty meal given at this time.
B. $\frac{1}{2}$ hour after fatty meal, showing contraction of gall-bladder with discharge of bile.
C. $\frac{3}{4}$ hour after fatty meal, showing slight further contraction of gall-bladder.

Note that the colon is well shown by the radio-opaque S.T.I.P.P. taken by the mouth.

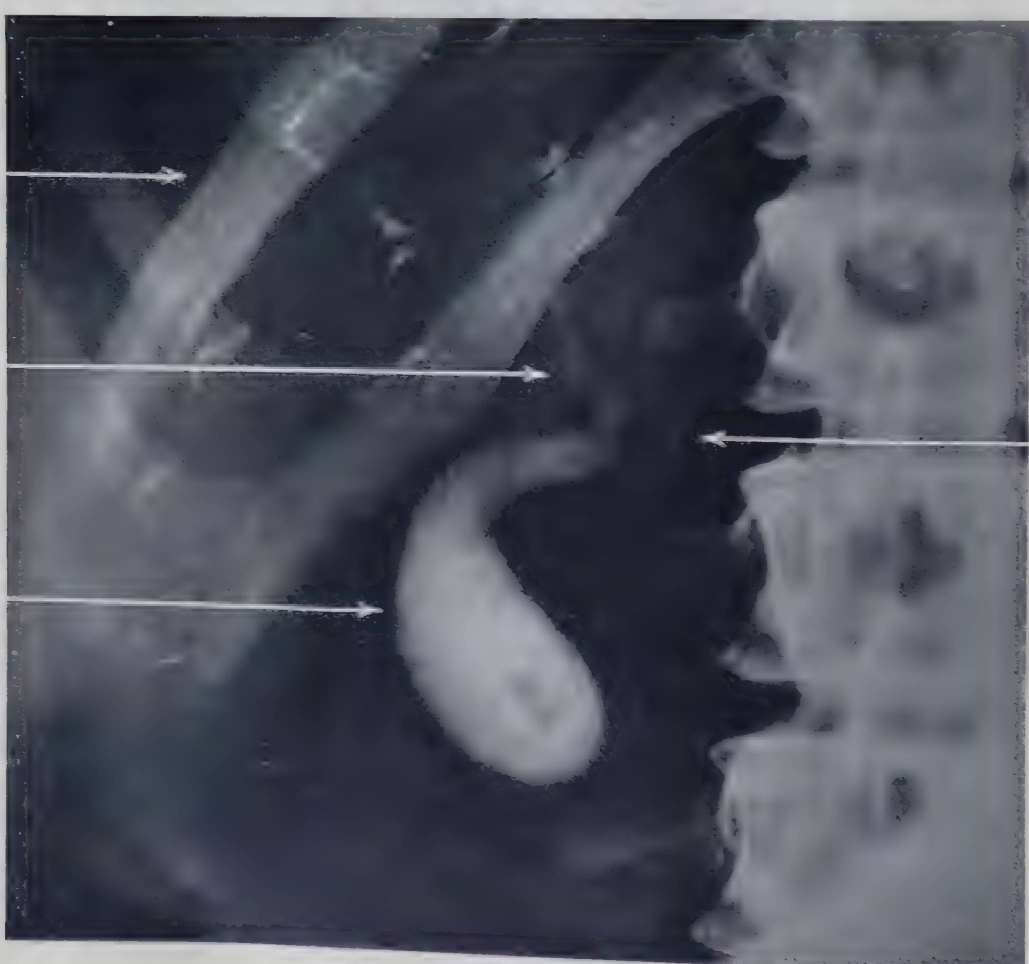

FIG. 2.—RADIOGRAPH (FEMALE ADULT), AFTER ADMINISTRATION OF S.T.I.P.P. (see pp. 667, 1556), SHOWING POSITION OF THE GALL-BLADDER AND THE CYSTIC DUCT THE BILE-DUCT ALSO IS FAINTLY SEEN.

hardened *in situ*; they can be seen also during life, *per anum*, with the aid of a rectal speculum; and they may interfere with the introduction of an enema-tube.

As a rule, two folds are found on the left and one on the right side; this latter is generally the largest, and is situated a little above the level of the peritoneal reflexion, viz., 3 or 3½ inches (7·5 to 8·5 cm.) above the anus; the other two folds are found about 1 to 1½ inches (2·5 to 3·5 cm.) higher up and lower down respectively. The folds are distinctly marked in the fœtus, and they seem to constitute an essential part of the

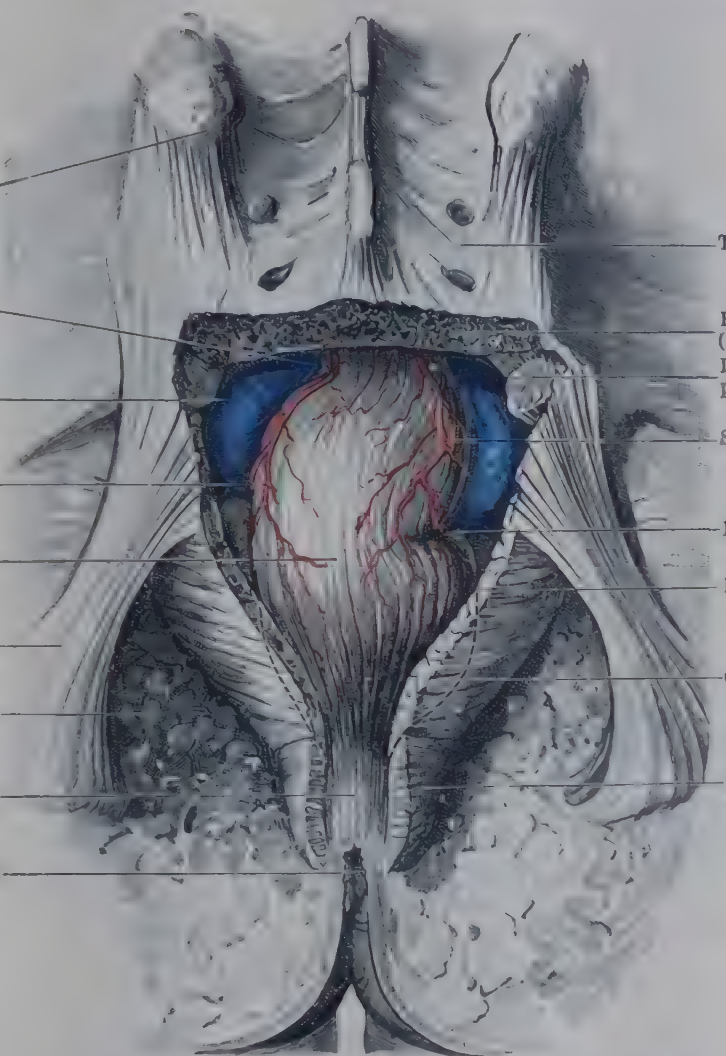

Fig. 554.—Rectum exposed by Dissection from Behind.

The sacrum has been sawn across through the 4th sacral vertebra, and its inferior part removed with the coccyx. The posterior portions of the coccygei, levatores ani, and of the external sphincter have been cut away. The "pinching in" of the lower end of the rectum by the medial edges of the levatores ani, resulting in the formation of the flattened anal canal, is suggested in the illustration, which has been made from a formalin-hardened male body, aged 30. The lateral flexures also are shown.

human rectum, their use being to support the contents of the rectum, which they break up into segments, each supported by a fold.

In *length* the rectum usually measures about 5 or 6 inches (12·5 to 15·0 cm.), but it may be much longer.

Its *diameter* is smallest above, near the junction with the pelvic colon, and is greatest below, near the anal canal, where there is an enlargement known as the **ampulla of the rectum.** When empty the rectum measures little over an inch (2·5 cm.) in diameter, but in a state of extreme distension it may be as much as 3 inches in width.

The folding is maintained by the arrangement of the longitudinal muscular fibres, the majority of which are accumulated in the form of two wide bands, one on the front of the bowel, the other on the back. The two bands, which are continuous with, and comparable in their functions to, the tæniæ of the colon, are shorter than the other coats of the rectum; hence they give rise, as in the case of the colon, to a folding or sacculation of the tube, which can be effective

only at the sides where the longitudinal fibres are fewest, for the front and back are occupied by the thickened longitudinal bands.

In addition to supporting the fæces, these foldings greatly increase the capacity of the rectum without unduly dilating the tube. When the rectum is empty (Fig. 556) its course is comparatively straight, its lateral flexures being but slightly marked, and its whole calibre very much reduced. In this condition it occupies only a small portion of the dorsal division of the true pelvis near the median plane, and at each side, between it and the side-wall of the pelvis, there is a large fossa of the peritoneum, which, when the bowel is empty, contains a mass of small intestine or pelvic colon (Figs. 556 and 558). When the rectum is distended the lateral flexures become

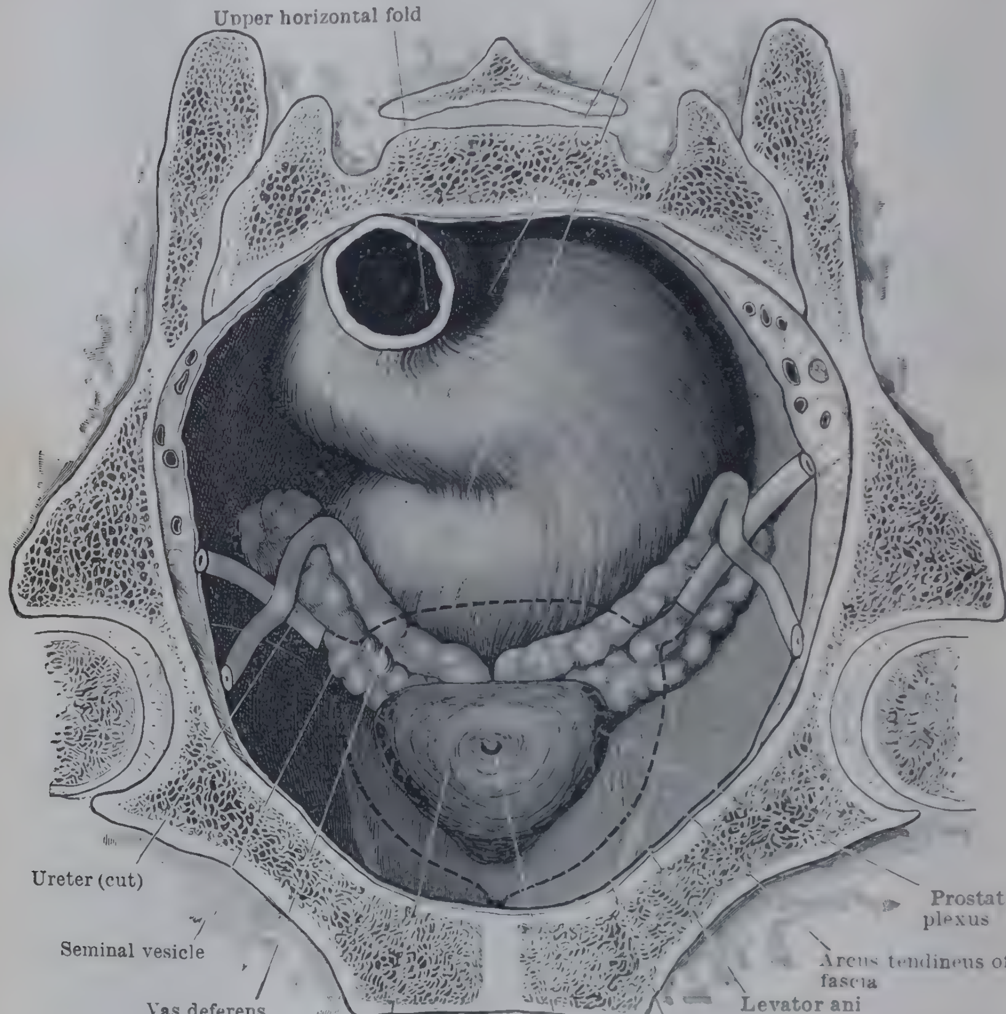

Fig. 555.—Distended Rectum *in situ*.

From a formalin-hardened male body, aged 56. The peritoneum and extraperitoneal tissue were removed, after the pelvis had been sawn along a plane passing through the upper part of the pubic symphysis in front and the lower part of the second sacral vertebra behind. The bladder, which was empty and contracted, has also been removed, but its form is shown by a dotted line. The rectum was very much distended, and almost completely occupied the pararectal fossæ.

much more marked, and the gut, bulging alternately to each side, passes laterally beneath the peritoneum, obliterating the pararectal fossæ (Fig. 555), and fills the greater part of the dorsal division of the pelvis.

Not uncommonly the abrupt curve at the junction of the rectum with the anal canal presents in front a knuckle-like projection (well seen on median section) immediately above the canal. It is most marked in females, and sometimes appears as if the bowel were doubled back upon itself at this point. The floor of the pouch thus formed may dip down in front even below the level of the upper aperture of the anal canal. That condition is most common in multiparæ and is evidently due to the relaxed condition of the pelvic structures, to the slight support afforded by the perineal body to this part of the gut in them, and to the great capacity and shallowness of the pelvis in the female (Fig. 657, p. 776).

Peritoneal Relations of Rectum (Figs. 554, 556).—Where the pelvic meso-colon ceases, its two layers separate and leave the posterior surface of the rectum destitute of peritoneum. Very soon the membrane quits its sides also and is then found on the front only; finally, it passes from the rectum on to the urinary

bladder in the male (Fig. 620, p. 740), and the vagina in the female (Fig. 627, p. 745); consequently the terminal part of the rectum is entirely devoid of peritoneum; the greater part of the rectum thus lies beneath the pelvic peritoneum and is capable of expanding and contracting without being in any way hampered by its partial peritoneal coat.

As the peritoneum is carried forwards to the base of the bladder in the male, it forms the floor of a recess called the **recto-vesical pouch** (Fig. 625, p. 744). In the female, as it passes to the upper part of the posterior wall of the vagina, it forms the floor of the **recto-uterine** or **recto-vaginal pouch**. In both sexes it passes from each side of the rectum on to the posterior wall of the pelvis, forming, when the rectum is empty, the bottom of a large fossa, known as the

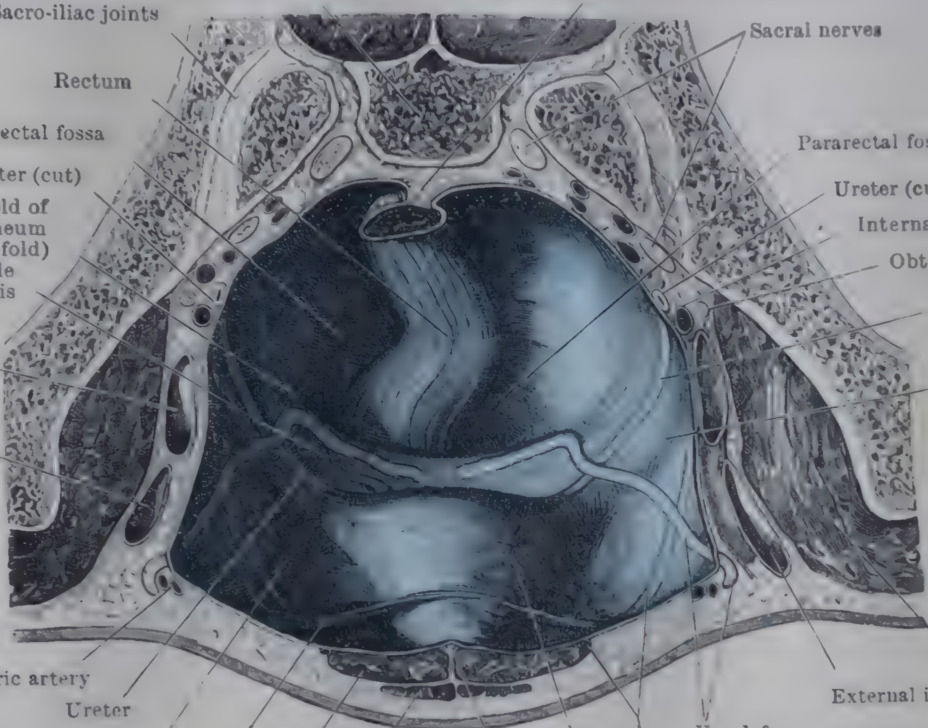

FIG. 556.—PERITONEUM OF PELVIC CAVITY SEEN FROM ABOVE.

The pelvis of a thin male subject, aged 60, was sawn across obliquely. Owing to the absence of fat the various pelvic organs were visible through the peritoneum, though not quite so distinctly as represented here. The urinary bladder and rectum are both empty and contracted; the paravesical and pararectal fossæ, as a result, are very well marked.

pararectal fossa. As the rectum becomes distended these fossæ are encroached upon by the enlarging bowel, and are soon obliterated.

The level at which the reflexion of the peritoneum takes place from the front of the rectum is of considerable practical importance in relation to operations in this region. As a general rule it is placed at a distance of 1 inch (2·5 cm.) above the base of the prostate, or about 3 inches above the anus, but the level is subject to considerable variation, being relatively much higher in well-developed muscular or fatty subjects, and lower in emaciated bodies owing to the thinness of the structures forming the pelvic floor. Further, the level is slightly raised by distension of the rectum and bladder, and lowered when they are empty. In the female the floor of the recto-uterine pouch is at a lower level and is relatively nearer the anus.

In the male infant at birth the peritoneum extends down to the base of the prostate (Symington, 1887), so that the rectum is not in direct relation to the bladder, which at that time is in a relatively higher position than in the adult.

As a rule it will be found that 2 inches (5·0 cm.) of the front of the adult rectum, exclusive of the anal canal, are entirely free from peritoneum, and this very distensible portion of the bowel forms

the ampulla of the rectum. The distance from the anal orifice to that part of the rectum which has a peritoneal covering in front is $3\frac{1}{2}$ inches (8·5 cm.). On the other hand, the back of the rectum is entirely free from peritoneum.

It is also of interest to notice that the connexion of the peritoneum to the rectum varies in its character at different parts: Above and in front it is closely adherent, and can be removed only with the greatest difficulty; at the sides and inferiorly the connexion is much looser. As a result the lower part of the peritoneum can be stripped off the rectum without much difficulty —an arrangement which admits of the free expansion of the rectal ampulla.

General Relations of Rectum (Figs. 554 and 556).—*Posteriorly* the rectum is related to the sacrum and coccyx, and below them to the posterior part of the pelvic floor—formed by the meeting of the two levatores ani in the ano-coccygeal body. When much distended it also comes into relation, on each side, with the lower part of the piriformis and the sacral plexus, but is separated from them by a very considerable amount of fibro-areolar tissue. In that tissue the two chief branches of the superior rectal vessels lie behind the rectum above, but lower down they are placed on its sides.

At its sides above are the pararectal fossæ and their contents (pelvic colon, or ileum); below the pararectal fossæ the rectum is in contact with the coccygei and levatores ani muscles.

Anteriorly in the male the rectum is separated from the bladder to within an inch of the prostate by the recto-vesical pouch of peritoneum, which usually contains some coils of small intestine. Below the reflexion of the peritoneum the front of the rectum is related to the posterior surface of the bladder, the vasa deferentia, seminal vesicles, and the posterior surface of the prostate gland (Fig. 555), from all of which it is separated by the recto-vesical septum.

The recto-vesical septum alone separates the rectum from a triangular area of the base of the bladder below the reflexion of the peritoneum and between the vasa deferentia. Through the triangle the operation of tapping the bladder from the rectum used to be performed.

The seminal vesicles, except when small, slope laterally and backwards round the front and sides of the distended rectum (Fig. 555), and, as it were, embrace it.

The ureters, as they run medially towards the base of the bladder, lie close below and in front of the vasa deferentia, and are not far separated from the distended rectum.

In the female the rectum is separated from the posterior surface of the uterus and the upper end of the vagina by the recto-uterine (recto-vaginal) pouch and the intestine which it usually contains. Below the peritoneal reflexion it is in direct contact with the posterior vaginal wall, to which it is loosely attached above, but more closely below.

The portion of the rectum below the level of the peritoneal reflexion is surrounded by a layer of fascia.

In the **child** the rectum, or at least its upper part, is relatively larger, and it pursues a much straighter course than in the adult. As pointed out above, its peritoneal covering is at a lower level at birth—reaching as far as the base of the prostate.

ANAL CANAL

In order to reach the exterior, it is necessary for the lower end of the bowel to pierce the floor of the true pelvis. This it does by passing through the narrow interval between the medial borders of the levatores ani muscles (Fig. 554); and the part of the large intestine through which the rectum communicates with the exterior is the anal canal. As it passes between the two muscles they pinch in the sides of the tube, and reduce its cavity to a mere slit-like passage.

The **anal canal** *begins* where the rectum proper terminates, namely, at the level of the levatores ani muscles, behind the apex of the prostate; and it *ends* at the anus. Its *length* is usually from 1 to $1\frac{1}{2}$ inches (2·5 to 3·5 cm.), and its antero-posterior diameter is from $\frac{1}{2}$ to $\frac{3}{4}$ inch (12 to 19 mm.) when the canal is closed. Its *direction* is downwards and backwards.

Relations.—It is *surrounded* by the external and internal sphincters, and above also by the borders of the levatores ani, these muscles forming a muscular cylinder around it (Fig. 558). *On each side* is situated the ischio-rectal fossa with its contained fat, which allows of the distension of the canal during the passage of fæces. *Posteriorly*, a mass of mixed fibrous and muscular tissue known as the **ano-coccygeal body** (Symington, 1888, 1912) intervenes between it and the coccyx. *Anteriorly*, it lies close behind the

perineal body and the bulb of the penis in the male, and a sound in the urethra can be easily felt by the finger introduced into the anal canal, particularly in thin bodies. In the female it is separated from the vagina by the perineal body.

Structure of Rectum and Anal Canal.—The wall of the rectum is made up of four coats. The **outer coat** is formed in part of peritoneum (already described), and, where the peritoneum is absent, of fibrous tissue which can be dissected off in several layers. In this fibrous tissue the rectal vessels run until they enter the muscular wall of the tube. In it also, at the back and sides of the rectum, a number of rectal lymph-glands are embedded.

The **muscular coat**, which is much thicker than in any other portion of the intestine, is composed of two thick layers of plain muscle—an outer longitudinal and an inner circular—like that of the intestine generally. The *longitudinal fibres*, although present all round, are accumulated chiefly on the front and back of the tube, where they form two broad bands; at the sides they are reduced to a thin layer, the deepest fibres of which are folded in and take part in the formation of the horizontal folds.

Where the rectum pierces the floor of the pelvis, the outer layer of longitudinal fibres is united to the deeper portion of the levator ani, partly by tendinous fibres and partly by an interchange of muscular fibres between the levatores and the muscular coat of the rectum. Below, the longitudinal fibres pass between the external and internal sphincter muscles, or through the latter to join the skin around the anus.

In sagittal sections of the pelvis near the median plane there can generally be seen a distinct band of red, longitudinally arranged, muscular fibres which descends on each side from the front of the coccyx to blend with the longitudinal fibres on the back of the rectum. That band is the *recto-coccygeus muscle.* It is composed of striated fibres above, but becomes plain muscle below.

Some plain muscular fibres which descend in the subcutaneous tissue of the lower part of the anal canal to join the skin around the anus were first described by Ellis (1867) as the *corrugator cutis ani.* The front of the rectum at the perineal flexure is, in the male, connected to the back of the membranous urethra by one or two slips of muscle termed the *recto-urethralis* (Fig. 402, p. 472).

The *circular fibres* form, along the whole length of the tube, a continuous layer, which is doubled inwards to assist in the formation of each horizontal fold and is thickened below to form the **internal sphincter** of the anal canal. The internal sphincter, as just pointed out, is formed by a great, and rather sudden, increase of the circular muscular fibres, which begins at the upper end of the anal canal. It surrounds the canal for about an inch (2·5 to 3·0 cm.), and may reach almost down to the anal orifice (Fig. 557).

The **submucous coat** is composed of loose areolar tissue, which allows of a free movement of the mucous layer on the muscular coat. The rectal plexus of veins is contained in this layer.

The **mucous coat** of the rectum is redder in colour than that of the colon. It is also thicker, and owing to the looseness of the underlying submucosa is thrown into numerous irregular rugæ when the rectum is empty; these disappear when the bowel is distended. Lymphatic nodules and intestinal glands are present; but the glands are not so numerous as in the colon, although their calibre is greater. The mucous coat of the rectum presents a characteristic punctated appearance which is due to the presence of a considerable number of rounded depressions, such as might be made by firmly pressing a finely pointed pencil against the membrane. These *rectal pits* are tubular in form, and have an accumulation of lymphoid tissue at the bottom of each, the whole appearance being such as might be produced if a small solitary nodule were drawn down from the surface into the intestinal wall.

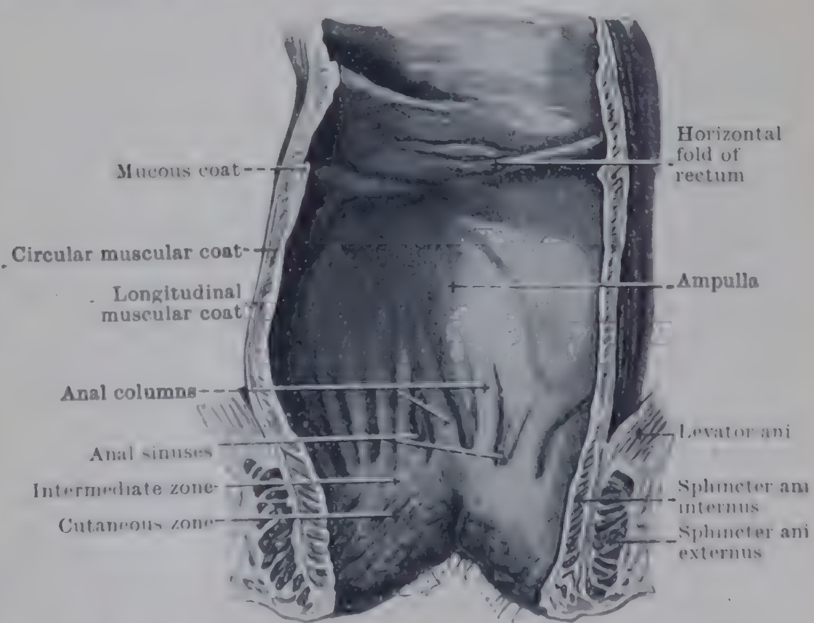

Fig. 557.—Interior of Lower Rectum and Anal Canal.

Anal Columns and Anal Valves.—The mucous coat of the anal canal presents a number (5 to 10) of *permanent* vertical folds, separated by grooves and known as the **anal columns** (Fig. 557). They are usually $\frac{1}{3}$ to $\frac{1}{2}$ inch in length, $\frac{1}{8}$ to $\frac{1}{4}$ inch in width, and they extend down to within $\frac{1}{2}$ or $\frac{2}{3}$ inch of the anal aperture. They are formed by infoldings of the mucous coat, containing in their interior some bundles of longitudinal muscle, and also, as a rule, an artery and a vein.

Very often the contained vein presents an enlargement, or a knob-like tortuous plexus in the lower part of the column; below this the plexus is continued down *external* to the mucous membrane of the lower zone of the anal canal into the anal veins. Dilated portions of the veins may form rounded nodular projections, known as hæmorrhoids or "piles", and this portion is therefore frequently termed the hæmorrhoidal zone of the anal canal. Sometimes the columns are very indistinct; occasionally no trace of them can be found in the adult, although in the fœtus they are usually well marked.

If a probe is passed downwards along the groove which separates two adjacent anal columns (Fig. 557), its point will usually catch in a small crescentic fold which joins the lower ends of the two columns. These little folds are the **anal valves**. They project inwards and upwards, and behind each there is a little pocket-like **anal sinus**.

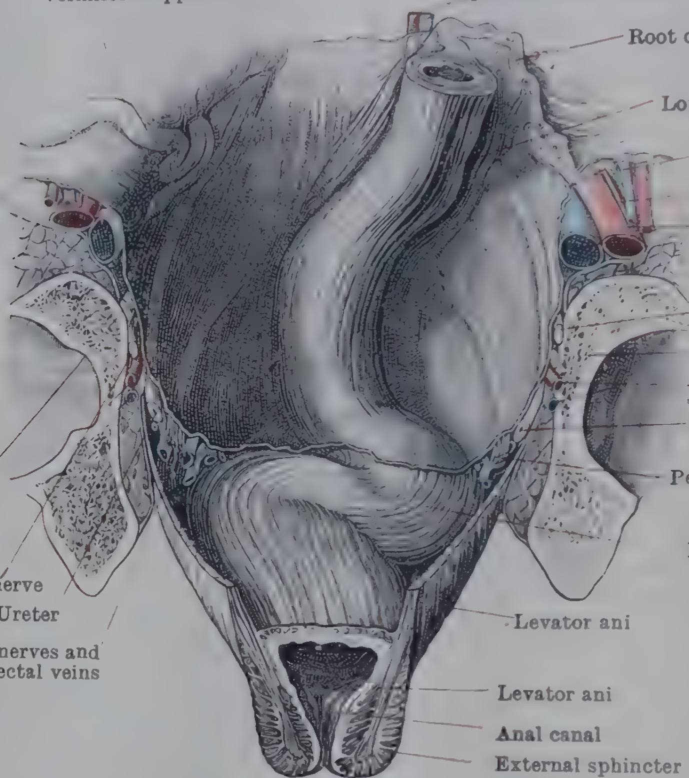

FIG. 558.—DISSECTION OF RECTUM AND ANAL CANAL FROM THE FRONT IN A SPECIMEN HARDENED BY FORMALIN INJECTION.

The front wall of the pelvis has been removed, and the bladder, prostate, and seminal vesicles taken away.

Anal Orifice.—At the inferior aperture of the anal canal, the modified skin of its lower zone passes into the ordinary skin.

The skin round the margin of the anus possesses hair-follicles and glands and forms a zone called the cutaneous zone. Above this zone there is a second zone, not sharply marked off, but its surface is smoother and no hairs arise from it. It is lined with a stratified squamous epithelium.

The region of the lowest part of the anal columns forms a third zone lined with columnar epithelium and clearly marked off from the second zone by a sinuous line which follows the level of the anal valves and crosses the bases of the columns between the valves; this sinuous line of union of mucous membrane and skin is known as the "white line" of Hilton (1863), and it corresponds to the junction of epithelium derived from the entoderm of the hind-gut with that derived from the ectoderm of the anal pit (pp. 62, 672).

Action of Anal Sphincters.—Three muscles act on the anal canal, namely, the paired levatores ani, the external sphincter, and the internal sphincter.

The fibres of the **levatores ani** which arise from the lateral part of the body of the pubis (pubo-rectalis) pass backwards on each side of the beginning of the anal canal, and meet behind the passage. The two muscular bands are closely approximated during contraction, like the limbs of a clamp, and, pressing on the sides of the anal canal, they assist in closing the upper part of that passage, whilst at the same time drawing it towards the pubes. There is little doubt that the *pubo-rectalis* in that way acts as one of the chief sphincters of the bowel; and it should be noticed that it is placed where its action would be most effective, namely, opposite the point at which the rectum is narrowed or "pinched in" to form the anal canal. In addition to its sphincter action the muscle supports the expanded bowel immediately above the

anal canal, and in that way sustains the weight of the fæces when the rectum is distended. It is probably relaxed during defæcation, except perhaps at the completion of the act. The muscle is under the control of the will and is closely associated with the deeper part of the external sphincter.

The **sphincter ani externus** forms a muscular cylinder around the lower two-thirds of the anal canal, with (except in the case of some of its inner fibres) an anterior and a posterior attachment. When the muscle contracts its fibres are tightly stretched between its two attachments, and the space between them is reduced to a narrow antero-posterior slit. By that action the anal canal is flattened from side to side and closed, so that, whilst the pubo-rectalis is the sphincter of the upper aperture of the anal canal, the external sphincter closes its inferior and greater part. It is under the control of the will, but under ordinary circumstances it is in a state of tonic contraction.

The **sphincter ani internus** is continuous with the circular fibres of the gut in structure and also in action, its chief use being to empty the anal canal completely after the passage of each fæcal mass.

Vessels and Nerves.—The **arteries** of the rectum and anal canal are the three rectal arteries; to these, another, less important though constant, source may be added—the median sacral artery.

1. The *superior rectal artery* is the principal artery of the rectum. It is the prolongation of the inferior mesenteric artery; and at first it descends in the root of the pelvic mesocolon until the rectum is reached. There, it divides into two chief branches which run downwards and forwards around the sides of the rectum—the right, usually the larger, lying more posteriorly, the left more anteriorly. From these two arteries secondary branches come off (about five to eight in all); they pierce the muscular coat about the middle of the rectum and then descend in the submucosa as a series of longitudinal "terminal branches" as far as the anal valves, above the level of which one is usually found beneath each of the anal columns. The terminal branches give off numerous twigs which form a plexus in the submucosa by anastomosing with one another and with branches of the middle rectal artery, and also, in the lower part of the bowel, with branches of the inferior rectal artery.

2. The *middle rectal arteries*, two in number—one on each side—are usually branches of the internal iliac but may arise from the internal pudendal; they run on the wall of the inferior part of the rectum, and each breaks up into four or five small branches, some of which supply the muscular wall of the lower part of the rectum, whilst the others pierce the muscular coat near the upper end of the anal canal and join in the submucosa with the plexus formed by the superior rectal artery already described.

3. The *inferior rectal arteries*, generally two or three in number on each side, arise at variable levels from the internal pudendal. They are distributed to the levatores ani and the sphincters. Some branches pierce the sphincters and break up in the submucosa into a close network which supplies the lower part of the anal canal and communicates above with the plexus formed by the superior and middle rectal arteries.

4. One or more small branches of the **median sacral artery** reach the posterior surface of the rectum, where they are distributed chiefly to the muscular coat.

The superior and middle rectal arteries anastomose freely in the plexus of the submucosa, and also by a few large branches on the exterior of the bowel: some perforating branches of the median sacral and inferior rectal arteries also join the plexus in the submucous layer at the lower part of the rectum. In addition, small branches of these several arteries unite with one another in the muscular coat. It should be remarked that the superior rectal artery supplies both the muscular and mucous coats in the superior part of the rectum, but that the muscular coats in the inferior part are supplied by the middle and inferior rectal vessels only. The inferior rectal artery is distributed chiefly on the posterior wall, and the middle rectal chiefly on the anterior wall.

The **veins** form two chief plexuses of large vessels devoid of valves, namely, an internal plexus situated in the submucous coat, and an external plexus in the outer coat. The internal plexus takes origin near the margin of the anus in a number of small (anal) veins, which are radially disposed beneath the skin of the anus and communicate below with the rootlets of the inferior rectal vein lying lateral to the external sphincter. The anal veins are joined by others from the surrounding parts to form larger and often tortuous vessels which ascend in the anal columns. Passing upwards, the veins are known as the "terminal veins"; they communicate freely with one another, and they unite into still larger vessels which pierce the muscular coat about the middle of the rectum and join to form the superior rectal vein.

From the inferior part of the internal plexus numerous vessels pass through the external sphincter to join a venous network on the outer surface of that muscle, from which the *inferior rectal veins* arise. The network also communicates with the internal plexus through the anal veins which descend from the latter beneath the skin of the anal canal to the exterior of the sphincter.

The various veins which pass out through the walls of the rectum unite freely on its exterior to form a rich venous plexus through which the three rectal vessels are brought into free communication with one another. Passing off from that plexus, the *superior rectal* joins the inferior left colic vein and forms with it the inferior mesenteric vein, which opens into the splenic; the middle rectal joins the internal iliac, from which the blood passes through the common iliac to the inferior vena cava; and the inferior rectal joins the internal pudendal—a tributary of the internal iliac vein. Thus, on the rectum, a free anastomosis is established between the veins of the portal and systemic circulations.

Most of the **lymph-vessels** of the rectum pass to the sacral lymph-glands.

The **nerves** are derived from various sources. The sympathetic fibres are derived from the *inferior mesenteric plexus* and from the branches of the *hypogastric plexus* that accompany the superior and middle rectal arteries to the rectum. The parasympathetic fibres arise from the *second* and *third* or *third and fourth sacral nerves* soon after these leave the sacral foramina. They run forward in the pelvic areolar tissue, join the pelvic plexuses, and reach the side of the rectum. Fibres of the *inferior hæmorrhoidal* branches of the pudendal nerve (third and fourth sacral) are distributed to the lower part of the anal canal as well as to the external sphincter.

Variations.—The best known anomalies of the rectum are those classed under the term **imperforate anus** or **atresia ani**. The atresia may be simply due to a partial or complete persistence of the anal membrane, which separates the anal pit from the hind-gut in the embryo; or the hind-gut may be deficient in its lower part when there is a considerable interval between the anal pit and the gut; or the rectum may open into the vagina, the uterus, the bladder, or the ureters, when usually no anus is evident; or finally the cloaca may persist. Other forms are also described, but the foregoing are those most commonly found.

LIVER

The **liver** (hepar) is a large glandular organ which lies immediately below the diaphragm, occupying the upper portion of the abdominal cavity mainly on the right side. It secretes a yellowish-green or brown fluid of bitter taste, called *bile* (fel). The bile is conveyed from it by two **hepatic ducts** which unite with each other to form a **common hepatic duct**. The common duct opens into the **bile-duct**, which conveys the bile to the duodenum. Connected with the bile-duct there is also a pear-shaped sac called the **gall-bladder** which is attached to the liver and serves as a temporary reservoir for the bile. The bile passes to and from it through a canal, called the **cystic duct**, which unites with the common hepatic duct to form the **bile-duct**.

In addition to secreting bile, the liver plays an important part in the metabolism of carbohydrate and nitrogenous materials which are absorbed from the food by the intestines and conveyed to the liver by the portal vein.

Physical Characters.—The liver is a large, mottled, reddish-brown mass, pliant to the touch, readily lacerated, and highly vascular. It is of uniform consistence, but the lacerated surface is granular. The granular appearance of the lacerated surface and the mottled colouring of the free surface are due to the lobules of which the liver is composed. Each lobule is polygonal or irregular in form and measures only 1 to 2 mm. in diameter; it is surrounded by a stroma of areolar tissue in which the vessels, nerves, and bile-capillaries lie.

Size and Weight.—The average dimensions of the adult liver are seven inches across (17·5 cm.), six and a half inches vertically (16 cm.), and six inches antero-posteriorly (15 cm.) where it is thickest. It is about $\frac{1}{50}$th of the body-weight, varying from 50 to 55 ounces in men, and from 43 to 48 ounces in women. The ratio to the body-weight is the same in both sexes, but it varies with age. In the fœtus and child it is relatively large and heavy. At birth it occupies the greater part of the abdominal cavity and is $\frac{1}{20}$th to $\frac{1}{18}$th of the body-weight; in a fœtus the ratio is still larger. The protuberance of an infant's abdomen is due chiefly to the liver.

Shape.—If the liver is not removed from the body until some time after death it becomes soft and flabby; it flattens out when placed on a table and appears to have only a superior and an inferior surface separated by a circumferential border. But if it is taken out shortly after death while still firm, or if it is hardened *in situ* and then removed, its form is fairly constant; and, although it is irregular and varies with the position of adjacent organs and with the degree of distension of the parts of the alimentary canal near it, nevertheless, for descriptive purposes, it may be looked upon as an irregular four-sided pyramid laid on one side. The pyramid has an edge-like apex, directed towards the left, a convex right surface, and four other surfaces—anterior, posterior, upper, and lower (or visceral)—the distinctive features of which are that the **anterior surface** is nearly flat, the **upper surface** is slightly convex on each side and slightly concave in the middle, the **posterior surface** is markedly concave from side to side, and the **lower surface** is uneven and oblique, looking to the left and backwards as

well as downwards. The anterior, upper, posterior, and right surfaces merge into one another over ill-defined, rounded borders; but the lower surface is marked off from the others by a definite, circumferential **lower border**. This lower border is indistinct between the posterior and the inferior surface, but forms a definite edge between the right lateral and the inferior surface. Between the anterior and inferior surfaces the lower border forms a characteristic sharp edge, and towards the left extremity of the liver it is the rounded edge of a sharp wedge between the stomach and the diaphragm (Figs. 559-562).

Porta Hepatis.—The porta hepatis, or hilum of the liver, is a deep, wide, transverse cleft, about two inches long, situated in the posterior part of the lower or visceral surface. Part of the upper border of the lesser omentum is attached to its lips (see p. 604). The hepatic artery, the portal vein, and the nerves of the liver enter through the porta, and the common hepatic duct and the lymph-vessels of the deeper parts pass out through it. These structures are

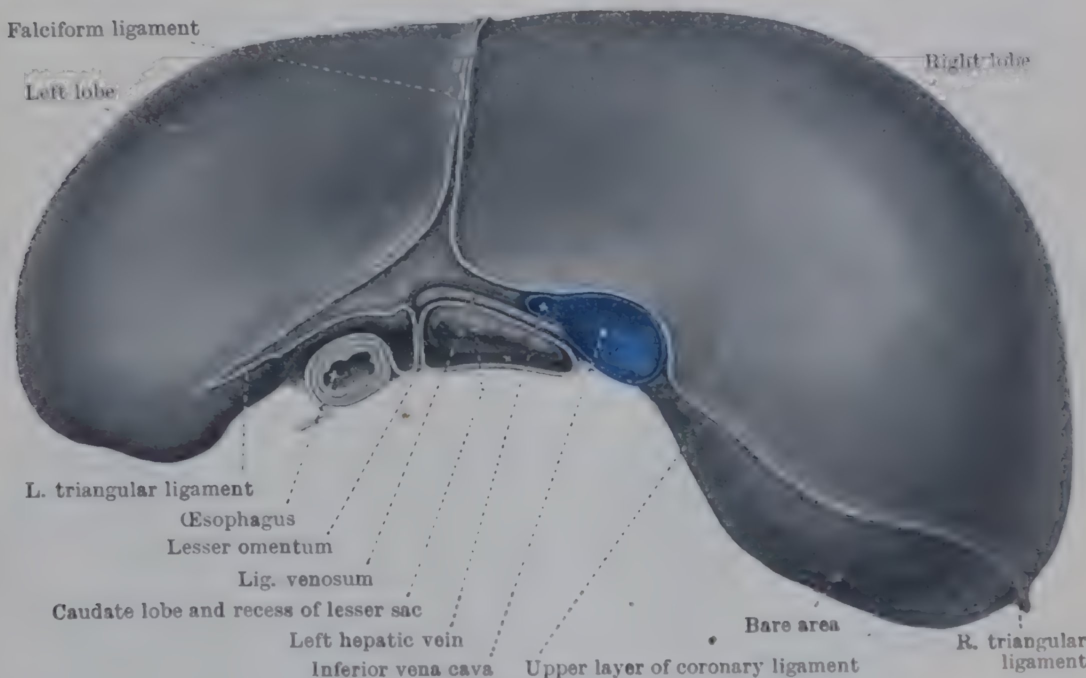

Fig. 559.—Liver viewed from Above.

surrounded by loose fibrous tissue which is continuous with the fibrous capsule of the liver.

The right and left hepatic ducts emerge from their lobes at the right and left ends of the porta, and unite near its right end to form the common hepatic duct, which unites, either inside or immediately outside the porta, with the cystic duct to form the bile-duct. The hepatic artery enters the porta to the left of the common hepatic duct, and its right and left branches run to their lobes behind the hepatic ducts. The portal vein divides similarly but at the right end of the porta, and its branches are behind those of the artery. Two or more lymph-glands are sometimes present in the porta, most commonly near its right end; if they become enlarged they may press upon the hepatic ducts and obstruct the flow of bile.

Surfaces.—The **right surface** of the liver is convex and roughly quadrilateral. It is closely related to the diaphragm, which separates it from the lower parts of the right lung and pleura and the lower six ribs and intervening intercostal spaces. Not uncommonly it descends below the ribs; its lowest part is then related to the fascia and muscles of the abdominal wall.

The **upper surface** is closely apposed to the diaphragm. On the right and left it is slightly convex and fits into the cupolæ of the diaphragm, which separate it from the pleuræ and lungs. Its middle part is slightly concave and lies below the pericardium and heart (Fig. 559).

The **anterior surface** is flat or slightly convex. In the infrasternal angle it is related to the xiphoid process, the linea alba, and the sheaths of the recti muscles,

and to the falciform ligàment, which lies between it and the abdominal wall with its left surface in contact with the left lobe of the liver and its right with the anterior abdominal wall. The smaller part of the anterior surface that lies to the left, and the larger part to the right, are under shelter of the ribs and costal cartilages in contact with the diaphragm.

The **lower or visceral surface** (Fig. 560) is in relation (*a*) with the right kidney posteriorly, (*b*) with the right flexure of the colon anteriorly, (*c*) with the second part of the duodenum to the left of the kidney, then (*d*) with the gall-bladder in its shallow fossa, and (*e*), near the apex, with the lesser omentum and the stomach.

The **posterior surface** (Fig. 562) is curved round the front of the vertebral column. On the right, a large convex part of it is in direct contact with the diaphragm, which separates it from the right pleura and lung and the lower

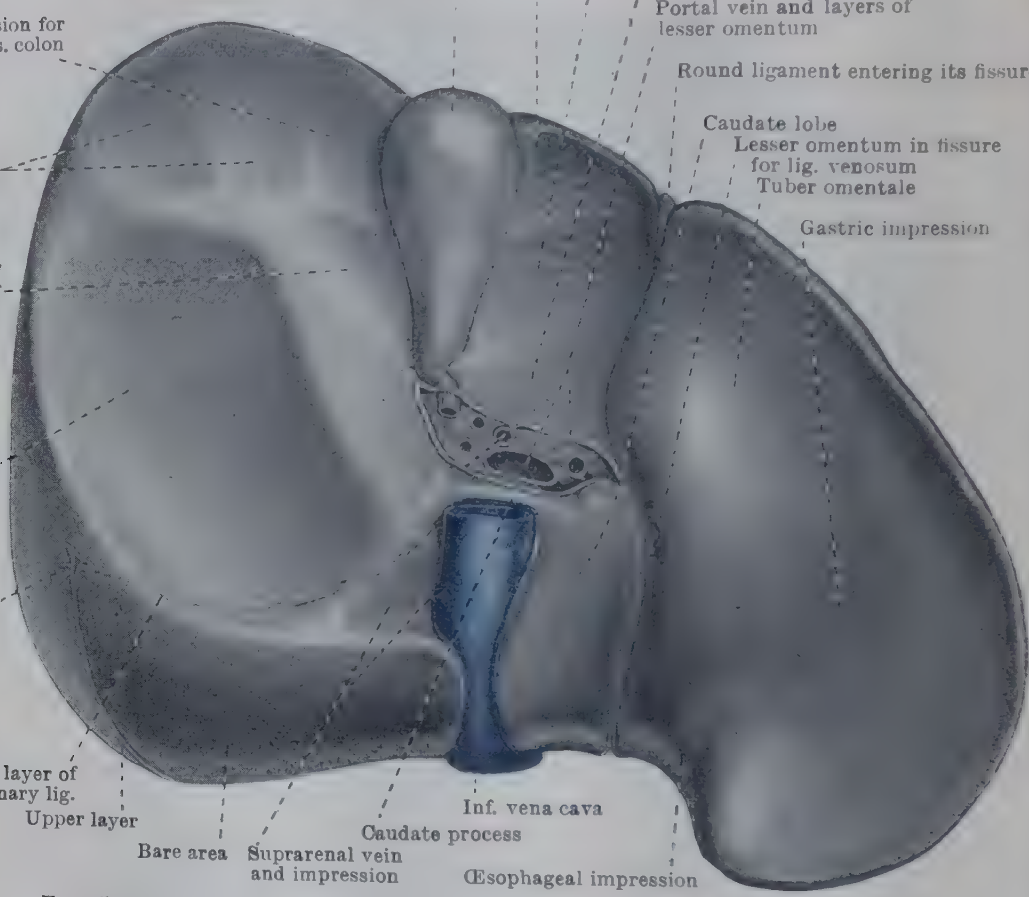

Fig. 560.—Lower (Visceral) and Posterior Surfaces of Liver.

ribs of the right side. Next, passing to the left, it is intimately attached to the upper part of the inferior vena cava, which is embedded in the liver in a deep **groove for the vena cava.** On the right of this groove there is an area which is in contact with the right suprarenal gland. To the left of the inferior vena cava, an oblong area of the surface lies on the front of the crura of the diaphragm, which separate it from the lower part of the descending thoracic aorta; that portion is called the **caudate lobe**; it is separated from the crura by the upper recess of the lesser sac (Figs. 515 and 559), and is bounded on the left by a deep, vertical cleft called the **fissure for the ligamentum venosum.** To the left of that, the surface is grooved vertically for the abdominal portion of the œsophagus, which produces the **œsophageal impression.**

Relation to Peritoneum.—The peritoneum covers the surfaces of the liver and adheres to its fibrous capsule, with the exception of (*a*) an area of the posterior surface, in contact with the vena cava and with the diaphragm, continued on to the posterior portion of the upper surface, and (*b*) a part of the inferior urface in contact with the gall-bladder. Also, along certain definite lines the

peritoneum passes from the liver to adjacent structures in the form of folds or reflexions which connect the liver with adjacent parts.

The largest of the folds is called the **falciform ligament**. It is a long, wide sheet, attached to the upper and anterior surfaces of the liver and to the lower surface of the diaphragm and the back of the linea alba—as far down as the umbilicus. Its line of attachment to the liver indicates the division of the liver into right and left lobes (see p. 661). Its lower border is free; it extends from the umbilicus to a notch in the lower border of the liver, and it encloses a fibrous cord called the ligamentum teres. At the lower border of the liver the **ligamentum teres** enters a deep cleft in the inferior surface called the **fissure for the ligamentum teres** (see p. 661), along which it passes to end by fusing with the left branch of the portal vein. The ligamentum teres (round ligament) is the remains of the umbilical vein of the fœtus and, during fœtal life, it conveyed purified, oxygenated,

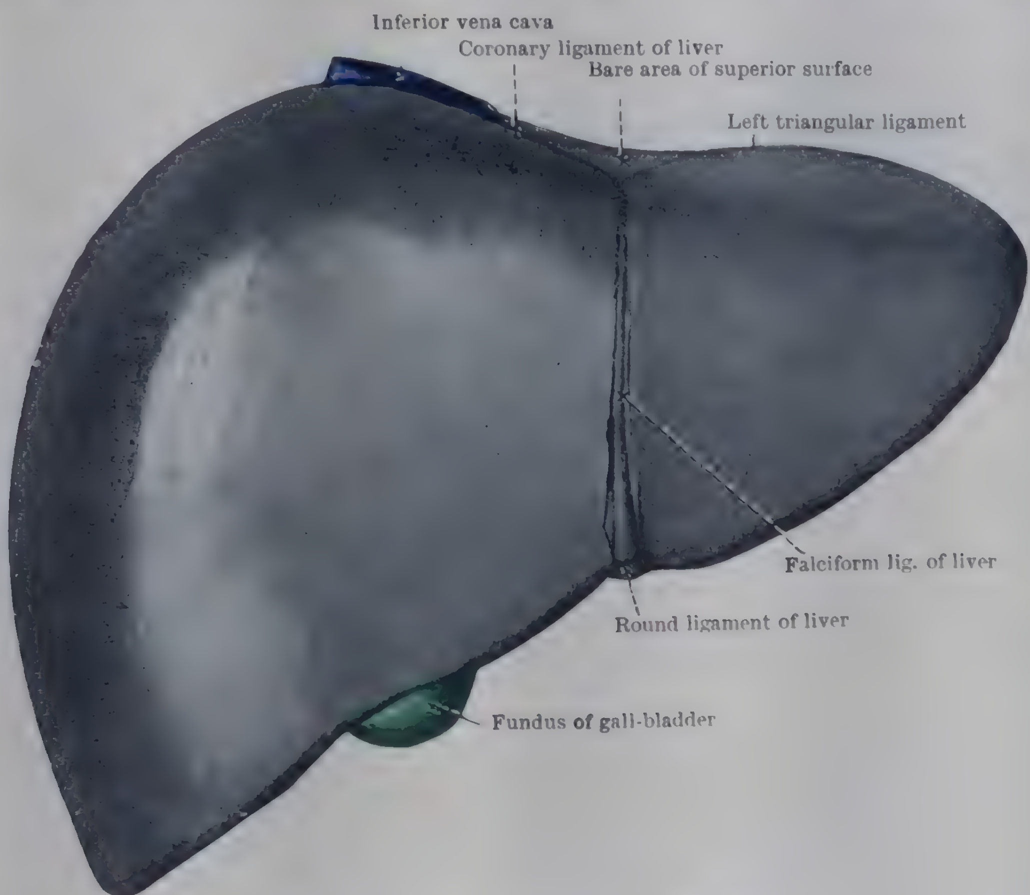

Fig. 561.—Liver viewed from the Front.

and food-laden blood from the placenta to the fœtus. Alongside it, in the adult, run some small venous channels which connect the left branch of the portal vein with the veins of the body-wall in the region of the umbilicus.

The falciform ligament consists of two layers of peritoneum. At the back part of the upper surface of the liver the left layer turns to the left and forms the anterior layer of a triangular fold called the **left triangular ligament**, which passes from the upper surface of the left lobe to the diaphragm (Fig. 559). At the left end of the left triangular ligament that layer turns to the right as the posterior layer of the left triangular ligament, and at the upper end of the fissure for the ligamentum venosum (see Fig. 559) it becomes continuous with the upper end of the lesser omentum.

At the point where the left layer of the falciform ligament turns to the left the right layer turns to the right in front of the inferior vena cava and along the posterior border of the upper surface, and then downwards along the posterior border of the right surface; along the whole of that line it is reflected to the diaphragm, and the reflected part is called the *upper layer* of the **coronary ligament**. At or near the meeting of the right and lower surfaces, towards the back, the line of reflexion makes an angular bend from which a fold called the **right triangular**

ligament passes to the diaphragm (Fig. 562). From the right triangular ligament to the lower end of the groove for the vena cava, the peritoneum is reflected to the diaphragm; that reflected portion is called the *lower layer* of the **coronary ligament** and it occasionally passes to the upper end of the right kidney instead of to the diaphragm. Continuing to the left, the line of reflexion passes in front of the inferior vena cava and behind a narrow bridge of liver, called the **caudate process**, which intervenes between the lower end of the groove for the inferior vena cava and the porta hepatis.

The part of the surface of the liver between the upper and lower layers of the coronary ligament, to the right of the inferior vena cava, is called the **bare area** of the liver, because it is devoid of peritoneum. It is closely attached to the diaphragm.

At the left border of the inferior vena cava the line of reflexion of the

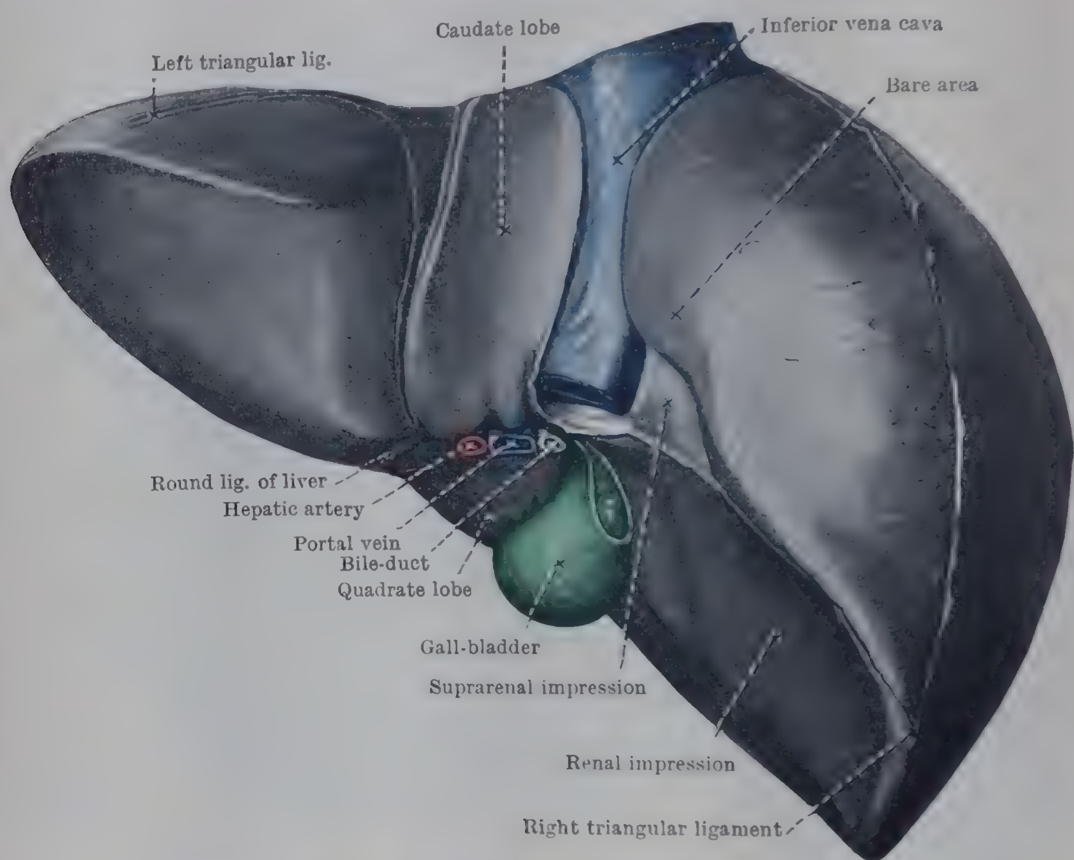

Fig. 562.—Liver viewed from Behind.

Comparison of the cut edges of peritoneum, as shown in this figure, with the cut edges of peritoneum in Fig. 538, p. 630, gives a very clear picture of the peritoneal reflexions from the surfaces of the liver. The upper and lower layers of the coronary ligament diverge from the right triangular ligament to enclose the bare area.

peritoneum ascends along the right border of the caudate lobe (Figs. 560, 562), and the reflected peritoneum, as it passes backwards to the diaphragm, forms the right boundary of the upper recess of the lesser sac; the line of reflexion then turns to the left above the caudate lobe from which it is reflected to the diaphragm as the roof of the recess. At the upper end of the fissure for the ligamentum venosum, the layer reflected from the right lobe comes into relation with the layer reflected from the left lobe, which is continuous with the posterior lamella of the left triangular ligament. The layers from the two lobes dip into the fissure for the ligamentum venosum, and line its walls. They return from the fissure together and extend from it to the stomach as the upper, left part of the lesser omentum.

From the lower end of the fissure for the ligamentum venosum the lines of attachment of the two layers of the lesser omentum pass to the inferior surface of the liver where they turn to the right along the margins of the porta hepatis, the left layer passing in front of the porta and the right layer behind it; and at

the right end of the porta the two layers join each other in the anterior margin of the opening into the lesser sac.

Lobes.—The liver is divided into two main lobes—a large right and a small left. The division is effected by the attachment of the falciform ligament on the upper and anterior surfaces (Figs. 559, 561), by the fissure for the ligamentum teres on the lower surface (Fig. 560), and by the fissure for the ligamentum venosum on the posterior surface (Fig. 562). But two subordinate lobes are cut off from the right lobe. They are the **quadrate** lobe on the lower surface to the left of the gall-bladder, and the **caudate** lobe on the posterior surface to the left of the inferior vena cava. The caudate lobe is connected by the caudate process with the main part of the right lobe.

In addition to the fissure for the ligamentum teres and the fissure for the ligamentum venosum, other surface depressions are the groove for the inferior vena cava and the fossa for the gall-bladder. The first two are deep, narrow clefts; the groove for the vena cava is a deep, wide furrow; the fossa for the gall-bladder is usually a mere shallow depression. They all represent, in Man, the much more definite fissures which, in many mammals, separate the liver into discrete or almost discrete segments.

The **fissure for the ligamentum teres** begins in a notch on the lower border of the anterior surface at the lower end of the attachment of the falciform ligament, and it extends to the left end of the porta hepatis. It contains the ligamentum teres (p. 659). Occasionally it is bridged over by liver-tissue.

The **fissure for the ligamentum venosum** is continuous with the fissure for the ligamentum teres at the left end of the porta hepatis; and it extends to the upper surface. The peritoneum which lines its sides is reflected from its floor as the upper, left part of the lesser omentum.

At the bottom of the fissure there is a fibrous cord, called the **ligamentum venosum,** which connects the left branch of the portal vein with the upper end of the abdominal part of the inferior vena cava. At the upper end of the fissure it turns to the right in front of the upper end of the caudate lobe and fuses with the left wall of the inferior vena cava. The ligamentum venosum is the remains of a fœtal blood-channel, called the *ductus venosus*, which during fœtal life transmitted blood directly from the umbilical vein to the inferior vena cava

Left Lobe.—The **left lobe** fits into the left cupola of the diaphragm, to which the posterior part of its *upper surface* is attached by the left triangular ligament. Its *lower surface* presents, in front and to the left, a deep concavity—the **gastric impression**—for the fundus and body of the stomach, whilst behind and to the right it bulges as a prominence called the **tuber omentale** because it rests against the front of the lesser omentum.

Parts of Right Lobe.—The **quadrate lobe** extends from the lower border to the porta hepatis, between the fissure for the ligamentum teres on the left and the fossa for the gall-bladder on the right. It is usually marked by impressions made by the pyloric end of the stomach and the first part of the duodenum.

The **fossa for the gall-bladder** extends from the lower border of the liver (at the level of the ninth right costal cartilage) to the right end of the porta hepatis. It is generally shallow, but sometimes it is so deep that the gall-bladder is almost entirely hidden in it. Its surface is devoid of peritoneum and is directly attached to the gall-bladder by areolar tissue through which small blood-vessels and lymph-vessels pass—and occasionally also minute **hepato-cystic ducts** which connect the bile-capillaries of the liver directly with the gall-bladder.

The **caudate lobe** is a relatively narrow, oblong lobe on the posterior surface of the right lobe. It forms the anterior boundary of the upper recess of the lesser sac and is related to the crura of the diaphragm opposite the lower part of the thoracic aorta and the lower thoracic vertebræ. The fissure for the ligamentum venosum bounds it on the left, and the groove for the inferior vena cava on the right. Its lower end is connected with the rest of the right lobe by the caudate process and is grooved antero-posteriorly by the cœliac artery. The part to the left of the groove is called the *papillary process*; and the part to the right is continuous with the caudate process.

The **caudate process** is a narrow band of liver-substance on the lower surface of the right lobe. It lies between the porta hepatis and the fossa for the inferior vena cava, and it forms the upper boundary of the opening into the lesser sac.

The **groove for the vena cava** is deep, rounded, and vertical—occasionally so deep that the vena cava is almost completely enveloped in it. Sometimes it is even bridged across posteriorly by liver-substance (*pons hepatis*). In it the walls of the inferior vena cava are closely attached to the fibrous capsule of the liver, through which the hepatic veins emerge from the liver-substance and join the vena cava on its anterior aspect—the main veins at the upper end of the groove and the smaller veins at varying levels.

The **remainder of the right lobe** forms the whole of the right surface and parts of the other four surfaces of the liver. Its *lower surface* is covered with peritoneum and is marked by three impressions (Fig. 560). The two to the right are (*a*) the smaller, below and in front, for the right flexure of the colon, and (*b*) the larger, above and behind, caused by the right kidney. The third is to the left of the renal impression and is caused by the commencement of the

FIG. 563.—LIVER OF A PIG INJECTED FROM THE HEPATIC VEIN.

second part of the duodenum. Its *upper*, *anterior*, and *right surfaces* are covered with peritoneum and lie in relation with the parietes (Figs. 559, 561). The *posterior surface* is the **bare area** of the liver. Through the areolar tissue of this area lymph-vessels from the liver pass to the diaphragm and so to the thorax, and also small veins which connect the portal circulation in the liver with the systemic veins in the diaphragm.

Fixation of Liver.—Adequate means of retaining the relatively heavy liver in its place is not provided by its connexions—which are the peritoneal folds, the attachment of its posterior surface to the diaphragm by areolar tissue, and its attachment to the vena cava by areolar tissue and the hepatic veins. The position is maintained partly by those connexions and partly by atmospheric pressure, but mainly by the **intra-abdominal pressure** caused by the tonic contraction of the muscles of the abdominal walls, which press the more movable contents of the abdomen against the less movable and keep them all in comparatively fixed positions. Atmospheric pressure, however, prevents sudden displacement of the liver, for the abdomen is a closed cavity: before the liver could move from its close contact with the diaphragm some viscus would have to be available to occupy the vacated space and prevent a vacuum, and none of the abdominal contents is sufficiently movable for that purpose.

Variations.—Few organs vary more in **size** than the normal, healthy liver; but increase or decrease is often pathological. The **position** varies normally with the size. The liver also moves down and up with every breath; and it descends slightly when the body is raised from

the reclining posture to the erect. Occasionally, without any evident cause, the liver and diaphragm are higher or lower than usual. In apparently healthy bodies the upper surface of the right lobe may be at the level of the fourth rib; or it may reach only the level of the sixth, and its lower border may be two or three inches below the costal margin—especially in women. Apart from pathological deformities, there may be congenital irregularities in **form** caused by additional fissures and lobes that resemble those in the higher apes and are commonly present in the fœtus (Thomson, 1899), or by division into several distinct lobes as in many other mammals. Grooving by the ribs and wrinkling on the surfaces opposed to the diaphragm are probably fixed by the hardening of the liver. In some cases a wide, tongue-like process (Riedel's lobe) projects downwards from the lower border on the right of the gall-bladder; it is more common in women than in men; it may be large enough to reach the iliac crest, and it has been mistaken for a tumour. **Correlated variations in form and position** normally result from the varying pressure of surrounding parts. Distension of the stomach or of the left part of the transverse colon pushes the liver to the right and increases its vertical diameter. Distension of the intestines flattens it from below upwards and increases its transverse diameter. But variations may be due to malformations of the thoracic framework, either congenital or acquired. When tight lacing was common, such malformations were frequent in women. When the chief constriction was low, the liver was forced up against the diaphragm and filled the whole left cupola as well as the right. More often, the constriction caught the liver; its upper part was forced upwards and to the left, and its lower part downwards.

Structure of Liver.—The liver is partially invested by an outer **serous coat**, which has been described with its peritoneal relations. Deep to that there is a thin **fibrous coat**—most evident where the serous coat is absent. In the neighbourhood of the porta hepatis it is more abundant, and there it surrounds the vessels entering the porta and accompanies them through the portal canals in the liver-substance. The fibrous coat is continuous with the fine areolar tissue which pervades the liver, surrounding its lobules and holding them together. The investment of fibrous tissue as a whole is known as the *hepato-biliary capsule* (Glisson's capsule).

The **liver-substance** proper is made up of an enormous number of small **lobules** $\frac{1}{25}$th to $\frac{1}{12}$th inch (1 to 2 mm.) in diameter, closely packed, and held together by a small amount of areolar tissue. In Man the lobules are not completely separated from one another all round their circumference but coalesce in places; the reverse is the case in certain animals such as the camel and the pig. Each lobule is composed of a large number of columns of liver-cells which radiate from the centre to the periphery.

Between the columns—which interlace freely—there is a sinusoidal, capillary-like network through which blood passes from interlobular veins at the margins to a central vein.

The endothelial wall of the network is incomplete, so that the liver-cells are in many places in contact with the blood. Some of the endothelial cells are modified into stellate cells which are a part of the reticulo-endothelial system and are known as the "star-cells" of Kupffer. The columns may be regarded as being composed of two layers of cells between which there is a minute channel—the intralobular bile-ductule—which passes from the centre to the periphery of the lobule.

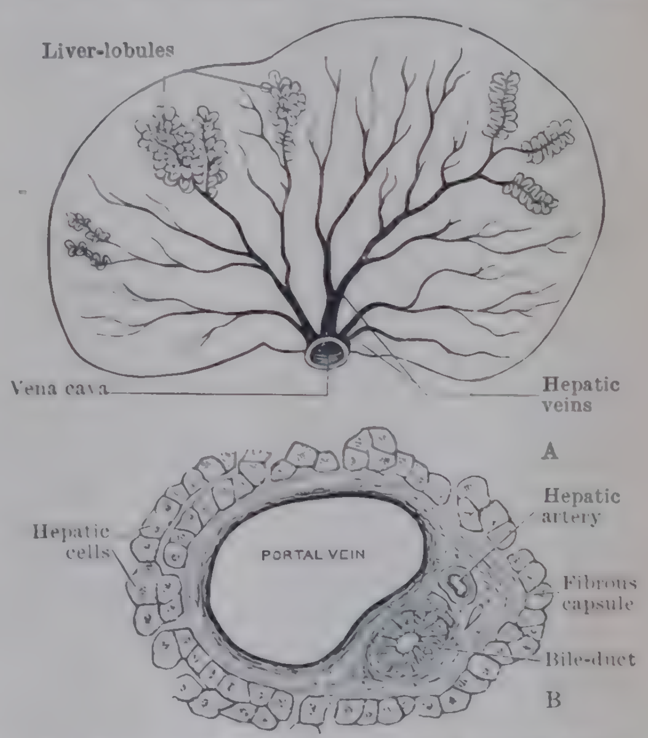

FIG. 564.—DIAGRAMS ILLUSTRATING STRUCTURE OF LIVER.

A. Arrangement of liver-lobules around the sublobular tributaries of the hepatic vein; B. Section of a portal canal, showing its contained branches of the portal vein, hepatic artery, and bile-duct, surrounded by a prolongation of the hepato-biliary capsule.

Vessels and Nerves.—Blood is conveyed to the liver by the hepatic artery and the portal vein, which enter the liver at the porta hepatis and break up into branches and finally into a sinusoidal network. The blood which has so entered is conveyed from the liver by the hepatic veins to the inferior vena cava.

The circulation within the liver is therefore arranged differently from that of other glands, and in order that the structure of the liver may be properly understood it is necessary to give some account of the relations which it presents to the blood-vessels which pass to and from it.

The **portal vein** and the **hepatic artery** pass to the liver between the two layers of the lesser omentum, accompanied by the bile-duct. Each breaks up into two chief branches—a right and a left—and several smaller ones, which enter the liver-substance, surrounded by a prolongation of the fibrous coat of the liver. Within the organ the three vessels run and divide together, so that every branch of the portal vein is accompanied by a corresponding (but much smaller) branch of the hepatic artery and of the hepatic duct; and the three, surrounded by

a prolongation of the hepato-biliary capsule, and accompanied by branches of the hepatic nerves and lymph-vessels, run in special tunnels of the liver-substance which are known as **portal canals** (Fig. 564, B).

The hepatic artery has but a small part to play in the hepatic circulation as its chief distribution appears to be to the fibrous tissue of the portal canals. The terminal branches of the artery end in the interlobular meshwork of veins through which some arterial blood is thus supplied to the liver-cells.

The portal vein within the liver divides, like an artery, into numerous branches, which eventually form an elaborate meshwork of *interlobular veins* around the periphery of the lobules. From this meshwork the small capillary-like channels described above pass into the interior of each lobule between columns of cells towards a channel in the centre of the lobule called the *central vein*. From the central veins the blood is carried into larger channels called *sublobular veins*, which pass to the hepatic veins.

The **hepatic veins** gradually unite with one another and run towards the inferior vena cava. Their mode of termination is variable but presents the following general arrangement: The left lobe is drained by a vessel which joins the upper part of the inferior vena cava. The right lobe is drained by one or two vessels which join the upper part of the inferior vena cava, and by a series of small vessels, 4 to 12 in number, which pass from the inferior portion of the right lobe to the inferior vena cava. The caudate lobe and the central portion of the liver are drained by vessels which pass to the inferior part of the hepatic portion of the inferior vena cava. The hepatic veins and their branches are not accompanied by branches of the bile ducts, and they are surrounded by a very small amount of areolar tissue.

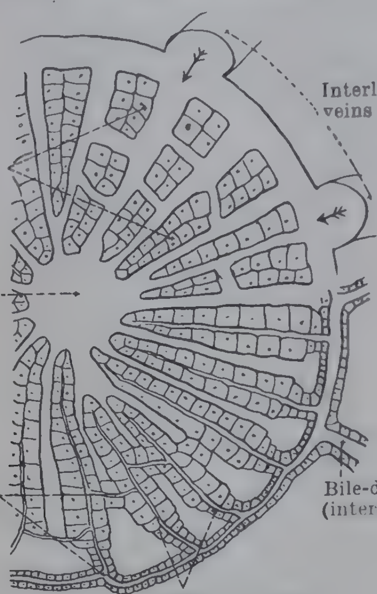

Fig. 565.—Diagram to illustrate Structure of Liver-Lobule.

The **lymph-vessels** of the liver pass either directly to the surface, where they appear beneath the peritoneum, or they accompany either (*a*) the portal or (*b*) the hepatic veins.

The **nerves** are both *sympathetic* and *parasympathetic*, being derived from both vagi and from the cœliac plexus. Branches of the anterior gastric nerve pass from the stomach between the layers of the lesser omentum to the hepatic plexus and are distributed to the liver, gall-bladder and ducts. Those from the cœliac plexus run along the hepatic artery—forming the hepatic plexus—to the porta hepatis, where they enter the liver with the blood-vessels. They are distributed chiefly to the walls of the vessels.

GALL-BLADDER AND BILE-PASSAGES

The excretory ducts of the liver begin within the hepatic cells as minute channels. Thence they run between the columns of hepatic cells (Fig. 565) and are known as the **bile-ductules**.

Hepatic Ducts.—Outside the lobules, the ductules join (Fig. 565) the **interlobular ducts**, which, by uniting, form larger and larger ducts, and finally end, as a rule, in two chief channels—a larger from the right lobe and a smaller from the left—called **the right** and **left hepatic ducts**, which unite in the porta immediately after leaving the liver-substance to form the **common hepatic duct**.

As a rule, five or six ducts leave the liver-substance at the bottom of the porta hepatis: they generally unite into right and left hepatic ducts; sometimes they all converge upon the common hepatic duct and unite at its beginning. The ducts from the caudate and quadrate lobes join the left hepatic duct.

The **common hepatic duct** is formed within the porta hepatis by the union of right and left hepatic ducts (Fig. 566). It passes downwards, and, just beyond the porta hepatis, it is joined by the **cystic duct** to form the **bile-duct**. Its length is usually about 1 or 1¼ inches (25 to 30 mm.), and in breadth, when flattened out, nearly ¼ inch, or about as much as a goose-quill.

Gall-Bladder and Cystic Duct.—The **gall-bladder** with the cystic duct may be looked upon as a diverticulum of the bile-duct, enlarged at its extremity to form a reservoir in which the bile is not merely stored but concentrated by the absorption of water from it by the mucous coat. It is pear-shaped,

and it lies obliquely on the inferior surface of the liver (Fig. 566). The wide end or **fundus** usually reaches the inferior border of the liver and comes into contact with the anterior abdominal wall behind the ninth costal cartilage opposite the lateral border of the rectus abdominis (Fig. 532). The **body** runs backwards, upwards, and to the left, lying in the fossa for the gall-bladder, and near the porta hepatis it passes rather abruptly into a narrow neck. The **neck** is curved medially towards the porta hepatis with an S-shaped kink in it and when distended it presents on its surface a spiral constriction which is

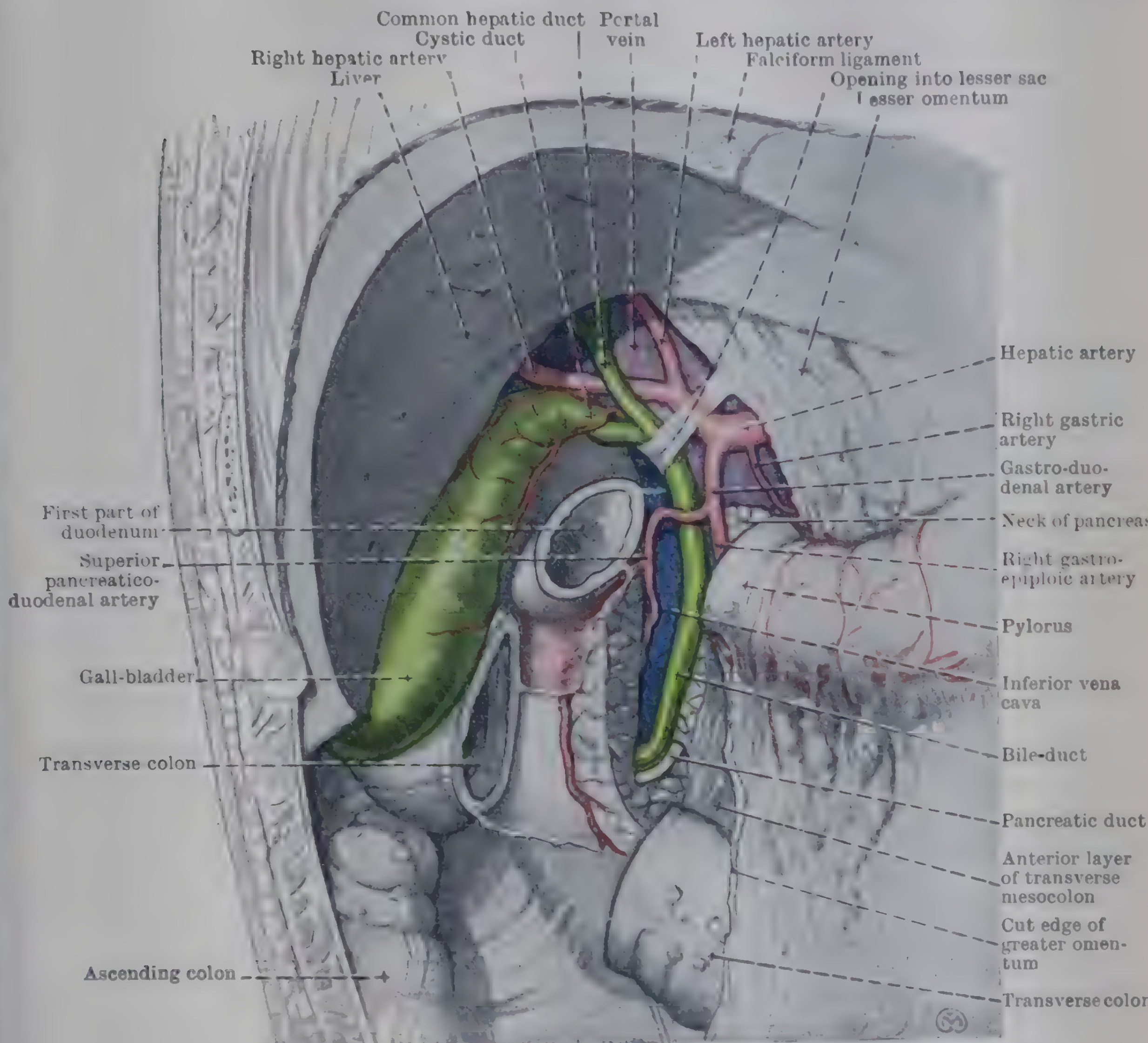

FIG. 566.—DISSECTION SHOWING RELATIONS OF GALL-BLADDER AND BILE-PASSAGES.

continued into the beginning of the cystic duct and is due to a series of crescentic folds placed more or less spirally round the interior of its cavity, forming the **spiral valve**. Having arrived near the porta hepatis, much reduced in size, it passes into the cystic duct.

As a rule the gall-bladder is covered with the peritoneum of the inferior surface of the liver, except on its antero-superior aspect, which is united to the walls of the fossa for the gall-bladder by areolar tissue. Sometimes, but rarely, the gall-bladder is suspended from the liver by a short peritoneal ligament. *Above*, the gall-bladder lies against the liver; and *below*, it rests on the transverse colon in front, and behind, near its neck, on the duodenum.

The fundus of the gall-bladder may not reach the inferior border of the liver or the abdominal wall. It may lie to the right of the right sagittal plane—possibly as a result of distension of the stomach and colon—or it may lie to the left, near the median plane and far below the ribs. Its total absence, as well as the presence of two distinct gall-bladders, and several other irregularities in form, have been recorded.

Its *size* is usually about 3 inches (75 mm.) in length, and 1 to 1¼ inches (25 to 30 mm.) in diameter. Its capacity varies between 1 and 1½ fluid ounces.

Vessels and Nerves.—The **artery** is the cystic, which comes from the right branch of the hepatic artery; it divides into two branches which diverge to descend over the upper and lower surfaces of the gall-bladder. The accompanying **veins** unite to form a single vein which enters the liver substance to the left of the neck of the gall-bladder. A variable number of accessory veins also enter the liver substance. These cystic veins communicate with the veins of the extrahepatic ducts, which also pass directly into the liver or join the intrahepatic branches of the portal vein. At the lower end of the bile-duct the veins anastomose with the veins of the duodenum and pancreas (Petrén & Karlmark, 1932). The **lymph-vessels** pass to glands that lie alongside the cystic duct and in the porta hepatis. The **nerves** come from the plexus on the hepatic artery and include sympathetic and parasympathetic (vagal) fibres.

The **cystic duct**, about half the diameter of the common hepatic duct (3 mm.), but usually slightly longer ($1\frac{1}{4}$ to $1\frac{1}{2}$ inches: 30 to 35 mm.), begins at the neck of the gall-bladder, pursues an irregular course backwards and medially, and joins the common hepatic duct at the mouth of the porta hepatis, to form the bile-duct. The spiral constriction found in the neck of the gall-bladder is continued into the beginning of this duct. Sometimes the cystic duct joins the right hepatic duct instead of the common hepatic duct.

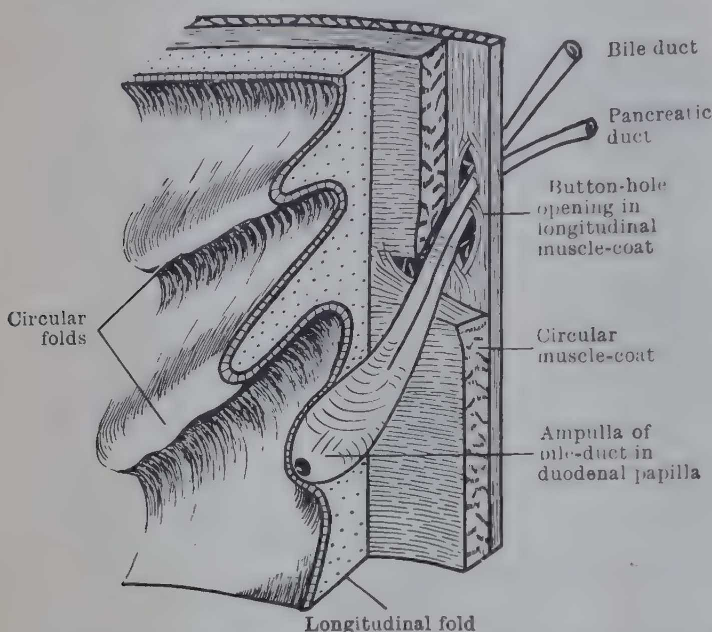

Fig. 567.—Diagrammatic Section of Wall of Duodenum to show Passage of Bile and Pancreatic Ducts and their Junction to form the Ampulla.

Bile-Duct (Ductus Choledochus).—The **bile-duct** is about 3 inches long (75 mm.) and of variable width—usually $\frac{1}{4}$ inch. It begins at the mouth of the porta hepatis, where it is formed by the union of the cystic and common hepatic ducts. (1) In the first part of its course it passes downwards in front of the opening into the lesser sac within the right free border of the lesser omentum, where it lies anterior to the portal vein and on the right side of the hepatic artery. (2) It then descends behind and to the left side of the first part of the duodenum, immediately to the right of the gastro-duodenal artery. (3) In this part of its course the bile-duct curves downwards and to the right, usually embedded in the head of the pancreas, but frequently in a groove on the posterior surface of the gland, where it comes into fairly intimate contact with the front of the inferior vena cava. (4) Finally it meets the pancreatic duct, and the two ducts, tapering abruptly, pierce the postero-medial wall of the second part of the duodenum in an oblique direction and open jointly into its interior through the constricted opening of the duodenal papilla (see p. 632).

In the first part of this oblique intramural passage or choledocho-duodenal junction, which averages from $\frac{1}{2}$ to $\frac{3}{4}$ of an inch (12 to 18 mm.) in length, the two ducts pass through a vertical 'button-hole' opening in the longitudinal layer of the intestinal muscle, and then through a similarly shaped but obliquely transverse opening in the circular layer. From the margins of this 'gridiron aperture' small bundles of muscle-fibres run to reinforce the angles of the two button-hole openings, whilst other fibres pass on to the walls of both the extramural and the intramural portions of the ducts, the whole arrangement constituting an extrinsic muscular mechanism for controlling the secretory flow (Fig. 567).

The greater part, however, of this oblique passage through the intestinal wall lies in the submucosa of the plica longitudinalis, in which the ducts unite to form the *ampulla of the bile-duct*, or in a considerable proportion of cases remain separate until they reach the opening of the duodenal papilla. The ampulla, when present, varies greatly in size, with an average diameter of $\frac{1}{8}$ of an inch (3 mm.), and a length which is usually slightly greater, and may be quite $\frac{1}{2}$ an inch (12 mm.) in extent. Its width is considerably greater than that of the lumen of either of the ducts, and is still more contrastingly greater than

that of the opening on the papilla, this being the narrowest part of the biliary passages. The presence of the ampulla is important in connection with the impaction of gall-stones, with resultant obstruction to the flow of bile and possible reflux of this secretion into the pancreatic duct.

The walls of the terminal part of the bile-duct and to a lesser extent of the pancreatic duct, are provided with a thin layer of paler circular muscle-fibres (*sphincter choledochus*), situated within the thicker and darker collar borrowed from the intestinal muscles. These circular fibres extend to a varying extent on to the ampulla (*sphincter ampullae*), but they do not reach the opening of the papilla. Opinion is still divided as to how far, if at all, these encircling fibres can be regarded as intrinsic sphincters, structurally and functionally independent of the intestinal muscles (Kreilkamp & Boyden, 1940; and Kirk, 1944).

The ampulla also contains a number of longitudinal muscle-fibres, which are extensions of two bundles in front of and behind the interval between the bile and pancreatic ducts. Some of these longitudinal fibres end in the connective tissue of the valvular folds of the mucous membrane with which the interior of the ampulla is richly lined.

The sphincteric arrangement of muscle-fibres round the termination of the bile-duct was first described by Francis Glisson in 1654. It was redescribed by Ruggero Oddi in 1887, since when the complex has become generally known to surgeons as the "*sphincter of Oddi*" (Boyden, 1936).

Structure of Gall-Bladder and Excretory Ducts.—The wall of the gall-bladder is composed of (1) an outer incomplete *serous coat* of peritoneum, (2) a *connective tissue coat* of fibro-elastic tissue, continuous in places with the connective tissue of the liver, (3) a *muscular coat* of plain muscle and elastic fibres arranged for the most part in a circular and oblique direction, and (4) a *mucous coat* consisting of tall columnar cells set on a lamina propria. The mucous membrane is raised into a number of small ridges which form a honeycomb pattern.

The walls of the excretory ducts present (1) an outer *adventitial coat* of fibrous tissue containing a few scattered outer circular and inner longitudinal plain muscle fibres, which increase in number as the duodenum is approached, (2) a thick *submucous coat* of connective tissue and elastic fibres, containing the alveoli of mucous glands, and (3) a *mucous coat*, lined by a single layer of columnar epithelium interspersed with goblet cells, with numerous folds and crypts.

Variations of Gall-Bladder and Ducts.—The gall-bladder may be attached to the liver by a peritoneal ligament. It may be deeply embedded in the liver, and its fundus may fall short of the lower border of the liver. It may be sacculated by constriction in its walls. It may be divided longitudinally into two gall-bladders, each with its own duct opening separately into a hepatic duct. It may be directly connected with the smaller bile-vessels by small channels, called **hepato-cystic ducts**, which pass from its upper wall into the liver. It may be absent, in which case one or other of the hepatic ducts is usually considerably dilated.

The hepatic ducts may be from two to five in number—accessory ducts coming usually from the right lobe of the liver. The right and left hepatic ducts may be so long that they descend into the lesser omentum before they unite; their increased length entails an elongated cystic duct and a shortened bile-duct. The cystic and hepatic ducts may open into the duodenum separately. The bile-duct itself may be double or septate, and it may have an inverted Y-shaped termination with one limb opening normally and the other into the duodenum more proximally or even into the stomach. The orifice of the bile-duct may be separate from that of the pancreatic duct. Any or all of the ducts may show different degrees of congenital dilatation or stenosis, and occasionally complete atresia.

A proper understanding of all these variations demands a knowledge of the development (see p. 681) and of the comparative anatomy of the biliary tracts (Zimmermann, 1935).

Radiographic Examination of Gall-Bladder.—Under normal conditions the gall-bladder and its contents do not throw a shadow on X-ray examination. By the use of artificial methods, however, especially by the administration of dyes (now usually by the mouth) which are excreted by the liver and concentrated with the bile in the gall-bladder, it is possible to demonstrate its position, form, and functional variations in size (Pl. LX, p. 649). Occasionally the wall of the gall-bladder becomes pathologically calcified and so appears in an ordinary radiograph (Pl. LII, p. 609).

PANCREAS

The **pancreas** is a long, soft, lobulated reddish or yellowish-grey gland which lies transversely on the posterior abdominal wall, its right end in the concavity of the duodenum (Fig. 568) and its left end touching the spleen.

It secretes a clear, watery, alkaline fluid—the *pancreatic juice*—which is conveyed to the duodenum by the **pancreatic duct** and constitutes one of the chief agents in intestinal digestion, for it contains ferments which transform starch into dextrin and sugar, split fats into glycerine and fatty acids, and reduce alkaline albuminous substances to peptone.

In **shape** the pancreas, when hardened *in situ* (Fig. 568), may be compared to the letter J placed thus ⊂.

The gland is divisible into a **head** with an **uncinate process**, a **neck**, a **body**, and a **tail**. The **head** corresponds to the hook of the ⊂. The stem of the ⊂ represents the **body** of the gland, and the left extremity of the body forms the **tail**. The narrow part that connects the head and body is the **neck** (Symington). An extension from the head to the left behind the superior mesenteric vessels forms the **uncinate process**. When removed from the body without previous hardening, the pancreas loses its true form, and becomes drawn out into a slender, tongue-shaped mass, with a wider end turned towards the duodenum, and a narrow end corresponding to the tail.

Its total *length*, when fixed *in situ*, is about 5 or 6 inches (12·5 to 15 cm.); after removal, if not previously hardened, it is easily extended to a length of 8 inches (20 cm.).

Its *weight* is usually about 3 ounces (87 grammes).

Relations.—The general position and relations of the pancreas may be briefly stated as follows: The head (Fig. 568) lies in the concavity of the duodenum, with the inferior vena cava behind it; the body crosses to the left in front of the aorta and the left kidney; and the tail touches the visceral surface of the spleen. The greater part of the organ lies behind the stomach.

In a description of the detailed relations, each part of the organ must be considered separately.

The **head of the pancreas**, flattened from before backwards, lies in the concavity of the duodenum. *Above*, in its right half, it is continuous with the neck; whilst to the left of the neck, a deep notch separates the upper and left part of the head from the neck, and contains the superior mesenteric vessels (Fig. 568). The margin of the head is moulded on the duodenum, which lies in a groove of the gland substance—the bile-duct being interposed as far down as the middle of the second part of the duodenum. The posterior surface of the head is applied to the front of the inferior vena cava, the right renal vessels and the left renal vein. Its anterior surface is in contact above and on the right with the beginning of the transverse colon (Fig. 538, p. 630), without the interposition of the peritoneum as a rule. Below that it is clothed with peritoneum and is covered by the small intestine.

The superior mesenteric vessels, after passing forwards through the notch between the head and the neck, descend in front of the uncinate process, which overlaps the aorta. The gastro-duodenal artery runs downwards behind the duodenum and divides into branches at the upper border of the head (Fig. 568).

The **neck of the pancreas** (Fig. 568) is a thin portion of the gland which lies in front of the portal vein and behind the pylorus, and it connects the head to the body. It is attached on the right to the upper portion of the head, and runs forwards, upwards, and to the left for about 1 inch (25 mm.), and passes into the body.

The neck is about ¾ inch (18 mm.) in width, and less than ½ inch (12·5 mm.) in thickness. *In front and to its right* lie the first part of the duodenum, the pylorus, and the lesser sac of the peritoneum; *behind and to the left* it rests upon the beginning of the portal vein, which is formed under cover of its lower border by the union of the splenic and superior mesenteric veins. It is generally marked off from the head by two grooves, of which the upper is occupied by the gastro-duodenal artery and its superior pancreatico-duodenal branch, and the lower by the superior mesenteric vessels.

As the transverse mesocolon is followed to the right it is found to end, as a rule, near the neck of the pancreas (Fig. 538). Beyond that, the posterior surface of the colon is connected by areolar tissue to the anterior surface of the head of the gland.

The **body of the pancreas** is of a prismatic form, and is largest where it lies in front of the left kidney (Fig. 568). From the neck it runs to the left and slightly backwards and upwards across the front of the aorta and left kidney, beyond which its extremity or tail comes in contact with the spleen. When hardened *in situ* it presents three surfaces

—anterior, inferior, and posterior—all of nearly equal width (namely, about 1¼ inches: 30 mm.).

The *anterior surface*, widest towards the left end, looks upwards and forwards (Fig. 568), and forms a considerable portion of the stomach-bed. It is completely

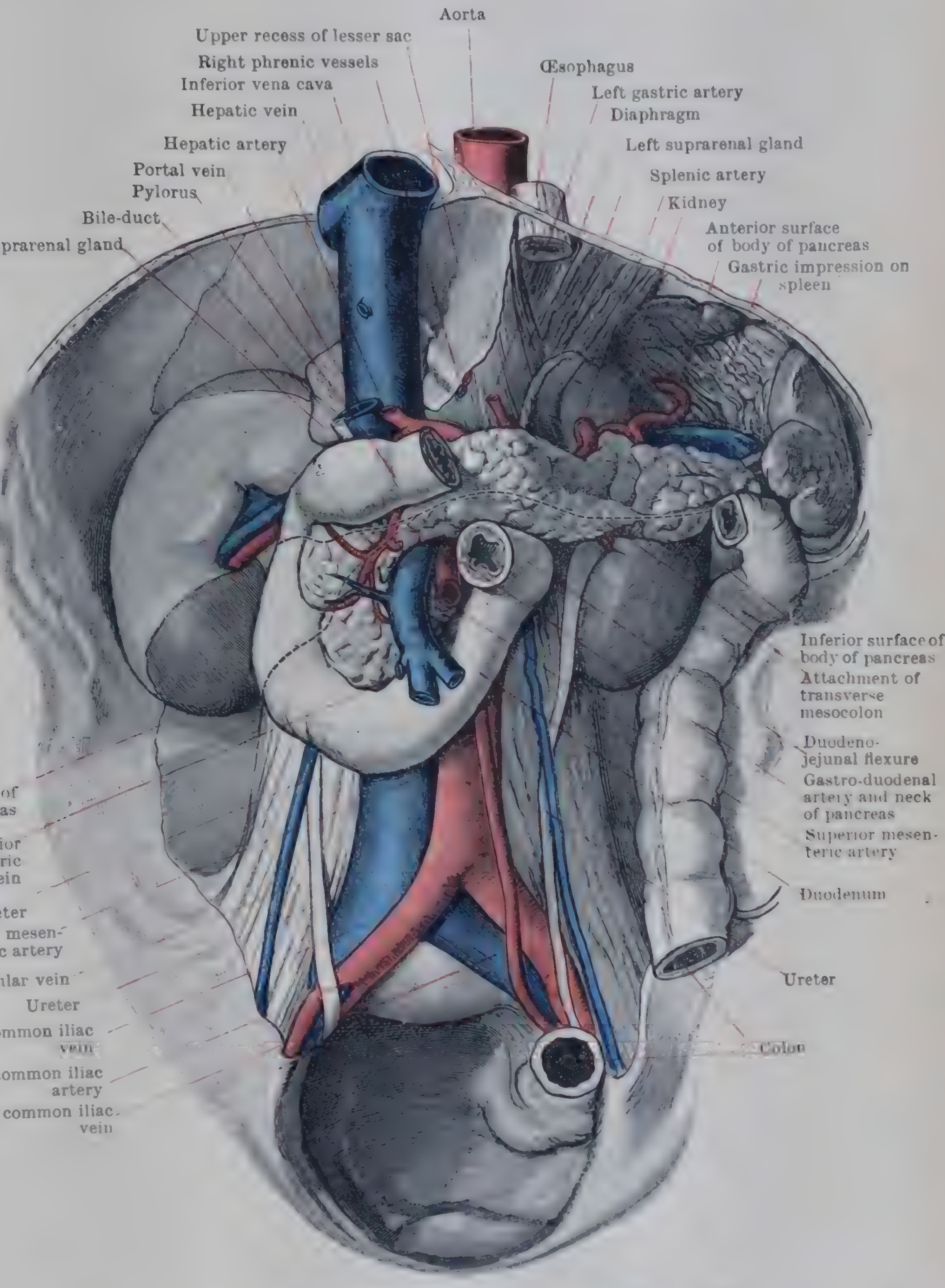

FIG. 568.—VISCERA AND VESSELS ON POSTERIOR ABDOMINAL WALL.

The stomach, liver, and most of the intestines have been removed. The peritoneum has been preserved on the right kidney and the recess behind the caudate lobe. When the liver was taken out, the inferior vena cava was left *in situ*. The stomach-bed is well shown. (From a body hardened by chromic acid injections.)

covered with the peritoneum of the posterior wall of the lesser sac, which separates the pancreas from the stomach (Fig. 569). Towards its right end where the body joins the neck it usually presents an elevation which, when the stomach is distended, projects against the back of the lesser omentum and is consequently known as the **tuber omentale**.

The *inferior surface* looks downwards and slightly forwards. It is completely covered with peritoneum which is continuous with the posterior layer of the transverse

mesocolon (Fig. 538). It is in contact with the duodeno-jejunal flexure towards its right end, with the left end of the transverse colon near its left end, and with a mass of small intestine (jejunum, which is always found packed in beneath it) in the rest of its extent.

The *posterior surface* looks directly backwards and is entirely destitute of peritoneum. It is connected by areolar tissue to organs that lie on the posterior abdominal wall. From right to left they are: the aorta with the origin of the superior mesenteric artery, the left renal vessels, the lower end of the left suprarenal gland, and the left kidney. In addition, the splenic artery runs its tortuous course to the left along the superior border of the pancreas, whilst the splenic vein runs behind the upper border of the gland.

The three surfaces of the body of the pancreas are separated by three borders.

The *lower border* is the most prominent, and gives attachment to the transverse

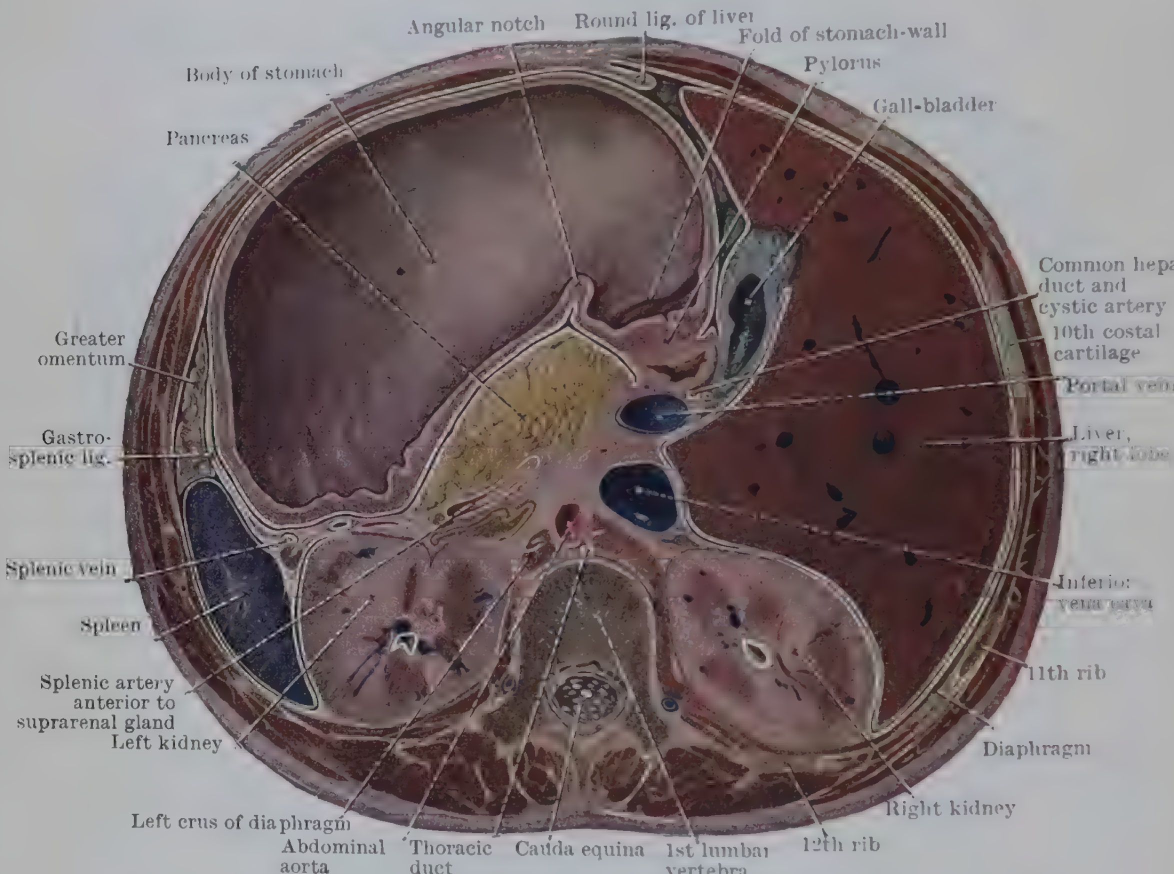

FIG. 569.—TRANSVERSE SECTION OF TRUNK AT LEVEL OF FIRST LUMBAR VERTEBRA.
Showing relations of stomach, pancreas, kidneys, etc. From a subject ten years old.

mesocolon (Fig. 568). It is, as it were, squeezed forward, by the pressure of the stomach above and the small intestine below, into the interval between these two sets of viscera, thus following the line of least resistance. Towards the neck that border is no longer prominent, but becomes rounded off, so that there the anterior and inferior surfaces are confluent.

The cœliac artery projects over the *upper border*, and sends its hepatic branch to the right, resting upon it, whilst the splenic artery runs to the left along it (Fig. 568).

The *posterior border* calls for no special description.

The **tail of the pancreas**, at the left end of the body, usually presents an abrupt, blunt ending, but it may be elongated and narrow. It is in near relation with the spleen to the left and with the left flexure of the colon below (Fig. 538, p. 630).

Ducts of Pancreas.—Almost invariably two ducts are found in the interior of the pancreas—the **pancreatic duct** and the **accessory pancreatic duct**.

The **pancreatic duct** begins at the tail by the union of small ducts that emerge from the lobules of that part of the organ. From there it pursues a rather sinuous or zigzag course (Fig. 570) in the axis of the gland; at first it runs nearly transversely to the right, until the neck is reached; it then bends downwards into the head,

approaches the second part of the duodenum and meets the bile-duct (see p. 666).

In its course through the gland the pancreatic duct receives numerous tributaries which join it, as a rule, at a right angle. The tributaries, as well as the main duct itself, are easily recognized by the whiteness of their walls, which contrasts with the darker colour of the gland-tissue. Beyond its point of junction with the accessory duct (see below), the main duct receives tributaries from the posterior part of the lower portion of the head and the uncinate process, and, towards its termination, it attains a considerable width ($\frac{1}{10}$ to $\frac{1}{6}$ of an inch: 2·5 to 4 mm.).

The **accessory pancreatic duct** is a small and variably developed duct (Fig. 570) which opens into the duodenum about $\frac{3}{4}$ of an inch above and slightly anterior to the pancreatic duct. From the duodenum it runs to the left and downwards and soon divides into two or more branches; one of these joins the pancreatic duct, and another, which descends vertically in front of the main duct, drains the anterior part of the lower portion of the head. Should the orifice of the main duct become obstructed, the communication with the accessory duct forms an outlet for the secretion into the duodenum.

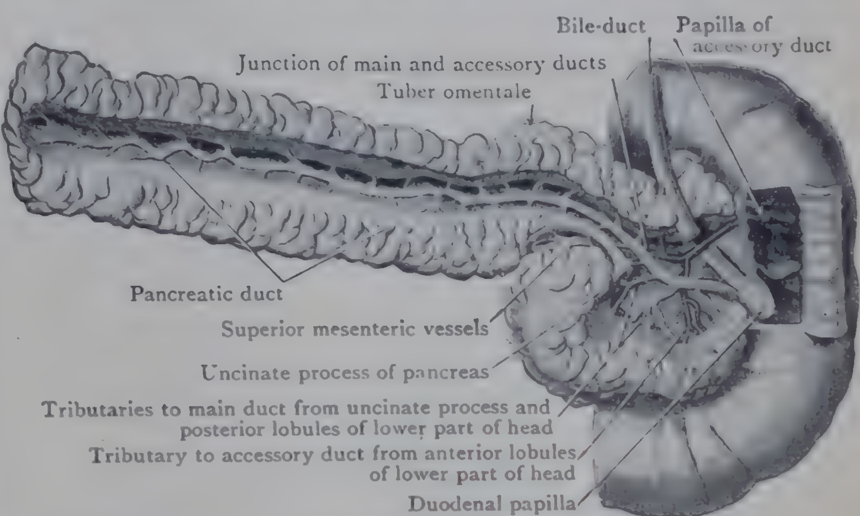

Fig. 570.—Dissection of Pancreas from Behind to show its Ducts.

Structure of Pancreas.—The lobules of the pancreas resemble closely in structure the lobules of the salivary glands and show a similar arrangement of secreting tubules and ducts. The tubules are lined with short cylindrical cells, with a deeply placed nucleus, and often showing granules in the free margin. The flattened spindle-shaped cells of the terminal ducts are continued into the commencement of the secreting tubules, where they are known as *centro-acinar cells.*

In addition, however, each lobule contains irregular groups of cells known as **islets of Langerhans.** These cells are not connected with the ducts, and they produce the internal secretion known as *insulin.*

Variations.—The chief variations found are: (1) A separation of the part of the head known as the uncinate process, which then forms a *lesser pancreas.* (2) A growth of the pancreas around the duodenum, which it may practically encircle for a short part of its course. And (3) an opening of its duct into the duodenum independently of the bile-duct. Accessory pancreatic tissue is also sometimes found in the wall of the stomach or of the jejunum, or even in the diverticulum ilei. Diverticula of the duodenum, already described (p. 633), ought perhaps to be mentioned in this connection.

Vessels and Nerves.—The **arteries** of the pancreas are: (1) The *superior pancreatico-duodenal*, a branch of the gastro-duodenal artery; its two terminal branches, anterior and posterior, run downwards, one in front of and the other behind the right margin of the head (Fig. 568), sending branches laterally to the duodenum, as well as numerous twigs into the substance of the pancreas. (2) The *inferior pancreatico-duodenal*, a branch of the upper part of the superior mesenteric artery or from the root of one of its jejunal branches; it runs upwards and to the right across the back of the head, and sends branches to it and to the duodenum, one of which runs between the head and the duodenum. The two pancreatico-duodenal arteries anastomose around the inferior border of the head. (3) *Pancreatic branches* of the *splenic artery* are several (3 to 5) fair-sized branches which come off from the splenic as it runs along the upper border of the gland; they enter the pancreas immediately and traverse its substance from above downwards, some sending branches in both directions along the course of the pancreatic duct.

The **veins** are: (1) The *pancreatico-duodenal veins* (Fig. 568), of which some pass downwards and to the left, on the front of the head, and join the superior mesenteric; while others cross the back of the head and open into the superior mesenteric or the portal vein; (2) several small *pancreatic veins* which join the splenic. The blood-vessels of the pancreas are described in detail, from the surgical point of view, by Pierson (1943) and by Falconer & Griffiths (1950).

The **lymph-vessels** pass mainly to the suprapancreatic glands.

The **nerves**, which are almost entirely non-medullated, are (1) sympathetic filaments which have passed through the hepatic and splenic plexuses, and (2) parasympathetic filaments from the vagi.

DEVELOPMENT OF DIGESTIVE SYSTEM

In the chapter on Embryology it has been pointed out that the alimentary canal is formed from three separate parts: (1) A middle, large entodermal portion, and (2) two smaller ectodermal parts, one at the cephalic end—the stomodæum or oral pit—and one at the caudal end—the proctodæum or anal pit. It has been shown further that the three portions are at first separated from one another by septa—the bucco-pharyngeal membrane and the anal membrane, respectively—but the septa disappear at an early date, and the three parts are thrown into continuity. There is thus formed a tube—the primitive alimentary canal—which extends through the body from the oral aperture to the anal orifice.

The entodermal segment of the primitive alimentary canal is derived from the dorsal portion of the entodermal sac and is divided into three portions as follows:—That portion which is enclosed within the head-fold and lies above the septum transversum is termed the fore-gut; the portion within the tail-fold is termed the hind-gut; and the middle portion is termed the mid-gut. The mid-gut at first is opposite the communication with the yolk-sac, and the other portions are cephalic to and caudal to this level. From the fore-gut are formed the posterior part of the mouth, the pharynx, œsophagus, stomach, and the greater part of the duodenum. The remainder of the small intestine and the large intestine as far as the left flexure of the colon are developed from the mid-gut. The hind-gut gives rise to the remainder of the large intestine as far as the "white line" of the anal canal. It should be noted that these three parts of the embryonic gut give rise to the abdominal parts of the adult alimentary tract which are supplied by the cœliac, superior mesenteric, and inferior mesenteric arteries respectively.

The primitive intestinal tube not only forms the basis of the alimentary canal and its associated organs, but it is also the source from which many other organs, not ultimately connected with digestion, are formed. Thus, the respiratory tract below the level of the orifice of the larynx is formed as an outgrowth from the ventral wall of the primitive fore-gut, and remains permanently connected with it at that point, though in structure and function it becomes very different from the tube from which it is derived. Other structures also, namely, the thyroid gland, the parathyroid glands, and the thymus, are formed as diverticula of the primitive pharynx, but they soon lose their connexion with the wall of the tube. Furthermore, the allantois, a diverticulum from the hind-gut, and the ventral part of the primitive hind-gut are cut off to form the urinary bladder and a portion of the urethra.

Development of Primitive Pharynx and Mouth

The blind, terminal part of the fore-gut in the head-region constitutes the primitive pharynx. Its roof is formed by the tissues that cover the ventral aspect of the mid- and fore-brain, and its floor by the tissues that overlie the heart and pericardium. Each side-wall is a lamina of tissue which extends from the floor to the roof, continuous, in front, with the bucco-pharyngeal membrane, which forms the oral wall of the pharynx and separates it from the oral pit. In the roof the tissues of the dorsal part of the base of the skull are formed. In the side-wall and in the floor extensive changes occur, connected with the appearance of structures known as the pharyngeal arches and pouches, and with the origin of numerous structures from them and the development of the tongue (see pp. 65-70, 810-812).

The cavity of the adult **mouth** is formed in part from the oral pit and in part from the cephalic end of the fore-gut or primitive pharynx. The line of division between the portions of the mouth derived from these two parts is difficult to trace on account of the very extensive changes which occur after the bucco-pharyngeal membrane has disappeared and are associated with the formation of the face and of the nose. The portion of the oral cavity derived from the fore-gut is lined with entoderm, and that derived from the oral pit with ectoderm. The position of the original bucco-pharyngeal membrane may be represented by an imaginary plane that extends from the anterior part of the body of the sphenoid to the floor of the mouth close to the mandible.

The enamel of the teeth and the secreting epithelium of the salivary glands are ectodermal structures, while the epithelium of the tongue is entodermal in origin.

The **upper lip** is formed from the tissues that cover the median nasal and maxillary processes (see development of face, p. 63). The **lower lip** similarly is formed from the tissues that cover the mandibular arches. By an ingrowth of epithelium from the surface into the subjacent mesoderm and by subsequent desquamation of the superficial layers, a groove is formed between the lips and cheeks on the one hand and the alveolar ridges on the other. That groove, when deepened, forms the vestibule of the mouth, and it is termed the *alveolo-labial sulcus*. The surface covered with mucous membrane becomes everted to form the red portion of the lips; and at birth it is divided into an outer, smooth portion and an inner portion whose surface is villous. The distinction between these two parts disappears shortly after birth. Several explanations of the formation of the **philtrum** or groove on the front of the upper lip have been put forward; most probably it is produced by the union of the margins of the two

globular processes with each other—the floor of the groove being formed along their line of union, and the ridges that bound the groove corresponding to the medial portions of the globular processes.

The **parotid glands** are formed as outgrowths of the epithelium in the outer wall of the alveolo-labial sulcus. The outgrowth on each side has been found in embryos 8 mm. long. It is at first a furrow. The posterior part of the furrow becomes closed off from the oral cavity and forms a tube which grows backwards for some distance on the surface of the first pharyngeal arch. The terminal portion of the tube gives rise to a number of buds which divide repeatedly and form the lobules of the gland. They are at first solid, and the alveoli do not become hollowed until about the twenty-second week. The epithelium of the terminal buds forms the secreting glandular epithelium, while that of the stalk forms the lining epithelium of the duct.

The **submandibular** and **sublingual glands** are formed in the alveolo-lingual groove, immediately behind the first arch, by outgrowths similar to those which form the parotid gland. The submandibular outgrowth occurs about the fifth week, and the sublingual outgrowths, several in number, on the outer side of it at the ninth week.

The **gums** are developed in two parts—labio-buccal and lingual (West, 1925). The labio-buccal part takes the larger share in the formation of the gums; its surface becomes villous, and it becomes divided into segments that correspond in number and size to the dental sacs of the deciduous teeth. The vessels of the developing gum furnish materials for the growth of the teeth, and they even pierce the reticulum of the enamel-organ.

Tongue.—Several elements in the floor of the primitive pharynx go to the formation of the tongue. One is a median elevation—the *tuberculum impar*—closely related to the ventral ends of the second pair of arches. Just in front of this there is a pair of swellings on the ventral ends of the mandibular arches, and behind it there are paired elevations called the *copula* that arise in relation to the fused ventral ends of the second and third arches. The anterior two-thirds of the tongue are formed by a fusion of the bilateral elements from the first arch incorporating the tuberculum impar to an extent that is still undetermined, and the posterior third is formed by the elements related to the copula (Fig. 84, p. 68). This dual formation of the tongue is reflected in the sensory nerve-supply to the **mucous membrane**, the anterior two-thirds of which are supplied by the lingual and the posterior third by the glossopharyngeal nerve. The foramen cæcum and the sulcus terminalis mark the junction of the two parts, the foramen cæcum representing the position where the outgrowth took place which forms the thyroid gland. The epithelial covering is derived from the entodermal lining of the pharynx, while the **muscle** substance is derived from mesoderm which is continuous with the occipital myotomes and derives its nerve-supply from the hypoglossal nerve.

The investing epithelium of the anterior two-thirds gives rise to the papillæ and the taste-buds, while that covering the posterior portion remains smooth. The papillæ appear about the third month as elevations of the corium covered with epithelium. The vallate papillæ are formed by ingrowths of the epithelium, in rings, around a central core. The superficial layers of the epithelium desquamate and form the trench around the papilla.

Tonsil.—The palato-glossal arch arises in the position occupied earlier by the second pharyngeal arch, behind which, in the embryo, lies the lower portion of the second pharyngeal pouch. Part of that pouch enlarges, and forms a recess termed the *sinus tonsillaris*. From the lower and greater part of the sinus tonsillaris the tonsil is developed; the upper part of the sinus persists, however, as the intratonsillar cleft. The tonsil at first is a smooth depression of the mucous membrane. About the fourth month of intra-uterine life downgrowths of the epithelium take place, which are afterwards converted into the tonsillar pits. Subsequently lymph-cells accumulate around the downgrowths and form the lymphoid tissue which constitutes the mass of the organ. The plica triangularis is formed from a tubercle which becomes flattened to form a fold on the anterior and medial aspect of the inferior part of the tonsil.

Development of Teeth

Teeth, like the skin, are formed from two sources; the enamel is derived from ectoderm and the dentine with its associated tissues—tooth-pulp and cement—from mesoderm. The stages of the formation and union of the two elements may be followed in the diagrams in Fig. 571.

The first stage is the formation, along the site of the future gum, of a thickened ridge of ectoderm which sinks to a deeper level by the active growth of the mesoderm on each side of it, and it becomes slightly furrowed along its surface. The ridge is termed the **primary dental lamina**; and its deep border widens out and soon divides into two secondary ridges, separated from one another by a process of mesoderm. The outer ridge is known as the **labio-gingival lamina**, as it marks the site of the formation of the groove between the lip and the gum; hollowed out by an extension of the primary furrow, it is converted into the *labio-gingival groove*. The inner ridge, now termed the **dental lamina**, alone is shown in Figs. III, IV, and V, for it is the source of the formation of the enamel of the teeth. The dental lamina is at first a continuous band of equal width throughout, but in each jaw on each side its deep surface comes to show five enlargements, one corresponding to each deciduous tooth, and for a time these enlargements remain connected together by a narrow strip of ectoderm. Each of these enlargements or **enamel-organs** is invaginated by a papilla of the mesoderm—the **dental papilla**—for which it forms a cap.

The connexion of the dental lamina with the surface ectoderm becomes drawn out into a thin stalk, and from the inner side of this stalk, superficial to each enamel-organ of a deciduous tooth, a small bud arises which is the source of the enamel-organ of the corresponding permanent tooth. Each enamel-organ is vesicular in shape: the cells in its interior form a loose *stellate reticulum* with fluid in its spaces; the row of long columnar cells (*ameloblasts*) in contact with the mesodermal papilla become the hexagonal enamel-prisms by the deposit on their free surface of successive droplets of calcareous enamel substance. This layer of cells caps not only the apex but also the upper part of the sides of the dental papilla. In the areas of this contact, dentine is formed by the superficial cells of the papilla, which are known as the *odontoblasts*. The peripheral margins of the cells become calcified around a central, minute, thread-like process from the cell-body, and thus they eventually form the hollow dentinal tubules. The dental papilla, which underlies the enamel-organ, assumes the shape of the crown of the future tooth; in the molars, for example, elevations are found in the position of the tubercles of the teeth. The cells in the interior of the papilla become the cells of the pulp of the tooth—vessels and nerves passing in among them from below.

Cement is formed, in the same manner as bone, around the deeper part of the papilla, up to and even beyond the level at which it is invested by the epithelial sheath formed by the prolongation of the enamel-organ already mentioned, which is in part perforated by the cells which form the cement.

The tissues immediately surrounding the enamel-organ and the dental papilla form a fibrous capsule termed the dental sac or follicle (Scott, 1948). The **dental sacs**, when fully developed, are large and distinct fibrous bags which lie in the tooth-sockets of the maxilla and mandible and are continuous above with the tissue of the gum. On the lingual side of the sacs of the deciduous teeth are found the germs of the permanent teeth, surrounded by their own sacs. The sacs are at first very small, and they are partly embedded in the wall of the deciduous dental sacs, but subsequently they come to lie in distinct but incomplete bony cavities of their own. The bone around the dental sacs, temporary and permanent, is always wanting over the summit of the sac, and the band of fibrous tissue which passes through that deficiency and connects the sac with the overlying gum-tissue is known as the **gubernaculum dentis**.

All the points mentioned are easily demonstrated on the mandible of a child at birth, particularly when the tissues have been allowed to soften a little. If, in such a specimen, the gum and periosteum are reflected upwards from the labial and lingual surfaces of the mandible and are freed as far as the upper border of the jaw, the gum, with the tooth-sacs depending from it like small bags, can be pulled out of the bony groove of the jaw; and, if the operation has been successfully performed, the tooth-sacs of the three front permanent teeth may be seen, in size from a small pin's head to a hemp-seed, hanging down behind the upper part of the corresponding deciduous sacs.

I. Shows the dental lamina D.L, the surface epithelium E and the enamel-germ E.G.

II. Shows the further growth of the enamel-germ and its invagination to form the enamel-organ.

III. The enamel-organ is more invaginated, and its inner layer of cells A becomes columnar. The dental lamina is thinner, but near its posterior or lingual edge there is an enlargement R.G which is the reserve germ for a permanent tooth. The superficial cells of the dental papilla P are becoming columnar.

IV. The inner columnar cells of the enamel-organ (ameloblasts) A have formed a cap of enamel En., inside which the superficial cells of the papilla, the odontoblasts O, have formed a layer of dentine D.

V. Shows a still more advanced stage. The deposit of dentine is extending downwards and enclosing the papilla to form the future pulp, in which a vessel V is seen.

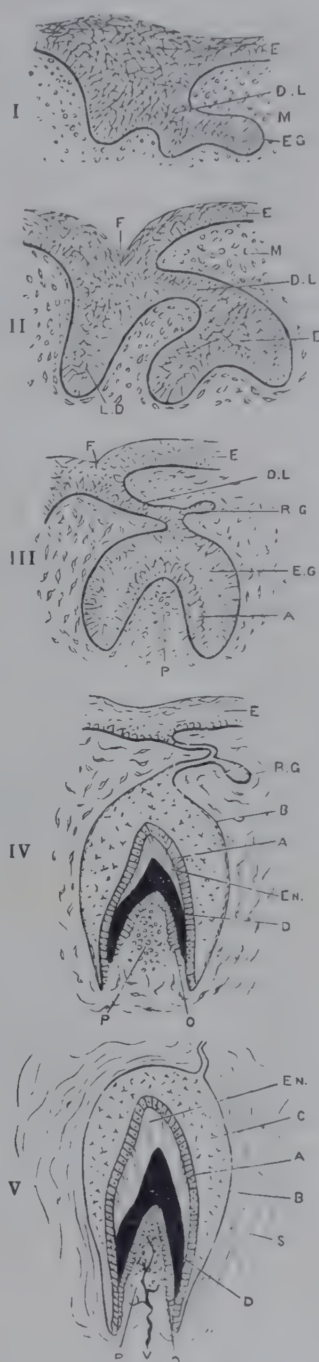

Fig. 571.—Diagrams to illustrate Development of a Tooth.

A, Ameloblasts; B, Outer layer of enamel-organs; C, Stellate reticulum; D, Dentine; D.L, Dental lamina; E, Epithelium; E.G, Enamel-germ or organ; En., Enamel; F, Primary dental lamina and furrow; L.D, Labio-gingival lamina; M, Mesoderm; O, Odontoblasts; P, Dental papilla; R.G, Reserve germ; V, Blood-vessel.

The *roots* of a tooth are formed by ingrowths from the base of the dental papilla, each papilla lying in a groove in the surface of the developing jaw. The groove is divided into compartments for the individual teeth by the formation of intervening septa of bone.

Permanent Teeth.—The anterior five permanent teeth (each of which replaces a deciduous tooth) are developed from the bud-like process on the connecting stalk of epithelium already mentioned and from a dental papilla which forms in relation to each of these buds on the lingual side of its predecessor. The hinder three permanent teeth in each jaw are formed in the same way as the deciduous teeth from an extension backwards of the original dental lamina behind the last deciduous tooth.

Eruption of Teeth, *i.e.*, the extrusion of the crown through the superficial investing tissues, is accompanied by an active absorption of these tissues and also by growth of the roots of the teeth. When the eruption of the deciduous teeth is about to take place, the labial wall and roof of the socket are absorbed; the tooth passes through the sac and appears above the gum, and the socket is re-formed closely around the tooth. The root, which is only partly formed at the time of the eruption, continues to elongate. When the permanent tooth is about to be erupted, it makes its way from its own bony cell through the lingual wall of the socket of its deciduous predecessor; the root of the deciduous tooth undergoes absorption at the same time, but quite independently of pressure from the permanent tooth. The socket, now occupied by both teeth, is again much enlarged by absorption, particularly on the labial side; what remains of the temporary tooth is shed; the permanent tooth passes onwards through the enlarged socket, and, making its way to the surface, appears above the gum. After some time, when the tooth has taken its final position, the socket is again re-formed, first around its neck, and, later on, as the root is built up, around it also, and thus the tooth is permanently fixed. All these processes occur while the alveolar parts of the jaws are themselves growing in height (Brash, 1926).

Morphology of Teeth

In most vertebrates below mammals all the teeth are alike in form; such a dentition is said to be **homodont**. In the majority of mammals, on the other hand, the teeth are arranged in groups of different size and form; such a dentition is **heterodont**.

Again, mammals have (neglecting exceptional cases) but two functional sets of teeth; they are consequently said to be **diphyodont**. Most vertebrates below mammals, on the other hand, have a continuous succession of teeth throughout life, and hence they are said to be **polyphyodont**.

The teeth of fishes and reptiles, and even of some of the mammals, such as dolphins and porpoises, are conical pegs set in the jaw, and none of them have flattened crowns or crowns furnished with tubercles like those of human premolar and molar teeth.

An intermediate form of teeth is shown in some carnivorous mammals in which, at the base of a conical tooth, a ring of enamel forming a cingulum is found. (See p. 569.)

The current view of the origin of the human teeth rests upon evidence that in each tooth three primary tubercles are represented. It is possible that this *tritubercular* origin may be accounted for by the fusion into one of three originally separate conical simple teeth.

The tubercles are found one on the lingual and two on the labial aspect. In the incisors and canine teeth the cingulum represents the lingual tubercle; and the cutting margin of the incisors and the conical apex of the canines represent the two labial tubercles fused together. In the premolars also the two labial tubercles are fused.

In the molar teeth, two labial tubercles and one lingual tubercle persist, but in these teeth additional secondary tubercles also are present. They are one or two in number and are added to the original tubercles at the back on the lingual side when four tubercles are present, and on both lingual and labial sides when there are five of them.

The complete or **typical mammalian dentition**, in its highest development, as in the horse, is represented by the following formula: I. $\frac{3}{3}$, C. $\frac{1}{1}$, PM. $\frac{4}{4}$, M. $\frac{3}{3}=44$. In the dentition of Man, therefore, one incisor and two premolars are wanting. Different views are held as to which teeth have been suppressed—most probably they are the second incisors and the first and second or first and last premolars.

In general it may be said that in the **dentition of the non-civilized races** the dental arches are squarer in front, the teeth larger and more regular, the canines stronger, the last molars better developed, and the tubercles on the molars more perfect than in the more civilized races. It may be mentioned that the teeth of a savage man, if seen in the mouth of a European, would be looked upon as an "exceedingly perfectly formed set of teeth" (Tomes).

For Flower's "dental index", which expresses the proportion in size of the crowns of the premolars and molars to the length of the cranio-facial axis in different races, see the works cited on p. 329.

Development of Œsophagus, Stomach, and Intestines

Development of Tissues of Œsophagus, Stomach, and Intestine.—The wall of these portions of the alimentary tube consists at first of an internal lining of epithelial entodermal cells, several layers thick, and of an external investment of mesenchyme. The intra-abdominal portion of the tube has also a partial external covering of the flattened cells which form the lining wall of the cœlom. The entodermal cells give rise to the epithelium of the adult œsophagus,

stomach, and intestine (whether it is stratified and squamous as in the œsophagus or columnar as in the stomach and intestine), to the secreting cells of the glands of the canal, including the liver and pancreas, and to the lining epithelium of the ducts of those and other glands. The epithelium may be ciliated for a time in the œsophagus, and in the duodenum it may be so thickened as to obliterate the lumen of the tube for a time.

The epithelium shows early very active proliferation, so that ridges and furrows are formed; and the glands arise from downgrowth of the epithelium. In both large and small intestine, the longitudinal ridges become broken up into isolated, finger-like stalks to form villi, which are present for some time in the large as well as in the small intestine. Additional villi are formed later on by a rapid growth of the epithelium in the intervals between the original villi. The circular folds of the intestine are formed much later, but are well formed at birth.

The **muscular coats** are formed from the mesenchyme by a gradual extension of its cells and their modification into the fibrils of plain muscle. The circular coat is the first to originate, and later the longitudinal coat. In the colon the longitudinal coat is formed first at the rectal end and thence spreads headwards; from the first it is in the form of three separate longitudinal bands, while in the small intestine it is a continuous sheet.

Vessels and Nerves.—The nerves and probably also the vessels grow into the wall of the intestine, the vessels being derived from the primitive vascular network connected with the yolk-sac. The cœliac artery and the superior and inferior mesenteric arteries represent splanchnic (vitelline) vessels which have persisted to supply the parts of the alimentary canal in the abdomen derived from the fore-gut, mid-gut, and hind-gut respectively.

Formation of Gastric and Intestinal Glands, etc.—The epithelial lining of the intestinal tube is composed, at first, of a single layer of cells, and the inner surface is smooth. In the second month the epithelium increases rapidly, and as a result its surface is thrown into folds and furrows, arranged irregularly. Mesenchymal tissue passes into the interior of the folds, and also blood-capillaries. The folds appear first in the stomach, especially in the regions of the curvatures, and later in the duodenum and small intestine, and then in the large intestine, where they are formed first in the rectum and last in the vermiform appendix. In the stomach the folds are arranged so as to surround small isolated depressions which afterwards become the gastric pits. In the small intestine isolated elevations are found, in place of continuous folds, and at a later stage new elevations are formed between the primary ones. Those papillary elevations form the villi. In the large intestine the arrangement resembles that in the stomach. The glands of the stomach and intestine are formed by an active proliferation of the epithelium at the bottom of the furrows; at first their cells are everywhere of a similar character, but they become differentiated later. In the stomach the formation of the glands begins about the end of the third month. The intestinal glands of the large intestine appear as depressions between adjacent elevations, and there is not so much active proliferation of cells as in the formation of the glands in the small intestine. The glandular epithelium of the gastric glands begins to assume its differentiated form in different parts, *i.e.*, cardiac and pyloric glands, towards the fifth month of development.

Organ Formation—Œsophagus.—The lengthening of the thoracic region of the trunk, which occurs with the growth and development of the heart and lungs, causes the œsophageal portion of the alimentary tube to become greatly lengthened. Vacuoles appear in the epithelial lining, and they coalesce to form the lumen.

Stomach.—As early as the fourth week, the fore-gut exhibits a fusiform enlargement in the region of the developing heart which is the first evidence of the differentiation of the stomach: this enlargement first takes the form of an outgrowth on the dorsal border to form the fundus. Soon, however, as the diaphragm is being formed, the stomach passes into the abdomen, and its dorsal wall—the future greater curvature—begins to grow more rapidly than the ventral wall. As a result the whole organ becomes slightly curved, and its inferior end is carried forwards from the posterior abdominal wall, giving rise to the curvature of the duodenum. The excessive growth of its posterior wall and the development of the liver on the right side cause the stomach to turn over on to its right side, which now becomes posterior or dorsal. As it rotates, the upper or cardiac portion moves to the left of the median plane, and the whole organ assumes an oblique direction across the abdomen. Already, at the fifth or sixth week, the adult form of the stomach is clearly indicated.

The rotation of the stomach around its long axis, which is accompanied by a rotation of the lower end of the œsophagus, explains why the gastric nerves are on the front and back of the lower end of the œsophagus instead of its right and left margins.

Intestines.—At first there is no separation into large and small intestines; the primitive canal is a simple, slender tube, with a convexity towards the umbilical orifice, through which the vitelline duct passes to the yolk-sac. Later, the tube increases in length, and in embryos of 8 or 9 mm. an outgrowth of the canal appears which represents the future cæcum, and indicates the separation into large and small intestines. Growing longer, the intestine forms a large loop with the vitelline duct springing from its apex (Fig. 572), and the superior mesenteric artery running down between the layers of its mesentery. That loop passes outside the body of the embryo and lies for some time in a part of the cœlom in the umbilical cord: but as the abdominal cavity increases in size the loop is retracted into the abdomen. The primary loop is known as the entero-colic loop, and from it are formed the intestine from the distal end of the duodenum to the left colic flexure. At the root of the loop, where the proximal and distal ends come to lie close to one another, lateral bendings of the intestine appear; the intestine head-

wards to the upper root bends over and forms a loop convex to the right—the gastro-duodenal loop, supplied by a branch of the cœliac artery, and giving origin to the duodenum. The caudal portion of the intestine, supplied by the inferior mesenteric artery, forms a loop convex to the left on the posterior abdominal wall (Fig. 572). There now takes place a change which entirely modifies the position of the parts—that is, a rotation of the entero-colic loop, with its mesentery, around the superior mesenteric artery as an axis (Fig. 572). The result of this rotation is that the original right side of the loop of gut and mesentery becomes the left side; and the beginning of the large intestine is carried across the duodenum (Fig. 572), thus explaining the passage of the transverse colon in front of the second part of the duodenum in the adult. At the same time the cæcum comes to lie near the middle of the abdomen below the liver—a position in which it is found during the third month. Subsequently, it passes farther to the right; and finally, descending, comes to occupy its adult position (Fig. 573).

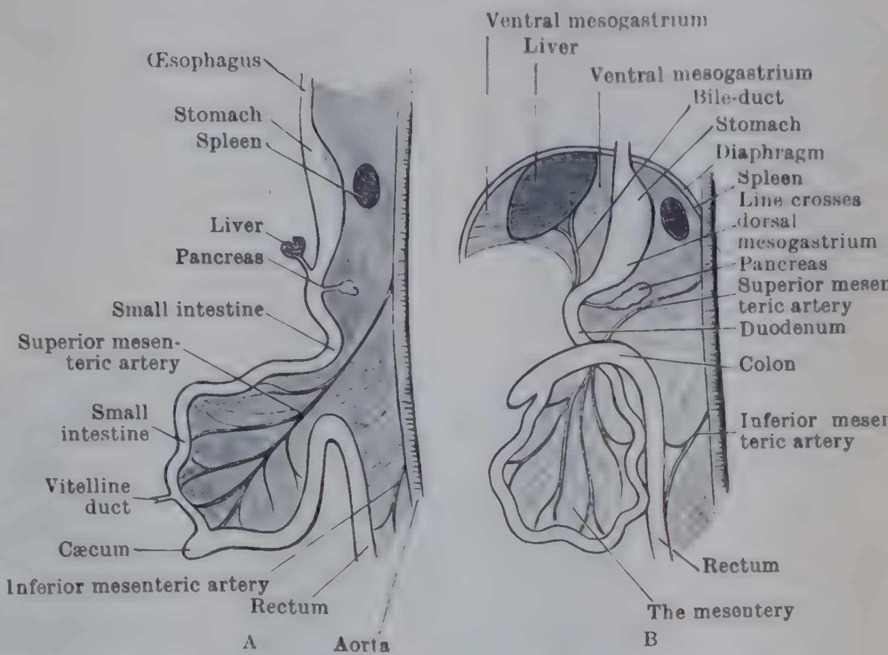

FIG. 572.—TWO DIAGRAMS TO ILLUSTRATE DEVELOPMENT OF INTESTINAL CANAL.

In both figures the parts are supposed to be viewed from the left side. The ventral mesogastrium is shown in Fig. B only, which shows also the rotation of the intestinal loop around the superior mesenteric artery.

The small intestine continues to grow in length, and, as a result, is thrown into coils, which become more and more complex as the length increases, until the adult condition is attained. The terminal portion of the large bowel retains its position on the left side and passes down to the anus.

Cæcum and Vermiform Appendix.—The cæcum appears in the sixth week of development as a small outgrowth of the wall of the primitive gut (mid-gut) not yet differentiated into small and large intestines. The outgrowth is of the same size throughout and is practically equal to the intestine in diameter. About the eleventh week it increases very considerably in length (its length being equal to about five times the diameter of the small intestine, and thus being relatively as long as in the adult); but even at that early date the basal portion, for about one-fifth of its length, is quite as wide as the intestine, whilst the remaining four-fifths of the outgrowth—the future vermiform appendix—is only about one-half or one-third the diameter of the gut. Thus, the distal portion of the outgrowth, which subsequently becomes the vermiform appendix, begins to lag behind even at this early period of its development.

The basal portion continues to expand with the gut; the distal part grows rapidly enough in length, but otherwise enlarges very slowly, so that, towards the end of fœtal life, the cæcum has attained a conical shape, the wider end joining the ascending colon, the narrow end tapering gradually and passing into the appendix. That form, known as the infantile type of cæcum, is retained for some time after birth, and it may (in 2 or 3 per cent of cases) persist even throughout life.

About the sixth or seventh month of intra-uterine life the wall of the terminal portion of the small intestine adheres to the medial side of the cæcum for some distance below the ileo-colic orifice. The connexion, which is made more intimate by the passage of two folds of peritoneum, one on the front, the other on the back, between the two parts, profoundly modifies the subsequent growth of the cæcum, and determines very largely its adult form. For, when the cæcum begins to expand, the medial aspect is prevented, by its connexion with the termination of the ileum, from enlarging as freely as the rest of the wall; in consequence of this the lateral part grows and expands much more rapidly, producing the lop-sided appearance already referred to, and soon comes to form the lowest part of the cæcum and the greater part of its sac; whilst the original apex, with the vermiform appendix springing from it, anchored, as it were, to the end of the ileum, is thrust to one side, and is finally on the medial and posterior aspect of the cæcum, a little way below the end of the ileum and usually behind it.

The position of the cæcum varies at different periods of intra-uterine life. About the eleventh or twelfth week it lies immediately beneath the liver and to the left of the median plane; it then gradually travels to the right, crossing the second part of the duodenum, and is found lying on the right side, just beneath the liver, at the fourth month. From there it descends slowly to its adult position, which it usually approaches towards the end of fœtal life, but it may not actually reach it until some time after birth.

Rectum.—The rectum and anal canal are formed from the tailward portion of the hind-gut and from the anal pit. The primitive closed, cloacal portion of the hind-gut becomes divided by a septum into ventral and dorsal portions. The ventral portion, with the allantois growing from it, forms the urogenital sinus; the dorsal portion forms the rectum and the upper part of the anal canal. The anal pit is separated from the primitive gut by the anal membrane, but that membrane disappears, and thus the anal canal comes to open on the surface.

A spindle-shaped enlargement of the terminal portion of the rectum is early formed; it persists until birth, and a smaller temporary enlargement is formed proximal to it. The wall of the distal swelling is thrown into numerous longitudinal ridges and folds from which the anal columns are formed.

The rectum and anal canal at first form a single, continuous, straight tube which passes downwards in front of the comparatively straight pelvic surface of the sacrum to the anal orifice. That is the condition which the parts present at birth. After birth, the bony pelvis undergoes great enlargement. The sacrum and coccyx become curved, and the antero-posterior diameter of the true pelvis increases very considerably. The urinary bladder and, in the female, the uterus—both of which are mainly in the abdomen at birth—descend into the true pelvis. The anal orifice appears to be moved farther forwards in the perineum owing to the bending

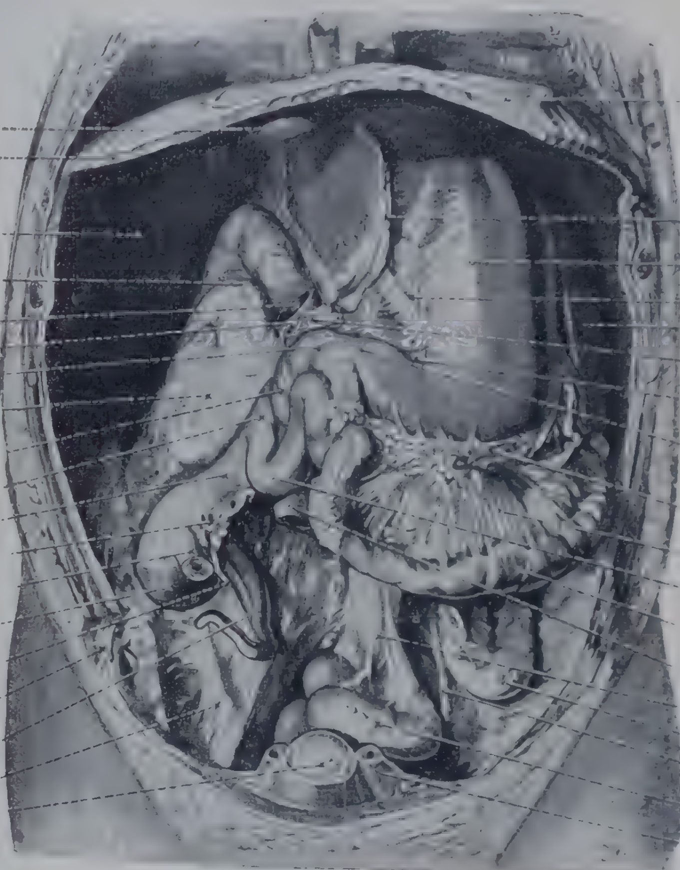

FIG. 573.—ABDOMINAL VISCERA IN THE NEW-BORN CHILD. The liver and the jejunum and ileum have been removed. The vertical stomach, the large suprarenal gland, the high position of the cæcum, and the whole arrangement of the large intestine are typical of the condition found at birth, and differ, as can be seen, largely from the adult condition.

of the sacrum and coccyx, and the rectum is pushed back into the hollow of the sacrum, whose curvature it follows. Another curvature is formed by the junction of the curved rectum with the straight anal canal as it passes downwards and backwards through the tissues of the pelvic floor. The increase in the thickness of the pelvic floor gives to the anal canal the length which it attains in the adult.

DEVELOPMENT OF PERITONEUM

At first the primitive alimentary canal is suspended from the dorsal wall of the embryo, along the median plane, by a simple **dorsal mesentery** which extends along the whole length of the tube and is common to all its divisions—a condition found in the adult stage of many reptiles. In the upper part of the cavity, after the stomach and liver descend into the abdomen, there is also a **ventral mesogastrium** (Fig. 572) which connects the stomach and duodenum to the liver and passes on over the liver to connect it to the anterior abdominal wall and septum transversum. The portion of the ventral mesogastrium between the stomach and liver

becomes the lesser omentum; its anterior portion, between the liver and the parietes, forms the falciform ligament (Fig. 572); and, in its inferior margin, the umbilical vein runs from the umbilicus to the liver.

The portion of the dorsal mesentery connected with the stomach is known as the **dorsal mesogastrium.** At first it is relatively short; but with the growth of the posterior border of the stomach, and the turning of that organ over on its right side, the dorsal mesogastrium becomes elongated and is folded on itself, forming more or less of a pouch directed downwards and to the left. The wall of this pouch becomes in part the greater omentum, and the cavity enclosed by it forms the greater part of the lesser sac. In the rotation of the stomach and the accompanying passage of the lesser omentum from an antero-posterior to a more or less transverse direction, a portion of the cavity of the abdomen is, as it were, caught in behind the stomach and lesser omentum. That portion of the cavity becomes the upper part of the lesser sac, and at first it communicates with the general cavity by a wide opening to the right of the lesser omentum; but the growth of the liver and other factors reduce it to a relatively small size, and it forms the opening into the lesser sac in the adult.

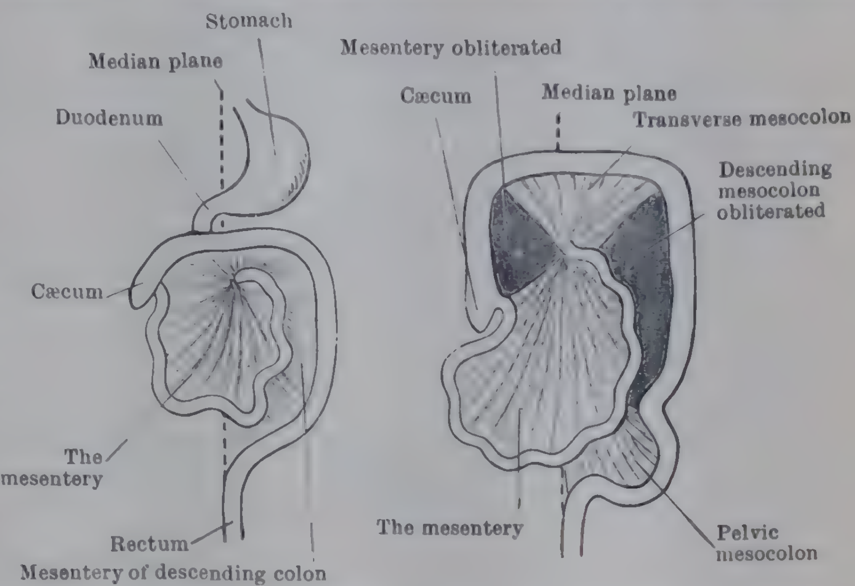

FIG. 574.—TWO DIAGRAMS TO ILLUSTRATE DEVELOPMENT OF THE MESENTERIES.

In the first figure the rotation of the intestinal loop and the continuous primitive mesentery are shown. In the second figure, which shows a more advanced stage, the portions of the primitive mesentery (going to the ascending and descending colons) which disappear, through their adhesion to the posterior abdominal wall, are shaded dark; the portions which persist are lightly shaded.

The upper recess of the lesser sac has a complicated origin. It represents the right of two pocket-like recesses, a right and a left, which are formed very early in the dorsal wall of the cœlom. The two recesses are narrow and horizontal slits which burrow into the dorsal wall and turn upwards by the side of the œsophagus. They are termed the "pneumato-enteric recesses". The left one disappears entirely. The apex of the right one remains occasionally as the "bursa infracardiaca" of the right lung, and is cut off by the diaphragm from the lower portion, which is the rudiment of the upper recess.

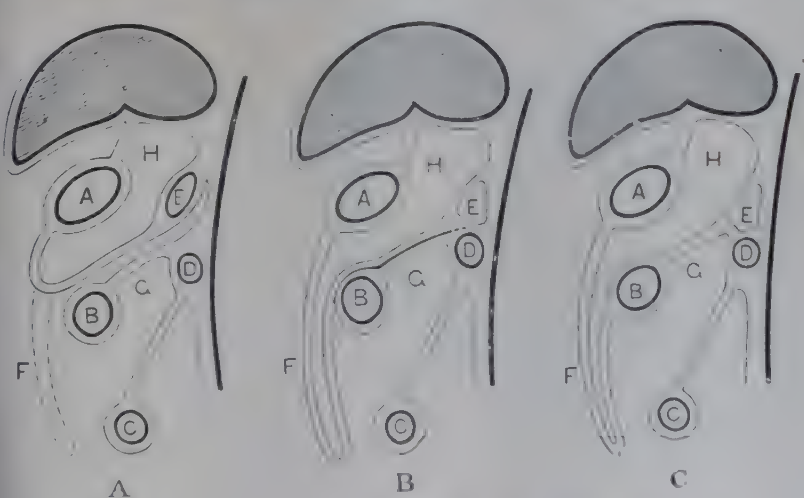

FIG. 575.—DIAGRAMS TO ILLUSTRATE DEVELOPMENT OF GREATER OMENTUM. (After Hertwig, 1892.)

A shows the beginning of the greater omentum and its independence of the transverse mesocolon; in B, the two come in contact; and in C, they have fused along the line of contact. (According to Lockwood, 1884, the two layers of the fold shown in A, instead of fusing, as shown in B, are drawn out—unfolded—producing the condition shown in C.) A, stomach; B, transverse colon; C, small intestine; D, duodenum; E, pancreas; F, greater omentum; G, placed in greater sac; H, in lesser sac.

The **greater omentum** is, as pointed out above, a bag-like growth of the lower part of the dorsal mesogastrium which passes downwards and to the left in front of the transverse colon. As shown in Fig. 575, A and B, it is first entirely unconnected with the transverse colon and mesocolon; but about the third or fourth month it becomes united to both, and the adult condition is established (Fig. 575, C). It would appear that the growth of the inferior part of the lesser sac, and of the greater omentum, is primarily due to a proliferation of the cells over a limited area of the dorsal mesogastrium and a resulting folding of this layer downwards and to the left.

In the upper part of the dorsal mesogastrium the **spleen** is developed, and the portion of that

fold which intervenes between the stomach and spleen forms the gastro-splenic ligament, whilst the part behind the spleen becomes the lieno-renal ligament.

Of the primitive mesentery, the portion connected with the stomach—the mesogastrium—becomes modified in the manner just described. The next division—the mesoduodenum—disappears completely, owing to the turning over of the duodenal loop on to its right side and its subsequent adhesion to the posterior abdominal wall, accompanied by the absorption of the right side of its mesentery. The mesenteries of the small and large intestine are continuous at first (Fig. 572, A). When the rotation of the intestinal loop takes place around the superior mesenteric artery (Fig. 572, B), the beginning of the large intestine, with its mesentery is carried to the right across the duodenum, and a fan-shaped portion of the general mesentery, lying within the concavity of the loop, is partially cut off; that, later on, forms the mesentery proper in the adult. At first it is continuous by its right border with the mesentery of the ascending colon (a part of the primitive mesentery), which itself is continued into the mesentery of the transverse, descending, and pelvic colons. Subsequently, as shown by the darkly shaded parts in Fig. 574, the backs of the mesenteries of the ascending and descending portions of the colon adhere to the posterior abdominal wall, and these mesenteries become lost; whilst the mesenteries of the transverse and pelvic portions of the colon remain free, and they persist in the adult.

At the same time, the mesentery proper (which was at first attached only at its narrow neck between the duodenum and transverse colon, and, below that, was continuous on the right with the ascending mesocolon) now acquires a new attachment to the posterior abdominal wall through the absorption of the ascending mesocolon (Fig. 574), and the adult condition is attained.

Development of Liver and Pancreas

The glandular tissue of the liver and pancreas and the epithelial linings of the ducts of those organs, including the gall-bladder and cystic duct, are formed from protrusions of the

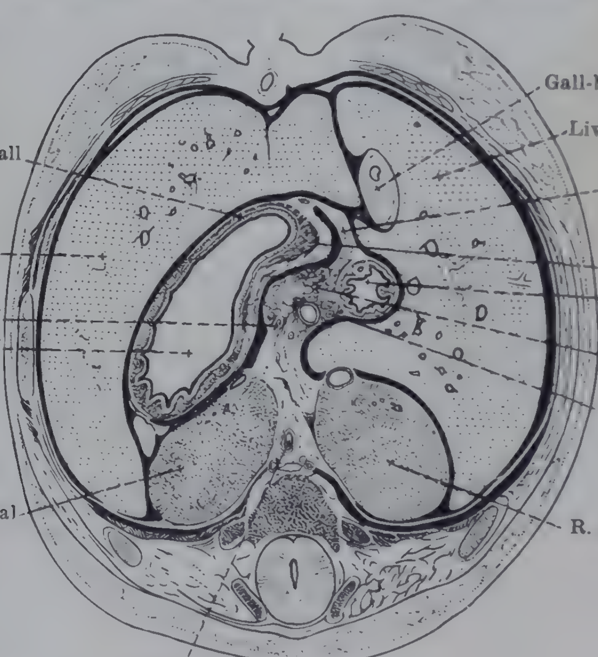

Fig. 576.—Transverse Section of 26 mm. Human Embryo, at Level of Upper Part of Umbilicus. (Embryo E 1. St. Andrews University Collection.)

The liver at this stage is of large size, and its left lobe extends into the left half of the abdominal cavity. The suprarenal glands are also relatively very large. The lesser omentum (ventral mesogastrium) is attached to the duodenum as well as to the lesser curvature of the stomach. Buds of developing pancreatic tissue are shown lying to the left side of the duodenum, while, dorsal to them, other buds surround the bile-duct, on the left side of which lies the portal vein. The cavity of the lesser sac is shown in black, behind and to the right side of the stomach.

epithelial wall of the fore-gut below the stomach. The areolar tissue framework of the glands is formed from the mesodermic tissue into which the protrusions grow.

Liver.—A longitudinal groove appears on the interior of the ventral wall of the fore-gut, close to its union with the mid-gut, at about the third week. The groove appears on the external surface of the gut as a projection which rapidly increases in size and grows forwards and upwards towards the lower part of the septum transversum. The septum transversum is a mass of mesodermic tissue which lies in front of the fore-gut, just caudal to the heart, and is attached to the ventral wall and side-walls of the trunk. The umbilical and vitelline veins pass through it on their way to the sinus venosus.

The liver-bud grows into the lower (caudal) portion of the septum transversum, and divides into two, from each of which strands of cells, termed *trabeculæ*, grow out, make contact with the vessels in the septum, and enclose them. By the growth of capillary vessels from the vitelline and umbilical veins and the growth of the trabeculæ, a spongy network is produced, the framework of which is formed by branching and anastomosing trabeculæ, while the spaces of the network represent portions of the lumen of the vessels and are filled with blood. This form of vascular network is known as a "sinusoidal tissue". The trabeculæ become hollowed out and are reduced in size, so that eventually a minute channel is formed in the centre of each of them, and is surrounded by a single layer of cells. The lumen of the channel becomes the lumen of a bile-ductule, and the cells surrounding it form the secreting cells of the liver-lobule. The bile-ductules of adjacent trabeculæ converge and unite to constitute the interlobular ducts. Adjacent trabeculæ become arranged into the form of a lobule, each with a vascular channel in its interior which communicates with the vascular network in the surface of the lobule by capillary intervals between adjacent trabeculæ. The central vein becomes a tributary of a hepatic vein, and the capillary network becomes the terminal distribution of branches of the portal vein.

The proximal portion of the original hollow diverticulum becomes the bile-duct, and the gall-bladder and cystic duct are formed by an evagination from it. For an account of the development of the choledocho-duodenal junction see Schwegler & Boyden (1936, 1937).

As the liver increases in size, it begins to bulge down from the lower part of the septum transversum into the ventral mesogastrium, so that now, instead of being situated within the septum, it looks like an appendage of its inferior surface. In other words, the septum begins to differentiate into two parts—an inferior, the liver, and a superior, which constitutes the greater portion of the diaphragm, both of these having been at first one continuous mass. In the course of development the separation of the two becomes more marked, and finally is complete everywhere except at the coronary and triangular ligaments behind, and at the falciform ligament in front, where they are still connected. As the liver separates off from the future diaphragm and descends into the abdomen, it lies between the layers of the **ventral mesogastrium** and divides it into two parts—the falciform ligament and the lesser omentum (*vide ante*).

Pancreas.—The pancreas is developed at a very early period (being present in embryos of less than 5 mm.) from two outgrowths from the alimentary canal—a dorsal and a ventral (Fig. 577).

The dorsal rudiment is an outgrowth from the dorsal wall of the intestine proximal to the origin of the hepatic outgrowth. The ventral rudiment grows at a later stage from the root of the hepatic bud in the form of two offshoots, one on each side. That on the left side, however, soon disappears.

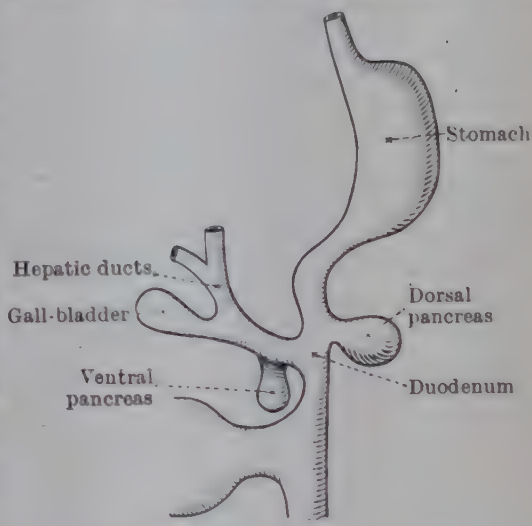

FIG. 577.—DIAGRAM OF DEVELOPMENTAL ORIGIN OF LIVER AND PANCREAS.

Through the rotation of the duodenum around its long axis, the dorsal and ventral rudiments approach one another and become fused, and their ducts open on the left side of the duodenum. The connecting stalk between the ventral rudiment and the hepatic bud becomes the main duct of the pancreas, while the connexion of the dorsal outgrowth with the duodenum remains as the accessory pancreatic duct. In embryos of the fifth week, a large dorsal pancreatic rudiment is present, and also a smaller ventral rudiment, which opens into the duodenum in common with the bile-duct and lies on the right of the portal vein. In the sixth week, the two rudiments meet and unite with one another, forming a long slender glandular mass which passes backwards within the dorsal mesentery (mesoduodenum) between the vertebral column and the greater curvature of the stomach. As the duodenum comes to lie on the posterior abdominal wall the dorsal extremity of the pancreas is displaced over to the left side, and the body of the gland and the head (included within the curve of the duodenum) also come to lie on the posterior abdominal wall.

The dorsal (proximal) outgrowth, which passes in front of the portal vein, gives rise to the main mass of the gland, including the upper and anterior parts of the head, the body, and the tail; the ventral outgrowth, which lies dorsal to the vein, becomes the uncinate process and the posterior portion of the lower part of the head.

Each developmental portion of the pancreas has at first its own duct, but a connecting channel is formed between the ducts of the dorsal and ventral rudiments, so that the **pancreatic duct** is a composite structure. The **accessory duct** (see Fig. 570, p. 671) is the terminal part of the duct of the dorsal outgrowth.

The primary diverticula give off buds which are lined with cylindrical epithelium, and these in turn give off other buds, and the process goes on until the mass of the gland is formed.

The **islets of Langerhans** are formed at a very early stage from the entodermal lining cells of some of the branching diverticula which lose their connexion with the system of

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RESPIRATORY SYSTEM

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THE **Respiratory System** (Fig. 578) comprises the *larynx*, *trachea*, *bronchi*, and *lungs*. The larynx and trachea are the successive parts of a median air-passage. The trachea bifurcates below into two smaller air-passages, called the right and the left bronchus, which conduct air to the right and the left lung respectively. A serous membrane, called the *pleura*, envelops each lung and lines the portion of the thoracic cavity which contains that lung.

The larynx opens into the inferior part of the pharynx, and the air that passes into and out of the air-passages traverses the pharynx and the nasal cavities, and also the oral cavity if the mouth is open. The connexion between the digestive and respiratory systems is explained by the fact that the respiratory system develops as an outgrowth from the ventral wall of the primitive fore-gut of the embryo.

LARYNX

The larynx is a mechanism specially adapted to protect the opening of the air-passage, to close it against the entrance of solids, liquids, and even air if necessary, and to control the expiration of air from the lungs, thus providing an organ of voice in Man. Above, it opens into the pharynx; below, its cavity is continuous with the lumen of the trachea or windpipe.

Position and Relations of Larynx.—In the natural position of the neck the larynx is situated anterior to the bodies of the fourth, fifth, and sixth cervical vertebræ. Its highest point, represented by the tip of the epiglottis, extends to the upper border of the body of the third cervical vertebra, whilst its lowest limit (the lower border of the cricoid cartilage) usually extends to the lower border of the body of the sixth cervical vertebra. From the vertebral column the larynx is separated not only by the prevertebral muscles and the prevertebral fascia but also by the posterior wall of the pharynx—indeed, the posterior surface of the larynx forms the inferior part of the anterior wall of the pharynx, and it is covered with the pharyngeal mucosa.

The larynx lies below the hyoid bone and the tongue, in the interval between the great vessels of the neck, and it forms a more or less marked projection on the front of the neck. In the median plane it is separated from the surface merely by skin and two layers of fascia; laterally it is overlapped by the the sterno-mastoid muscle, and is covered with the two strata of thin ribbon-like muscles that are attached to the thyroid cartilage and the hyoid bone. It is clasped by the upper parts of the lobes of the thyroid gland.

The position of the larynx is influenced by movements of the head and neck. Thus, it is elevated when the head moves backwards and is depressed when the chin is carried downwards towards the chest, but its relation to the vertebræ is scarcely changed. During deglutition the larynx moves upwards. The pharyngeal muscles attached to it, and more especially the palato-pharyngeus muscles, are responsible for bringing about these movements. In the production of vowel-sounds the pharynx undergoes marked alterations in outline, and the larynx accommodates itself to these in position and

in the relation of its thyroid to its cricoid portions. In singing, there are no changes of position other than those essential to vowel-production. In untrained singers the pharyngeal and laryngeal movements are erratic and lacking in orderly control.

In the fœtus, shortly before birth, the larynx lies nearer the head. The tip of the epiglottis then corresponds in level to the atlas, and the lower border of the larynx to the

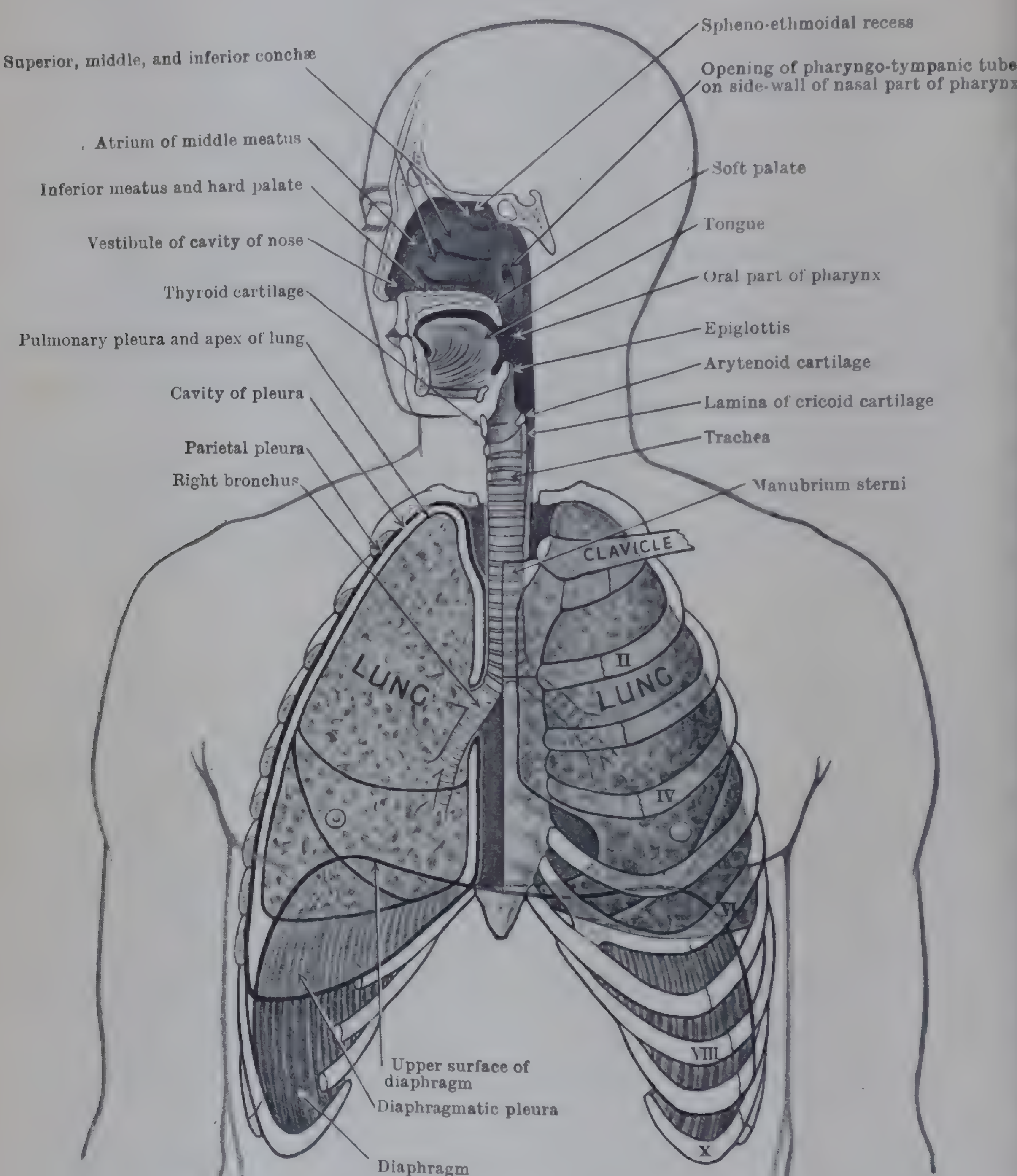

FIG. 578.—DIAGRAM OF GENERAL ARRANGEMENT OF RESPIRATORY SYSTEM.
The lung, pleura, and ribs of the right side are represented as cut.

lower border of the body of the fourth cervical vertebra. From four years onwards, in both sexes, the larynx maintains a fairly constant position in the neck—namely, the adult position given on the previous page. The elasticity of the trachea ensures practical uniformity of laryngeal relations in all positions of the head and neck.

General Construction of Larynx.—The framework is composed of several cartilages which are connected by synovial joints and also by extensive elastic membranes. Two elastic cords, which stretch from the anterior to the posterior wall of the larynx, form the groundwork of the vocal folds. Many muscles operate upon

the cartilages of the larynx, bringing about changes in the relative positions of the vocal folds, and producing different degrees of tension in those folds. The cavity of the larynx is lined with mucous membrane, under which, in certain localities, are collected masses of mucous glands.

CARTILAGES OF LARYNX

There are three single cartilages and three pairs of cartilages in the laryngeal wall. They are named as follows:—

Single cartilages	Thyroid. Cricoid. Epiglottic.	Paired cartilages	Arytenoid. Corniculate. Cuneiform.

The **thyroid cartilage**, the largest of the laryngeal cartilages, is formed of two quadrilateral plates, called the **laminæ**, which are fused together in front in the median plane. The laminæ diverge posteriorly to enclose a wide angular space open behind. The *anterior borders* of the laminæ are fused only in their inferior parts. Above they diverge to produce a deep, narrow, V-shaped, median notch called the **thyroid notch**. The median prominence just below the notch is known as the **laryngeal prominence** (Adam's apple).

The angle formed by the meeting of the two laminæ of the thyroid cartilage presents considerable individual variation and shows marked differences in the two sexes and at different periods of life. In the adult male the average angle is about 90°; in the adult female about 120°. In the fœtus the larynx is relatively large compared with the trachea and is flattened antero-posteriorly. In the infant the laminæ meet in a gentle curve, convex forwards.

The *posterior border* of each lamina of the thyroid cartilage is thick and rounded and is prolonged beyond the superior and inferior borders in the form of two slender cylindrical processes, termed horns or cornua. The **superior horn** is the longer. It is directed upwards, with a slight dorso-medial inclination, and its end or tip, which is rounded, is joined to the tip of the greater horn of the hyoid bone by the lateral thyro-hyoid ligament. The **inferior horn** is shorter and stouter. It curves downwards with a slight inclination towards the median plane. On the medial face of its extremity there is a circular, flat facet which articulates with a similar facet on the lateral surface of the cricoid cartilage.

The *superior border* of each lamina is, for the most part, slightly convex. In front it dips suddenly to become continuous with the margin of the thyroid notch, and, behind, as it joins the superior horn, it exhibits a shallow concavity. The *inferior border* is divided by a rudimentary **inferior tubercle** into a short, concave, posterior part and a longer anterior part, also concave, but to a lesser degree.

The *lateral surface* of each lamina is divided into two unequal areas by the **oblique line** which runs from a prominence (the **superior tubercle**) situated immediately antero-inferior to the root of the superior horn, forwards and downwards to end in the inferior tubercle. The area behind the oblique line is much smaller than that in front and is covered by the inferior constrictor muscle of the pharynx. The anterior area is, for the most part, covered by the thyro-hyoid muscle. To the oblique line are attached the sterno-thyroid, thyro-hyoid, and inferior constrictor muscles.

The *medial surface* of the lamina is smooth and slightly concave.

The **cricoid cartilage** is shaped like a signet-ring. Its posterior part or *lamina* is a broad, thick plate, more or less quadrilateral in form. In front and laterally the circumference of the ring is completed by a curved band called the *arch*. The lumen of the ring is circular below but elliptical above. The upper border of the **lamina** presents a broad, shallow, median notch. On each side of the notch there is an obliquely placed oval facet which articulates with the base of the arytenoid cartilage. The posterior surface of the lamina is divided by a median ridge into two depressed areas which give attachment to the posterior crico-arytenoid muscles. The **arch** of the cricoid is narrow and band-like in front, but laterally its upper border rises rapidly to join the upper border of the lamina.

The *inferior border* of the cricoid is nearly horizontal, although it commonly presents three slight, downward projections, one being on each side and one median. It is connected to the first ring of the trachea by an elastic membrane—the crico-tracheal ligament. On the *lateral surface* of the cricoid cartilage, at the place where the arch joins the lamina, a vertical ridge runs downwards from the arytenoid articular facet. On this, a short distance from the inferior border of the cartilage, a prominent circular facet articulates with the inferior horn of the thyroid cartilage (Fig. 582). The *inner surface* of the cricoid cartilage is smooth, and is lined with mucous membrane.

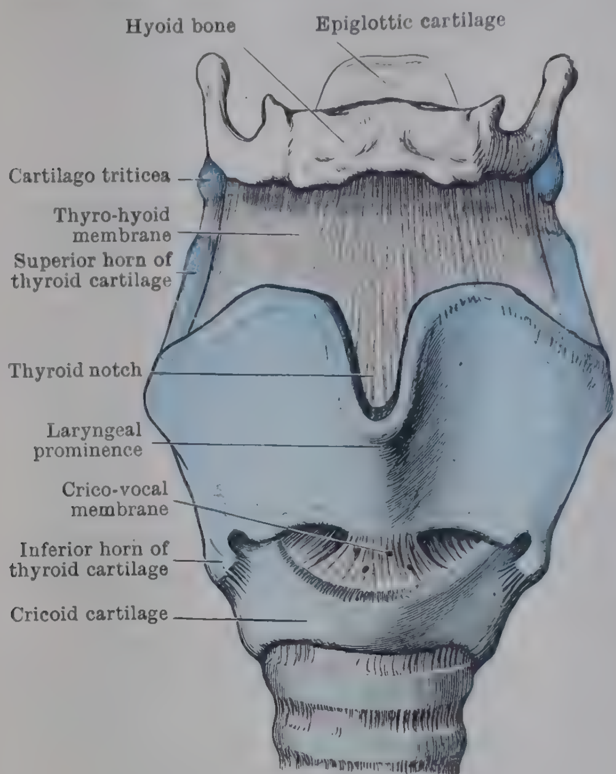

Fig. 579.—Anterior Aspect of Cartilages and Ligaments of Larynx.

The arch of the cricoid cartilage lies below the inferior border of the thyroid cartilage. The lamina is received into the interval between the posterior portions of the laminæ of the thyroid cartilage.

The **arytenoid cartilages** rest, one on each side of the median plane, upon the upper border of the lamina of the cricoid cartilage, in the interval between the posterior portions of the laminæ of the thyroid cartilage. Each has the form of a three-sided pyramid, the pointed **apex** of which curves postero-medially. It supports the corniculate cartilage. The **base** is triangular in outline. It is prolonged forwards into a small, sharp-pointed **vocal process** which gives attachment to the vocal ligament or supporting band of the vocal fold; and it is prolonged laterally into a stout, prominent angle, called the **muscular process**, which gives attachment to the lateral crico-arytenoid muscle in front and to the posterior crico-arytenoid muscle behind. Near the muscular process the base bears an elongated, concave **articular facet** for articulation with the upper border of the lamina of the cricoid cartilage. The *medial surface*, which is the smallest of the three, is triangular, flat, and vertical. It faces the corresponding surface of the opposite cartilage, from which it is separated by a narrow interval, and it is clothed with the lining mucous membrane of the larynx. The *posterior surface* is smooth and is concave in the vertical direction. It lodges and gives attachment to the transverse arytenoid muscle. The *antero-lateral surface* is the most extensive of the three (Fig. 582). Its middle part is marked by a deep depression in which a mass of mucous glands is lodged. Into this surface the vocalis and thyro-arytenoid muscles are inserted, whilst a small tubercle a short distance above the base gives attachment to the vestibular ligament—the feeble supporting ligament of the vestibular fold. The three surfaces of the arytenoid cartilages are separated from one another by an anterior, a

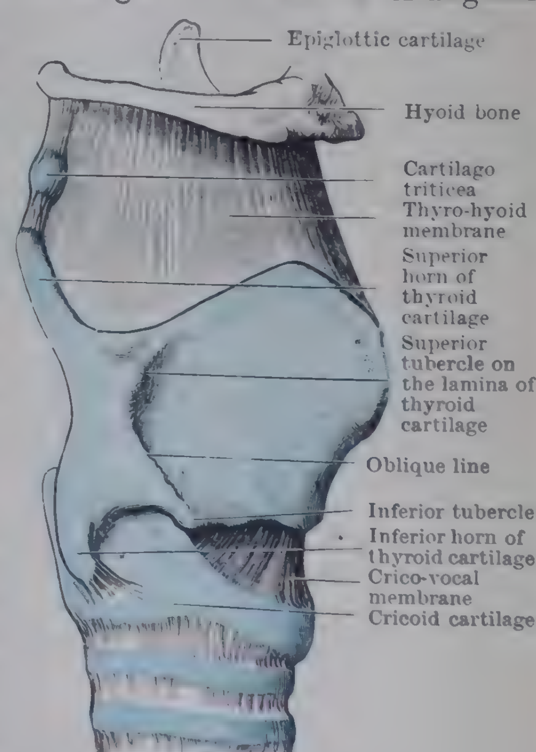

Fig. 580.—Profile View of Cartilages and Ligaments of Larynx.

posterior, and a lateral border. The *lateral border* is the longest, and it pursues a sinuous course from the apex to the muscular process at the base. A small nodule of elastic cartilage, called the **sesamoid cartilage**, commonly found on the lateral border of the arytenoid cartilage, is held in position by the investing perichondrium. The *anterior border* of the arytenoid cartilage is vertical and, at its base, reaches the vocal process.

The **corniculate cartilages** are a pair of small conical nodules of elastic fibro-cartilage; each surmounts the apex of an arytenoid and prolongs its upper, curved end in a postero-medial direction. Each corniculate cartilage is enclosed within the posterior part of the corresponding ary-epiglottic fold of mucous membrane.

The **cuneiform cartilages**, which may be very large, are not always present. They are a pair of rod-shaped pieces of elastic fibro-cartilage, each of which occupies a place in the corresponding ary-epiglottic fold immediately anterior to the arytenoid and corniculate cartilages. On the laryngeal surface of each cartilage a collection of mucous glands stands out in relief under the mucous membrane (Fig. 585).

Epiglottis.—The **epiglottis** is supported by a thin, leaf-like lamina of elastic fibro-cartilage, called the **epiglottic cartilage**, which is placed behind the root of the tongue and the body of the hyoid bone, and in front of the aperture of the larynx. When divested of the mucous membrane that covers it behind and also covers its upper part in front, the epiglottic cartilage has the outline of a bicycle-saddle. It is extensively pitted and has numerous foramina. Glands are lodged in the pits; blood-vessels and nerves pass through the foramina. The *broad end* of the epiglottic cartilage is directed upwards, and it is free. Its *margins* are, to a large extent, enclosed within the ary-epiglottic folds. The *anterior surface*, free only in its upper part which is covered with mucous membrane, looks towards the pharyngeal part of the tongue. The *posterior surface*, covered throughout its whole extent by the lining mucous membrane of the laryngeal cavity, looks towards the vestibule of the larynx. The *inferior extremity* or *stalk of the epiglottic cartilage* is pointed and is attached by a strong fibrous band—the thyro-epiglottic ligament—low down on the posterior surface of the thyroid cartilage below the median notch.

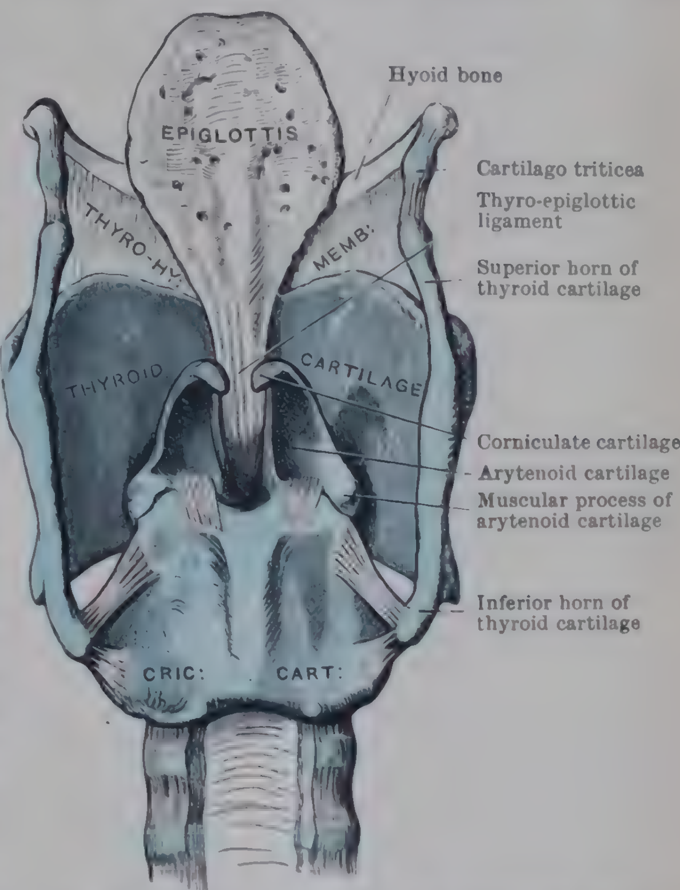

FIG. 581.—POSTERIOR ASPECT OF CARTILAGES AND LIGAMENTS OF LARYNX.

Structure and Ossification of Cartilages of Larynx.—The thyroid and cricoid cartilages and the greater part of the arytenoid cartilages are composed of hyaline cartilage. The apical parts and vocal processes of the arytenoid cartilages, and the corniculate, cuneiform and the epiglottic cartilages, are formed of elastic fibro-cartilage, and at no period of life do they exhibit any tendency towards ossific change. The thyroid, cricoid, and basal portions of the arytenoids, as life advances, may be more or less completely transformed into bone and so become visible in radiographs (Pl. LXI, p. 696). This transformation bears no constant relation to age and is already present in some subjects in the third decade. The commonest sites of ossification are the posterior and lower margins of the thyroid and the lamina of the cricoid cartilages; and in old age the thyroid, cricoid, and the hyaline parts of the arytenoids

ARTICULATIONS, LIGAMENTS, AND MEMBRANES OF LARYNX

Crico-Thyroid Joints.—These joints are formed by the apposition of the circular facets on the tips of the inferior horns of the thyroid cartilage to the elevated circular facets on the sides of the cricoid cartilage. Each joint has a ligamentous capsule lined with synovial membrane. Among the posterior fibres of the capsule there is a strengthening band. The movement that takes place at the crico-thyroid joints is mainly rotatory, the thyroid cartilage rotating around a transverse axis that passes through the centres of the two joints. Some gliding is possible here, especially in an antero-posterior direction.

Crico-Arytenoid Joints.—Each of these joints has a ligamentous capsule lined with synovial membrane. The cricoid articular surface is convex, whereas that of the arytenoid is concave; both are elongated or elliptical in form, and they are applied to each other so that the long axis of the one intersects or crosses that of the other at an acute angle. In no position of the joint do the two facets accurately coincide—a portion of the cricoid facet is always left uncovered. The capsule of the joint is strengthened behind by a band which, being inserted into the postero-medial part of the base of the arytenoid cartilage, effectually arrests excessive forward movement of that cartilage.

The movements that take place at the crico-arytenoid joints are gliding and rotatory. During easy, quiet breathing the arytenoid rests upon the lateral part of the cricoid facet. It can glide forwards and backwards upon the cricoid facet, and pass towards or from the median plane and its fellow of the opposite side. When it glides forwards the vocal process is tilted downwards towards the cricoid ring, and when it glides backwards it is tilted upwards. In the rotatory movement the arytenoid cartilage revolves around a vertical axis; by this movement the vocal process is swung laterally or medially so as to open or close the rima glottidis.

Between the arytenoid and corniculate cartilages there is a more or less rudimentary joint with a capsule, some fibres of which reach the cricoid cartilage. This joint commonly has no synovial lining.

Thyro-Hyoid Membrane.—This is a broad, membranous, and slightly elastic sheet which occupies the interval between the hyoid bone and the thyroid cartilage. The median part, composed largely of elastic fibres, is thickened to form the **median thyro-hyoid ligament**. This ligament is attached below to the margins of the thyroid notch, and above to the upper border of the body of the hyoid bone. In order to reach the upper border, the ligament ascends behind the body; and between the ligament and the body a *bursa* is interposed. On each side of the median ligament, the thyro-hyoid membrane is thin and loose. It is attached, below, to the upper border of the thyroid cartilage, and, above, to the upper border of the greater horn of the hyoid bone. It is pierced by the internal laryngeal nerve and by the superior laryngeal vessels. On each side the thickened cord-like lateral margin of the membrane, or **lateral thyro-hyoid ligament**, is composed chiefly of elastic fibres. It extends from the tip of the greater horn of the hyoid bone to the tip of the superior horn of the thyroid cartilage. In each lateral ligament the *cartilago triticea*, a small, oval cartilaginous or bony nodule, usually develops (Figs. 579-581).

The median thyro-hyoid ligament lies in front of the epiglottis, from which it is separated by a fatty pad (Fig. 585). The lateral part of the membrane is clothed on its deep aspect with pharyngeal mucosa (Fig. 584).

Crico-Vocal Membrane.—The crico-vocal membrane is attached below to the entire upper border of the arch of the cricoid cartilage from one arytenoid facet to the other. The median part, or **crico-thyroid ligament**, tense, strong, elastic, and of triangular shape, has its apex inserted into the lower border of the thyroid cartilage at the junction of the laminæ. From this attachment the lateral part of the crico-vocal membrane extends backwards to be inserted into the inferior border of the vocal process of the arytenoid cartilage. Between the anterior and posterior attachments the upper border of this part of the crico-vocal membrane is thickened and free and forms the **vocal ligament**—the supporting ligament of the vocal fold.

The crico-thyroid ligament, pierced by minute vessels and crossed by the crico-thyroid branch of the superior thyroid artery, directly unites the cricoid and thyroid cartilages. The lateral part of the membrane narrows the lumen of the larynx; it is clothed on its medial surface with the lining mucosa and on its lateral surface by the lateral crico-arytenoid muscle, which separates it from the thyroid lamina.

The **vocal ligament**, just defined as the upper border of the crico-vocal membrane, is attached in front, close to its fellow of the opposite side, to the middle of the angular depression between the two laminæ of the thyroid cartilage, and behind to the tip and upper border of the vocal process of the arytenoid cartilage. The vocal ligament is composed of elastic fibres, and embedded in its anterior extremity there is, commonly, a minute nodule of elastic fibro-cartilage. Its medial border is sharp and free, and it is clothed with mucous membrane which here is very thin and tightly bound to the ligament.

The **vestibular ligament** supports the vestibular fold. It is weak and indefinite, but is slightly longer than the vocal ligament. In front it is attached to the angular depression between the two laminæ of the thyroid cartilage above the vocal ligament and close to the attachment of the thyro-epiglottic ligament; it extends backwards to its insertion into a tubercle on the antero-lateral surface of the arytenoid cartilage a short distance above the vocal process. It is composed of fibrous and elastic tissue continuous with the areolar tissue in the ary-epiglottic fold, and it is covered with loosely attached mucosa.

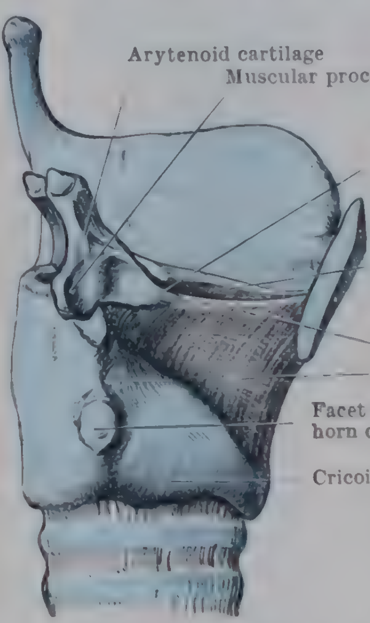

Fig. 582.—Dissection to show Crico-Vocal Membrane. The right lamina of the thyroid cartilage has been removed.

The **epiglottis** is bound by ligaments to the base of the tongue, to the wall of the pharynx, to the hyoid bone, and to the thyroid cartilage. The **glosso-epiglottic fold** is a prominent median fold of mucous membrane that extends from the free part of the anterior surface of the epiglottis to the back of the tongue. The **pharyngo-epiglottic folds** are a pair of folds of mucous membrane that pass from the lateral margins of the epiglottis to the lateral walls of the pharynx at the sides of the tongue; they enclose a certain amount of elastic tissue. By these three folds the depression between the back of the tongue and the epiglottis is marked off into a pair of fossæ, termed the **epiglottic valleculæ**, which are invariably filled in swallowing soft, semi-solid masses of food. It is, therefore, in them that foreign bodies, such as small fish-bones, should first be sought. A pair of **ary-epiglottic folds** also pass from the lateral margins of the epiglottis to the arytenoid cartilages. These very prominent folds of mucous membrane extend backwards and downwards and help to form the rim of the laryngeal inlet (Fig. 583). Between the ary-epiglottic fold and the lamina of the thyroid cartilage is the lateral food-gutter in which the opaque shadow of barium can be clearly seen on X-ray examination during the act of swallowing (Pl. LXIV, Fig. 1, p. 697).

The **hyo-epiglottic ligament** is a short, broad elastic band, partly broken up by adipose tissue, that connects the anterior surface of the epiglottic cartilage to the upper border of the hyoid bone (Fig. 585). The **thyro-epiglottic ligament** is strong and thick, and is composed mainly of elastic tissue; it extends downwards from the stalk of the epiglottic cartilage to be attached to the angle between the two laminæ of the thyroid cartilage below the median notch (Fig. 581).

The triangular interval between the anterior surface of the epiglottis and the

CAVITY OF LARYNX

The **cavity of the larynx** is smaller than might be expected from an inspection of the exterior of the larynx. It is divided into three portions by two horizontal folds of mucous membrane that project medially from each lateral wall of the cavity. The upper pair of folds are the **vestibular folds**; the lower, more definite pair are the **vocal folds** (Figs. 583, 584, 585). By controlling the exhalation of air, the vocal folds are of significance in voice-production. Changes in their relative position and in their tension are brought about by the action of muscles and by the recoil of elastic ligaments.

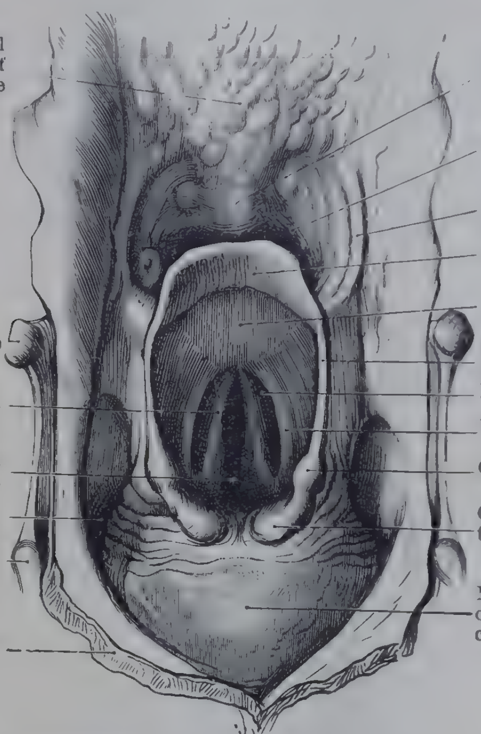

Fig. 583.—Laryngeal Inlet, exposed by Removal of Posterior Wall of Pharynx and viewed from above.

The **inlet of the larynx** opens off the pharynx, is obliquely set, and is more or less triangular in outline. The base of the triangle is anterior and is formed by the free border of the epiglottis. The apex is lower than the base and lies in the interval between the two arytenoid cartilages. The sides are formed by the **ary-epiglottic folds**. The two layers of mucous membrane that compose the ary-epiglottic folds enclose some areolar tissue, sphincteric muscle-fibres belonging to the ary-epiglottic muscles, and, posteriorly, the cuneiform and corniculate cartilages. These cartilages produce rounded prominences on the fold called the *cuneiform* and *corniculate tubercles.* When the ary-epiglottic sphincter is in action, these tubercles are approximated to the epiglottic tubercle and so assist it to complete the closure of the laryngeal inlet.

On each side of the laryngeal inlet there is a small pocket of the pharynx termed the **piriform fossa.** This fossa is part of the lateral food-gutter that leads from the oral pharynx, behind the tongue, and round the laryngeal inlet to the entrance of the gullet (Fig. 583; Pl. LXIV, Fig. **1**, p. 697). Foreign bodies may be caught in this pocket. It is bounded on the medial side by the arytenoid cartilage and the ary-epiglottic fold, and on the lateral side by the thyroid lamina and thyro-hyoid membrane. Stretching across the anterior border of the fossa in a fold of mucous membrane is the internal laryngeal nerve.

The **vestibule of the larynx** is the **uppermost compartment** of the laryngeal cavity. It extends from the laryngeal inlet to the vestibular folds. Its inferior part is compressed from side to side, hence its width diminishes from above downwards, and, owing to the obliquity of the laryngeal inlet, its vertical height is less behind than in front. *In front* it is bounded by the posterior surface of the epiglottis. Its upper part is shaped like the spout of a jug, being concave from side to side and convex from above downwards; its lower part is concave and it tapers towards the anterior ends of the vestibular folds, but above these there is a marked swelling, called the **tubercle of the epiglottis**, which overlies the upper part of the thyro-epiglottic ligament. Each *side-wall* of the vestibule of the larynx is formed by the ary-epiglottic fold. For the most part it is smooth and slightly concave. Posteriorly it diminishes considerably in vertical depth where the cuneiform and corniculate elevations appear—the latter behind the former (Figs. 583, 585). The *posterior wall* of the

laryngeal vestibule corresponds to the interval between the upper parts of the arytenoid cartilages. Its width depends largely on the position of these cartilages; when they are placed near each other the loose mucous membrane that covers the posterior wall is thrown into longitudinal folds.

The **middle compartment of the larynx**, much the smallest of the three, is the space between the level of the vestibular folds above and that of the vocal folds below (Figs. 584, 585). Each side-wall of this compartment, called the *sinus of the larynx*, bulges laterally in the shape of a canoe laid on its side, undercutting the vestibular fold more than the vocal fold. The *saccule of the larynx* opens by a slit-like mouth into the anterior part of the sinus. The saccule is a diverticulum of mucous membrane that extends upwards between the vestibular

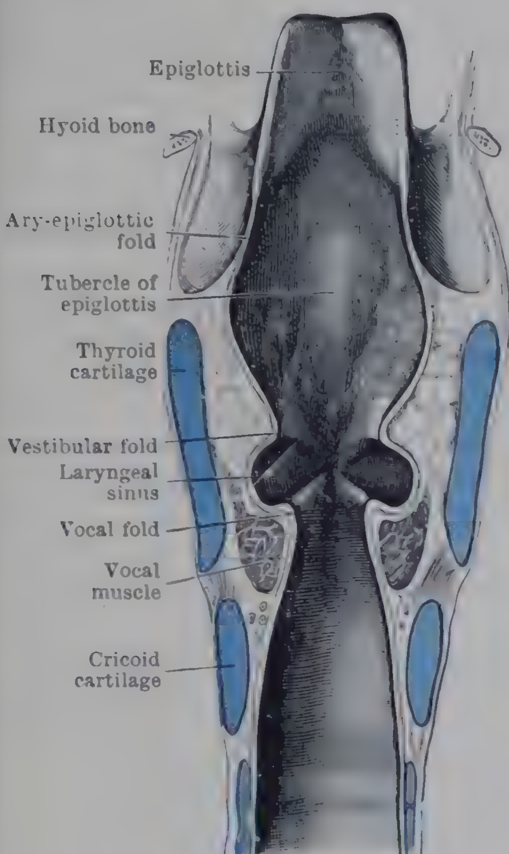

Fig. 584.—Coronal Section through Larynx to show its Compartments.

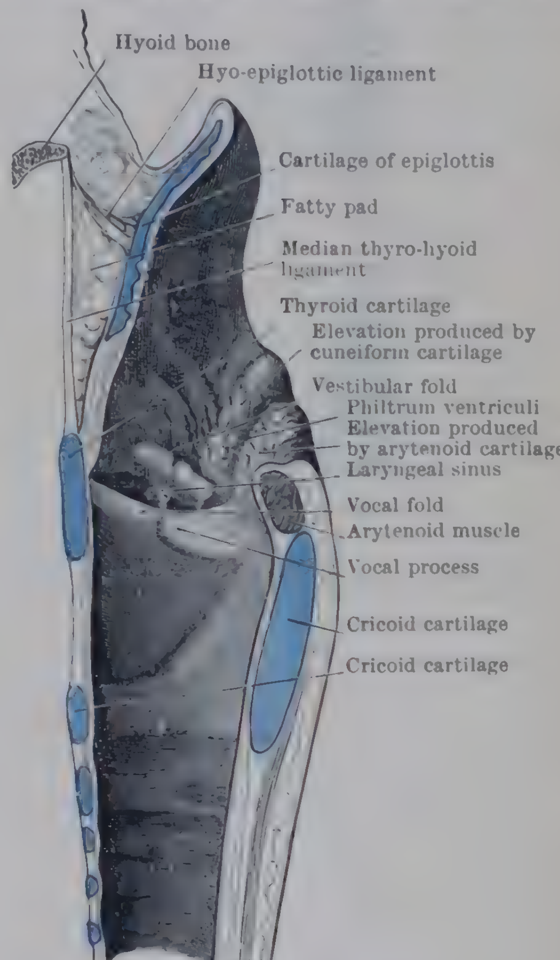

Fig. 585.—Median Section through Larynx to show Side-Wall of its Right Half.

fold medially and the thyro-arytenoid muscle laterally. It ends blindly, usually at the upper border of the thyroid cartilage, but it may protrude outwards through the thyro-hyoid membrane. The laryngeal saccule is very much larger in many of the Primates, and it may attain an enormous size in the great apes and extend even into the axilla (Negus, 1929, 1949; Brash, 1947).

The **vestibular folds** or "false vocal cords" are two prominent folds of mucous membrane that extenp antero-posteriorly, one on each side-wall of the laryngeal cavity. In front they reach the angle between the two laminæ of the thyroid cartilage, but behind they do not extend so far as the posterior wall of the larynx; each ends at the lower end of the elongated elevation produced by the cuneiform cartilage. The vestibular fold is soft and rather flaccid, and it presents a free border which is slightly arched—the concavity looking downwards. Deep to the mucosa of that fold there are: (1) the vestibular ligament; (2) numerous glands which are chiefly aggregated in its middle part; and (3) a few muscle-fibres.

The interval between the two vestibular folds is termed the **rima vestibuli** and is considerably wider than the interval between the two vocal folds. It follows that when the cavity of the larynx is examined from above, with the laryngoscope,

The **vocal folds** or "true vocal cords", placed below the vestibular folds, extend from the angle between the laminæ of the thyroid cartilage in front to the vocal processes of the arytenoid cartilages behind. Each vocal fold is sharp and prominent, and the mucous membrane that covers it is very thin and firmly bound down to the subjacent vocal ligament. In colour it is pale, almost pearly white, whilst behind it the point of the vocal process, which stands out clearly in relief, presents a yellowish tinge. In cross-section the vocal fold is triangular, and its free border looks upwards as well as medially. The right and left vocal folds and the interval between them are called the **glottis.**

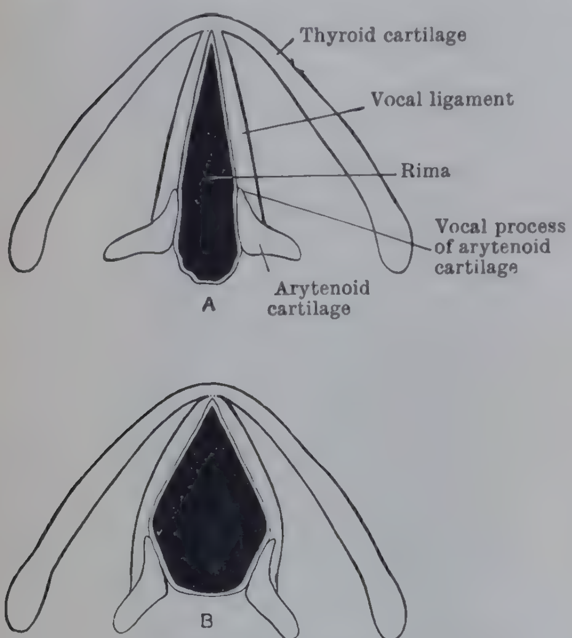

FIG. 586.—DIAGRAMS OF RIMA GLOTTIDIS.
A. During ordinary easy breathing. B. Widely opened.

The vocal folds, because they control the stream of air, are significant in voice-production. The vestibular folds, being part of the protective mechanism by which the airway is closed against the entry of food or foreign bodies, take no part in voice production. Indeed, they can in great part be destroyed and no appreciable difference in the voice results.

Rima Glottidis.—This name is applied to the elongated fissure through which the middle compartment of the larynx communicates with the lower compartment. It is placed a little below the middle of the laryngeal cavity, and it constitutes the narrowest part of that cavity. Its anterior part is bounded by the vocal folds; its posterior part is bounded by the bases and vocal processes of the arytenoid cartilages. The anterior part—between the vocal folds—constitutes more than half of its length and is called the **intermembranous part**. The broader, shorter posterior part—between the arytenoid cartilages—is termed the **intercartilaginous part.** By changes in the position of the arytenoid cartilages the form of the rima glottidis undergoes constant alterations (Fig. 586). In ordinary easy breathing it is lanceolate in outline; it widens during inspiration and narrows during expiration. When the rima is opened widely, the broadest part of the fissure is at the extremities of the vocal processes of the arytenoids, and there each side of the rima glottidis presents a marked angle. During phonation the two vocal folds are approximated to each other so that the rima is reduced to a linear chink (Fig. 591, A).

The length of the rima glottidis differs very considerably in the two sexes, and upon this depends the different character of the voice in the male and female. According to Moura (1879), the following are the average measurements in the quiescent condition of the rima :—

Male—Length of entire rima glottidis, 23 mm.	intermembranous, 15·5 mm. intercartilaginous, 7·5 mm.
Female—Length of entire rima glottidis, 17 mm.	intermembranous, 11·5 mm. intercartilaginous, 5·5 mm.

By stretching the vocal folds, however, the length of the rima glottidis may be increased in the male to 27·5 mm., and in the female to 20 mm.

The position of the rima glottidis may be indicated on the surface by marking a point on the median line of the neck 8·5 mm. below the thyroid notch in the male, and 6·5 mm. in the female (Taguchi, 1889).

The **lowest compartment** of the cavity of the larynx extends from the rima glottidis to the lower border of the cricoid cartilage. It is narrow and compressed laterally at the rima, but below this it gradually widens out until it becomes circular like the trachea, with which it is continuous. It is bounded by the sloping medial surfaces of the crico-vocal membrane and by the medial surface of the cricoid cartilage—both lined with smooth mucous membrane.

The **mucous membrane** lining the larynx is continuous above with that of the pharynx, and below with that of the trachea. Over the posterior surface of the epiglottis it is closely adherent, but elsewhere, above the level of the vocal

folds, it is loosely attached by submucous tissue. Over the vocal folds the mucous membrane is very thin and is tightly bound down.

In certain inflammatory conditions the lax submucous tissue in the upper part of the larynx becomes infiltrated with fluid, producing an œdema of the glottis which may even threaten suffocation from occlusion of the upper part of the cavity. The close adhesion of the mucous membrane to the vocal folds, however, prevents the œdema from extending below the level of the rima glottidis. Hence, as a last resort, an opening made into the respiratory passage below this level will always restore a free airway.

Above the level of the rima glottidis the laryngeal mucous membrane is extremely sensitive, and contact with a foreign body immediately induces an explosive cough. In the lower compartment of the larynx the mucous membrane, like that of the trachea, is lined with columnar ciliated epithelium. Over the vocal folds there is stratified squamous epithelium. In the sinus of the larynx and in the inferior part of the vestibule columnar ciliated epithelium again appears. The upper part of the epiglottis and the upper parts of the side-walls of the vestibule are covered with stratified squamous epithelium similar to that in the mouth and pharynx.

The mucous membrane of the larynx has a plentiful supply of acinous glands, and in only one place, namely, over the surface of the vocal folds, are they completely absent. For the most part the glands are aggregated in groups.

MUSCLES OF LARYNX

Of the many muscles connected with the larynx, two groups may be recognized—extrinsic and intrinsic.

The **extrinsic muscles** are those that attach the larynx to other parts, and, strictly speaking, they include all muscles attached to the hyoid bone, since physiologically it is a part of the larynx.

The **intrinsic muscles** all lie within the compass of the larynx itself and perform the functions outlined below. They are composed of striated muscle-fibres and are innervated by the accessory nerve through the laryngeal branches of the vagus. With the exception of the crico-thyroid muscle, they all lie under cover of the thyroid cartilage.

a. **Sphincters**

- i. Of *inlet*—
  - Oblique arytenoids
  - Ary-epiglottics
  - Thyro-epiglottics
- ii. Of *vestibule*—
  - Thyro-arytenoids

b. **Adjusters**

- i. Of *larynx*—
  - Crico-thyroids
- ii. Of *rima glottidis*—
  - Posterior crico-arytenoids
  - Lateral crico-arytenoids
  - Transverse arytenoids
  - Vocal muscles

More or less inconstant muscle-bundles, partially separated from one or other of the foregoing muscles by extension of attachment, are sometimes dignified by special names and descriptions. There is no particular reason for including them in a practical account.

The muscles of the larynx ensure a free passage for the stream of air in respiration, control the speed of expiration in speech and singing, shut off the air-stream in fixation of the chest, adjust the position of the larynx to that of the hyoid bone and tongue in movements of the throat, and provide an effective sphincter against the entrance of foreign material during swallowing. In closing the laryngeal inlet, the arytenoid cartilages are closely approximated, drawn forwards, and inclined towards the epiglottis. Thus, the laryngeal inlet is converted into a T-shaped fissure. The median limb of the T is the interval between the closely approximated arytenoid cartilages; the cross limb is bounded in front by the epiglottis and behind by the cartilages in the ary-epiglottic folds. The apices of the arytenoid cartilages, with the corniculate cartilages, are pressed against the tubercle of the epiglottis, and the lateral margins of the epiglottis are pulled backwards so as to make the transverse limb of the fissure distinctly

named in the list above. The thyro-arytenoid muscles, assisted by the oblique arytenoid muscles, form a true sphincter vestibuli. The oblique arytenoid, the ary-epiglottic, and the thyro-epiglottic muscles pull upon the epiglottis to produce tight application of its tubercle to the arytenoid and corniculate cartilages.

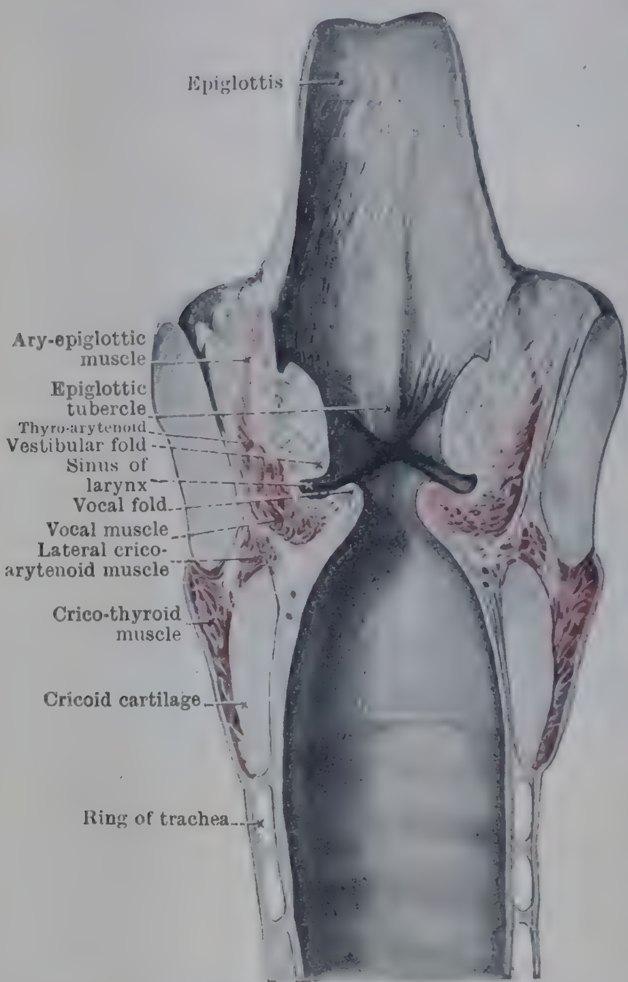

Fig. 587.—Coronal Section of Larynx to show Situation of Muscles.

Innervation of Larynx.—The nerve-supply of the larynx (Dilworth, 1921) is derived from the superior and recurrent laryngeal branches of the vagus nerve.

The **superior laryngeal nerve,** *via* its internal laryngeal branch, is the 'sensory' or receptor nerve from the mucous membrane of the larynx; its *external laryngeal* branch furnishes the 'motor' or effector fibres to the crico-thyroid muscle. All the other muscles of the larynx receive their 'motor' or effector nerve-fibres from the **recurrent laryngeal nerve.** The left recurrent laryngeal nerve winds tightly round the arch of the aorta and is commonly involved in aneurysm of the arch; the right nerve winds tightly round the right subclavian artery.

The recurrent laryngeal nerve may be damaged also in cancer of the gullet, thickening of the pleura, mediastinal tumors, extension of tumors from the neck and breast, wounds and operations in the neck, distension of the left atrium of the heart, progressive nervous diseases affecting the cervical spinal cord and medulla, and in toxic conditions like diphtheria, influenza, and lead poisoning. In recurrent laryngeal palsy the posterior crico-arytenoid is first affected and the corresponding vocal fold remains in the position of phonation. Later, when the palsy spreads to the other muscles supplied by the nerve, the vocal fold is fixed in the cadaveric position, *i.e.*, midway between adduction and abduction. The voice is hoarse but not lost since, during phonation, the healthy vocal fold crosses the median plane to meet its fellow. If both recurrent laryngeal nerves are damaged the vocal folds are fixed in the cadaveric position and phonation is impossible. There is no stridor except on deep inspiration.

Paralysis of the superior laryngeal nerve is very rare, but is stated to be caused by cold or overstrain of the voice as well as by lesions of the medulla oblongata. If the external laryngeal branch alone is damaged there is difficulty in producing high notes and the voice soon becomes tired. This is due to loss of flexion of the thyroid cartilage upon the cricoid normally produced by contraction of the crico-thyroid muscles whenever the root of the tongue is raised. If the internal laryngeal nerve also is damaged there is loss of laryngeal sensation.

Attachments of Laryngeal Muscles

The **crico-thyroid muscles** bridge over the crico-thyroid interval. Each is covered laterally and in part by the thyroid gland and by the sterno-thyroid and sterno-hyoid muscles. Between the right and left crico-thyroid muscles there is a median triangular area in which the crico-thyroid ligament is visible.

The crico-thyroid muscle **arises** from the lateral surface of the arch of the cricoid cartilage. Its fibres radiate backwards and upwards to be **inserted** into the inferior border and the adjacent part of the medial surface of the lamina of the thyroid cartilage, and into the anterior border of the inferior horn. The muscle is partly continuous with the inferior constrictor.

The cricoid cartilage is held fixed against the vertebral column by the crico-pharyngeus (*i.e.*, the lowest fibres of the inferior constrictor), except during the act of swallowing, when it is in momentary relaxation. Hence, when the anterior fibres of the crico-thyroid muscle contract, the thyroid cartilage rotates downwards on the cricoid, like a visor; but during the act of swallowing the cricoid rotates on the thyroid. The posterior fibres of the crico-thyroid muscle cause

PLATE LXI

Fig. 1.—Lateral Radiograph of Slender Neck of Woman, showing Cavities of Pharynx, Larynx and Trachea and partially-ossified Laryngeal Cartilages.

Note the relation of the shadow of the Epiglottis to the dorsum of the Tongue and the Hyoid Bone; and that the lower portion of the laryngeal part of the Pharynx is closed.

Fig. 2.—Lateral Radiograph of Shorter Neck (Man, aged 74), showing Cavities of Pharynx, Larynx and Trachea and ossified Laryngeal and Tracheal Cartilages.

Note that the laryngeal part of the Pharynx is closed but that there is air in the upper part of the Œsophagus.

PLATE LXII

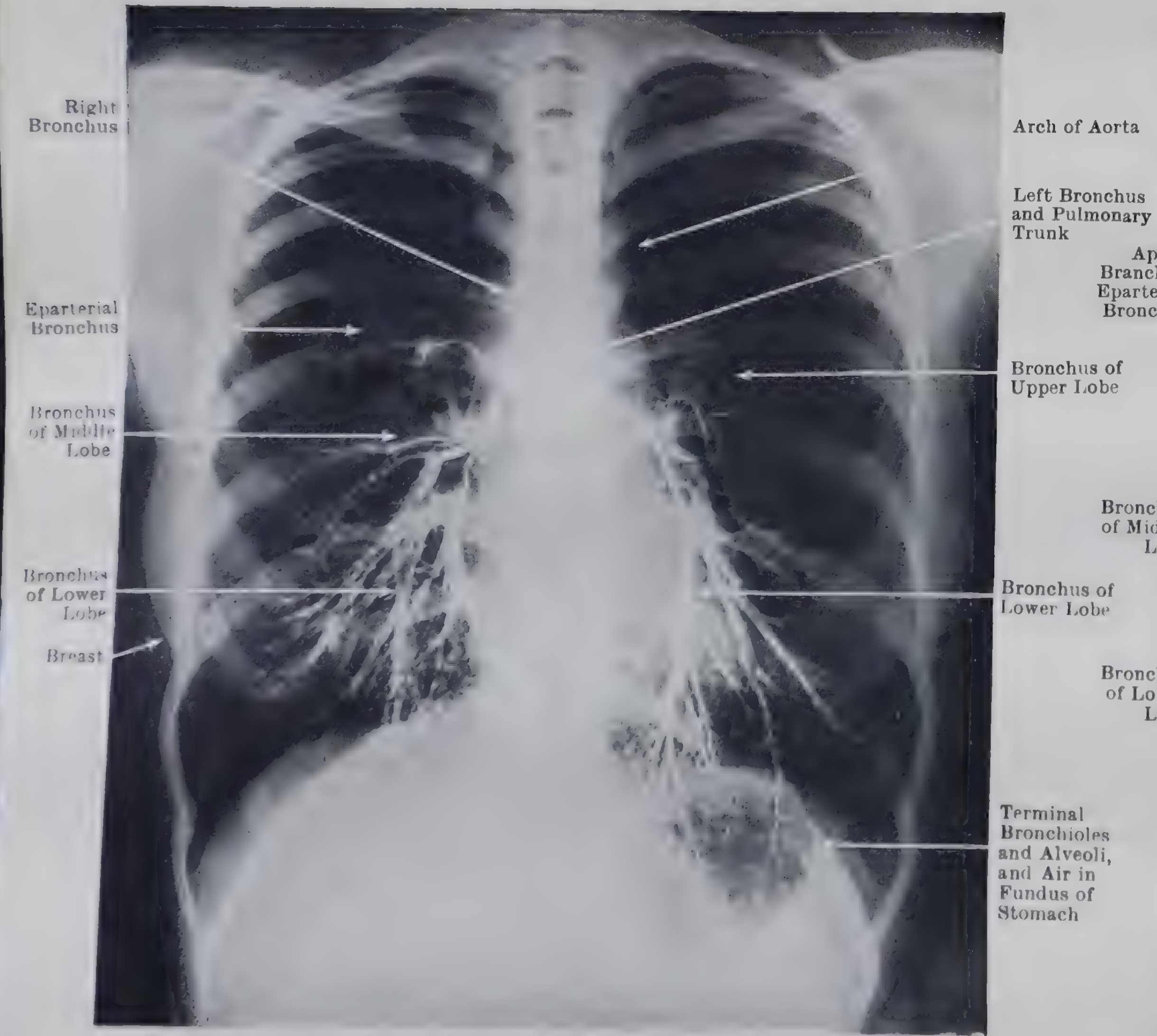

Fig. 1.—The Distribution of both Bronchi.

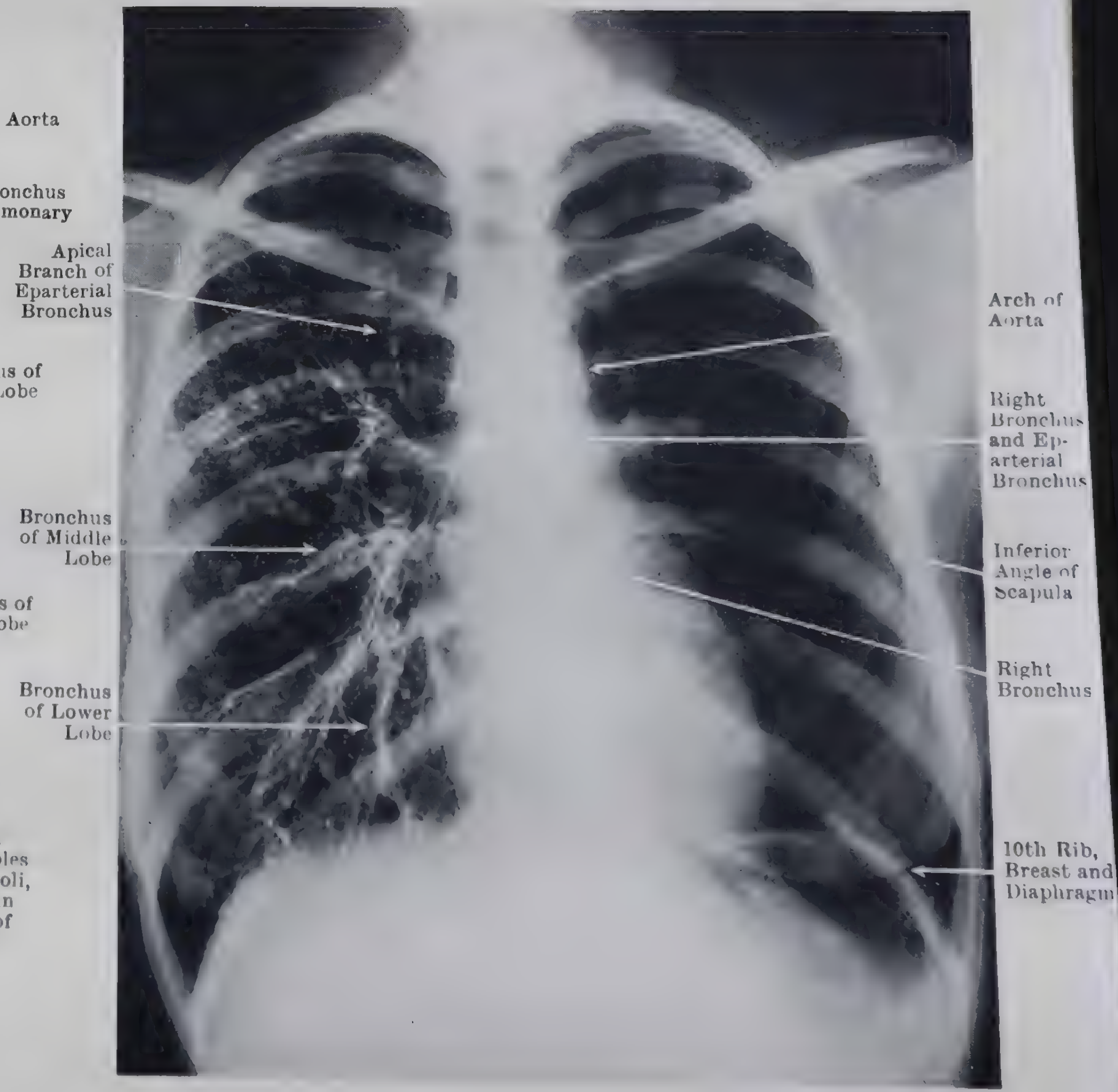

Fig. 2.—The Distribution of the Right Bronchus in more detail.

Plate LXII.—Anterior Radiographs of Thorax of Woman after injection of Lipiodol, showing the Distribution of the Bronchi. (Dr. Carleton B. Peirce, Royal Victoria Hospital, Montreal.)

For the distribution of the bronchi in relation to the broncho-pulmonary segments, see Fig. 604, p. 717.

FIG. 1.—LEFT ANTERIOR OBLIQUE TO SHOW THE RIGHT BRONCHUS AND ITS BRANCHES IN DETAIL.

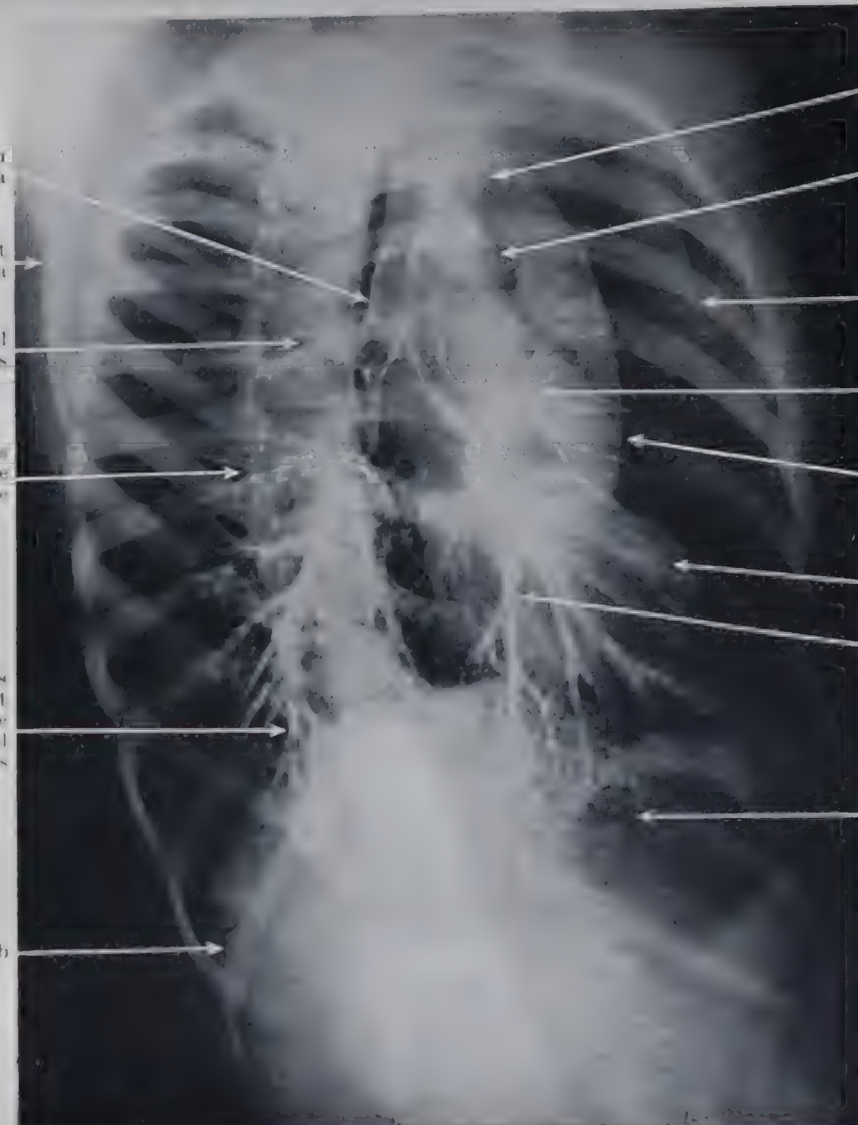

FIG. 2.—RIGHT ANTERIOR OBLIQUE TO SHOW THE LEFT BRONCHUS AND ITS BRANCHES IN DETAIL.

PLATE LXIII. ANTERIOR OBLIQUE RADIOGRAPHS OF THORAX OF WOMAN AFTER INJECTION OF LIPIODOL TO SHOW THE BRONCHI AND THEIR BRANCHES. (Dr. Carleton B. Peirce, Royal Victoria Hospital, Montreal.)

For the distribution of the bronchi in relation to the broncho-pulmonary segments, see Fig. 604, p. 717.

PLATE LXIV

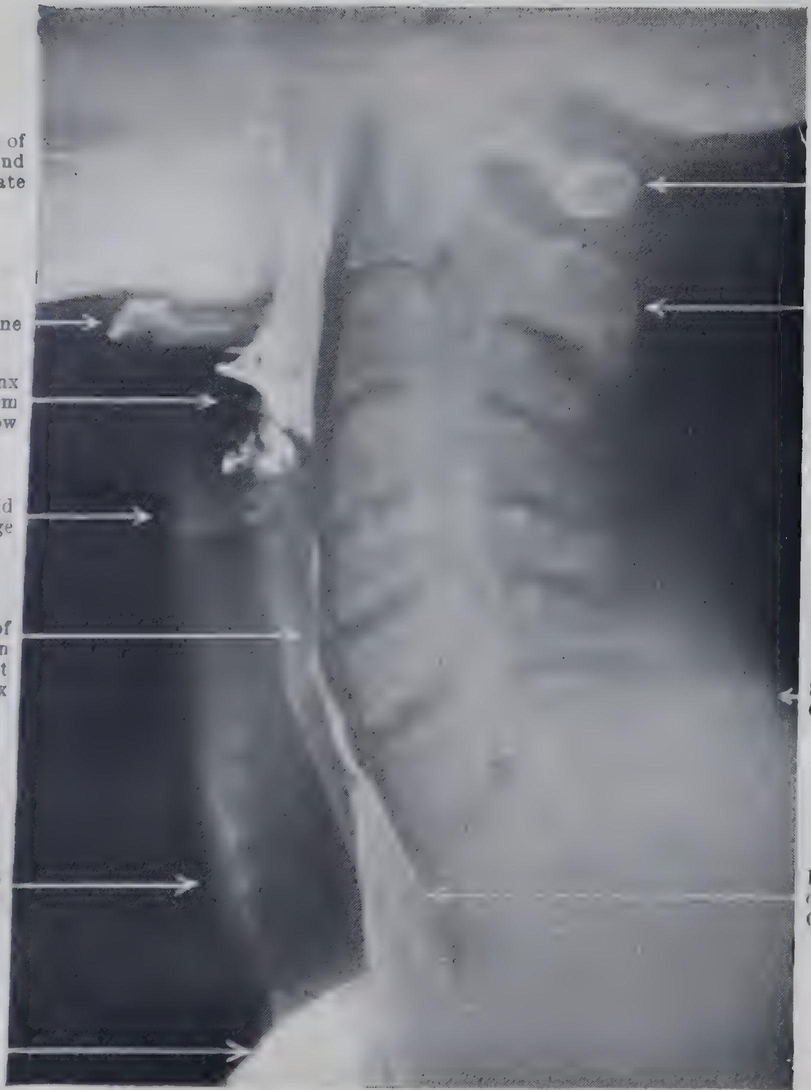

FIG. 1.—LATERAL RADIOGRAPH AS THE BARIUM PASSES INTO THE ŒSOPHAGUS.

Some barium remains in the oral pharynx and in the upper part of the laryngeal pharynx.

FIG. 2.—ANTERO-POSTERIOR RADIOGRAPH AS THE BARIUM PASSES INTO THE ŒSOPHAGUS.

Note the deviation of the œsophagus to the left.

PLATE LXIV.—RADIOGRAPHS OF NECK AND UPPER THORAX OF YOUNG W

[Facing p. 697

the thyroid cartilage to glide forwards (Negus, 1929). While this action does, in certain combinations with other muscles, increase the tension of the vocal folds, its chief function is to render the larynx as a whole more flexible in movements of the throat.

The **thyro-arytenoid muscle** forms a common mass with the vocal muscle, and the two can be separated only by artificial means.

It lies in the lateral wall of the larynx, medial to the lamina of the thyroid cartilage and lateral to the sinus of the larynx, the vocal muscle, and the crico-vocal membrane; its inferior border is in contact with the lateral crico-arytenoid muscle; its superior border extends farther upwards than the vocal fold and is in contact with the inferior border of the thyro-epiglottic muscle.

It **arises** from the inferior half of the medial surface of the lamina of the thyroid cartilage, close to the angle, and also from the lateral part of the crico-vocal membrane. The muscle-fibres pass backwards and upwards to be **inserted** into the lateral border and muscular process of the arytenoid cartilage; some of the fibres, however, turn round that cartilage and become continuous with the transverse arytenoid muscle.

The muscle, acting alone, would approximate the arytenoid cartilage to the thyroid and hence was formerly said to antagonize the crico-thyroid. But since it acts when the position of the arytenoid is stabilized by contraction of the crico-arytenoids and transverse arytenoid, the arytenoid cartilage obviously cannot move.

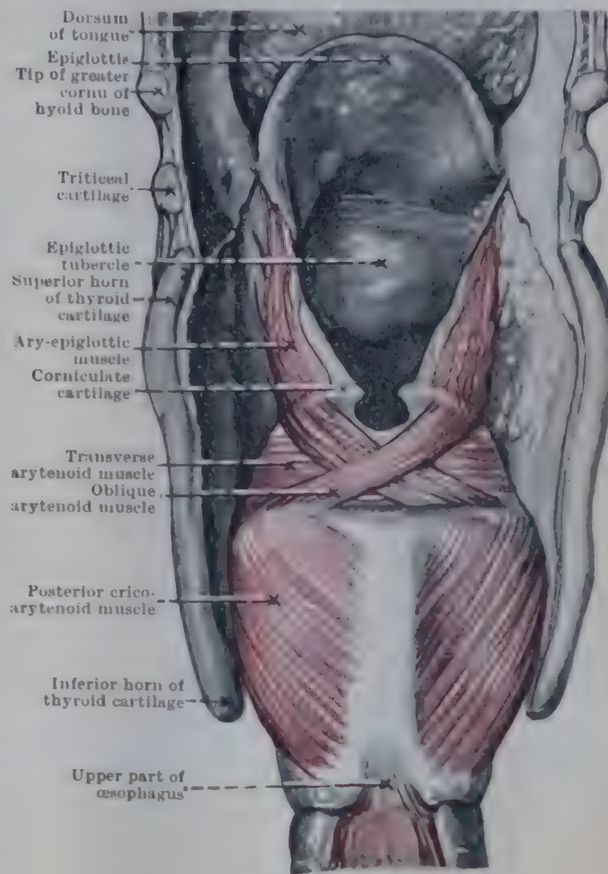

FIG. 588.—MUSCLES ON BACK OF LARYNX.

The thyro-arytenoid muscles narrow the vestibule of the larynx and force the vestibular folds into close contact; thus, they constitute a sphincter of the vestibule.

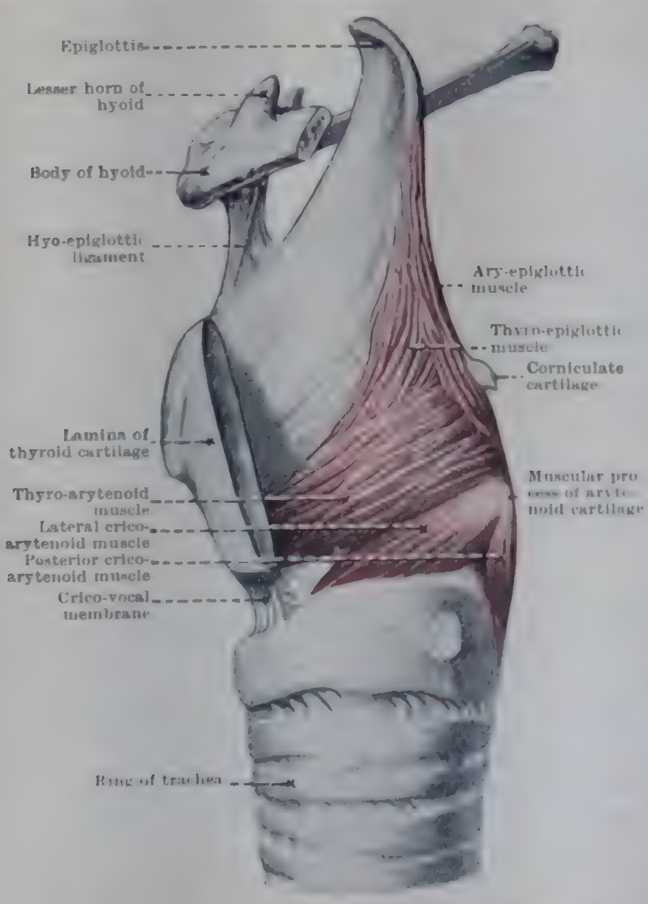

FIG. 589.—MUSCLES OF SIDE-WALL OF LARYNX.

The **vocal muscle** of each side is a triangular, somewhat prismatic muscle which forms a common muscular mass with the thyro-arytenoid. It is closely applied to the lateral aspect of the vocal ligament, and receives its prismatic form from that adaptation.

The vocal muscle **arises** from the inferior part of the angle between the two laminæ of the thyroid cartilage, and also from the corresponding vocal ligament, whence the fibres run backwards to be **inserted** into the lateral aspect of the vocal process and the depression on the antero-lateral surface of the arytenoid cartilage.

The muscle produces and adjusts tension throughout the vocal ligament and, with the assistance of the transverse arytenoid in approximating the vocal fold to its fellow of the opposite side, reduces the rima to a mere chink or even closes it altogether.

Each **posterior crico-arytenoid muscle** arises, by a broad origin, from the medial and inferior parts of the depression on the posterior surface of the lamina of the cricoid cartilage at the side of the median ridge. The fibres converge upwards and laterally to be **inserted** into the muscular process of the corresponding arytenoid cartilage. The highest fibres are short and nearly horizontal; they are inserted into the back of the muscular process. The intermediate fibres are the longest and are very oblique; they are inserted

direction and are inserted into the front of the muscular process in common with the lateral crico-arytenoid.

The posterior crico-arytenoid draws the muscular process of the arytenoid cartilage medially and backwards, swings the vocal process and the vocal fold laterally, and thereby opens the rima glottidis.

Each **lateral crico-arytenoid muscle arises** from the posterior half of the upper border of the arch of the cricoid cartilage, and also from the lateral part of the crico-vocal membrane. The muscle-fibres run backwards and upwards, and converge to be **inserted** into the anterior surface of the muscular process of the arytenoid cartilage. The muscle is commonly inseparable from the thyro-arytenoid muscle.

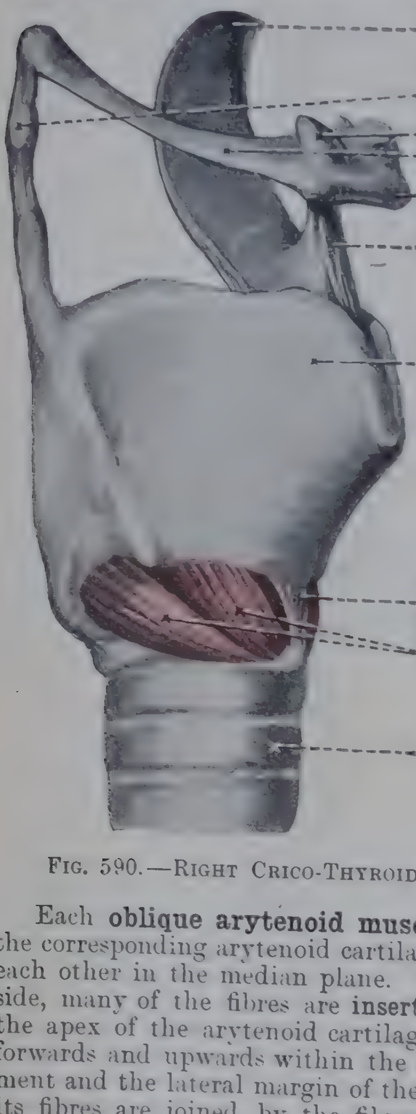

FIG. 590.—RIGHT CRICO-THYROID MUSCLE.

The lateral crico-arytenoid muscle draws the muscular process of the arytenoid cartilage forwards and laterally, turning the vocal process of the same cartilage medially, and approximating it to its fellow of the opposite side, thus assisting in the closure of the rima glottidis.

The **transverse arytenoid muscle** is an unpaired muscle which bridges the interval between the two arytenoid cartilages. The anterior surface of the muscle is in contact with the posterior surfaces of the arytenoid cartilages and, between them, with the mucous membrane of the larynx. Its posterior surface is partly concealed by the oblique arytenoid covered by the mucous membrane of the pharynx. The inferior border extends to the lamina of the cricoid cartilage, and its upper border does not quite reach the apices of the arytenoid cartilages.

The **attachments** of the muscle are to the posterior surface of the muscular process and the lateral edge of the arytenoid cartilage on each side. All the fibres run in a transverse direction, and some turn round the arytenoid cartilage to become continuous with the thyro-arytenoid.

The transverse arytenoid muscle approximates the arytenoid cartilages, thereby tending to close the rima glottidis.

Each **oblique arytenoid muscle arises** from the posterior part of the muscular process of the corresponding arytenoid cartilage. The two muscles proceed upwards and medially, and cross each other in the median plane. Reaching the apex of the arytenoid cartilage of the opposite side, many of the fibres are **inserted** there; others are joined by a fresh slip that arises from the apex of the arytenoid cartilage and forms with it the **ary-epiglottic muscle**, which extends forwards and upwards within the ary-epiglottic fold to terminate in the thyro-epiglottic ligament and the lateral margin of the epiglottic cartilage. As the muscle approaches the epiglottis its fibres are joined by the fibres of the thyro-epiglottic muscle and some fibres from the stylo-pharyngeus also are mingled with those of its upper border.

The oblique arytenoid and ary-epiglottic muscles form the sphincter of the laryngeal inlet.

Each **thyro-epiglottic muscle arises** from the medial surface of the lamina of the thyroid cartilage immediately above the origin of the thyro-arytenoid. The fibres run upwards and backwards to be **inserted** partly into the margin of the ary-epiglottic fold and partly into the lateral margin of the epiglottis, being intermingled with the fibres of the ary-epiglottic muscle.

The thyro-epiglottic muscle is part of the sphincter of the inlet of the larynx.

Growth-Alteration and Sexual Differences in Larynx.—A considerable amount of variation may be noticed in the size of the larynx in different people. It is quite independent of stature, and it explains to a great extent the difference in the pitch of the voice in different persons. But quite apart from those individual variations, there is a sexual difference in the size of the larynx. The larynx of a man is not only absolutely but also relatively larger than the larynx of a woman in all its diameters, more particularly in the antero-posterior diameter. To a large extent the increase is produced by strong development of the laryngeal prominence in men. The greater antero-posterior diameter of the male larynx necessarily implies a greater length of the vocal folds and a lower or deeper tone of the voice in men than in women.

In a new-born child the larynx is relatively large and, in comparison with the calibre of the trachea, very large. The epiglottis varies much in size at birth: it may be large or may be quite diminutive, and it is always soft in texture. The valleculæ and the piriform fossæ are so small as to be almost rudimentary. During the first six years of the child's

life great changes take place. The calibre of the trachea is much increased and the tracheal cartilages are stiffened. The epiglottis also grows considerably and becomes stiffer. The larynx itself grows at a slower rate, so that by the age of six years the calibre of the trachea is almost uniform in size with that of the larynx. As the larynx grows, the vocal folds increase in length and the vocal processes of the arytenoid cartilages become relatively shorter.

From the age of six years (or four years in well-developed children) till adolescence there is little growth in the larynx, but in the male at puberty renewed vigour of growth results in the comparatively large size of the larynx. At the same time the valleculæ and the piriform fossæ greatly increase in size in both sexes.

In a man who has been castrated when young, the larynx attains a size exceeding that of a woman only to a small degree, and the high pitch of the voice is retained.

Observation of Laryngeal Movements

When the cavity of the larynx is illuminated and examined with a laryngoscopic mirror, the parts which surround the inlet of the larynx, as well as the interior of the organ, come into view. Not only that, but when the vocal folds are widely separated it is possible to inspect the interior of the trachea as far as its bifurcation.

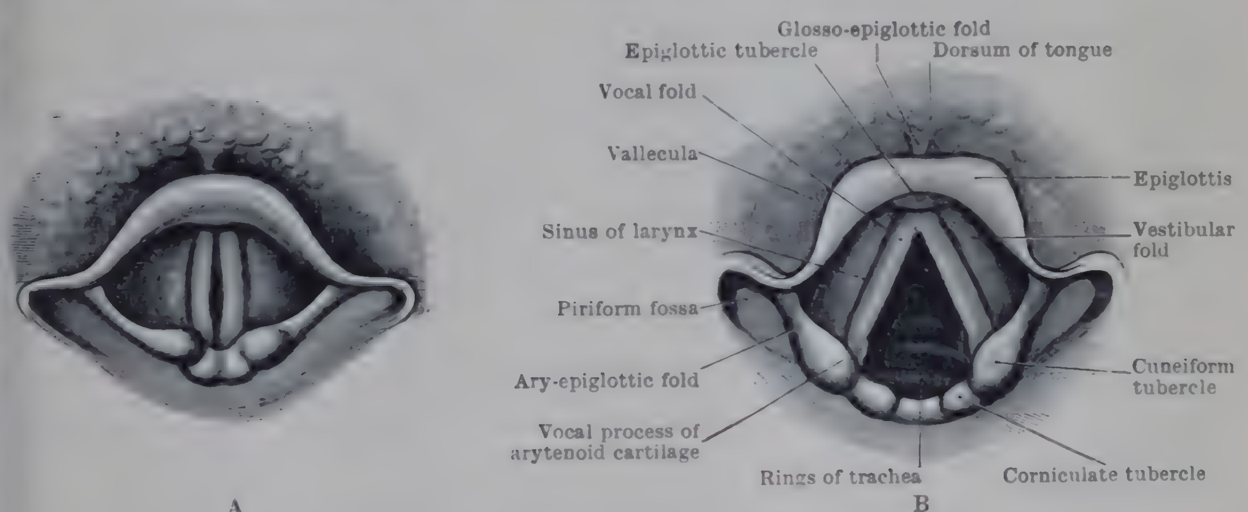

FIG. 591.—CAVITY OF LARYNX SEEN WITH LARYNGOSCOPE.

A. Rima glottidis closed. B. Rima glottidis widely opened.

In such an examination the upper border of the epiglottis is a conspicuous object. Behind this the bulging on the anterior wall of the vestibule, formed by the tubercle of the epiglottis, may also be seen. The glosso-epiglottic fold, with an epiglottic vallecula on each side of it, also is seen in the interval between the epiglottis and the back of the tongue. The ary-epiglottic folds—sharp and sloping – are clearly visible, and in the posterior portion of each can be seen the two prominent tubercles which are formed by the enclosed cuneiform and corniculate cartilages. Posterior to these tubercles is the back-wall of the pharynx; lateral to each fold a piriform fossa is visible. In the interior of the larynx the vestibular and vocal folds are easily recognized, and between them, on each side, the entrance to the laryngeal sinus appears as a dark line on the side-wall of the larynx. The vestibular folds are red and fleshy-looking; the vocal folds during phonation are tightly stretched and pearly white—the white colour being usually more apparent in the female than in the male. The outline and yellowish tinge of the vocal process, at the attachment of the vocal fold, and the outline of the anterior part of the base of the arytenoid cartilage may be seen. The vocal folds during inspiration are seldom at rest. In quiet breathing the lanceolate outline of the rima (Fig. 586, A) is very characteristic, widening during inspiration and narrowing during expiration. In forced or deep inspiration the rima opens widely, presenting a pentagonal outline (Fig. 586, B) and thus permitting the airway to be used to full capacity. It should be borne in mind that the picture afforded by the laryngoscope does not give a true idea of the level at which the different parts lie. The cavity is foreshortened, and its depth appears diminished.

On the X-ray screen the respiratory airway is viewed from the side (Plate LXI, p. 696). In quiet breathing the laryngeal vestibule is fairly widely open, though not dilated as in forced inspiration. The epiglottis and ary-epiglottic folds are conspicuous objects. The arytenoid cartilages with their surmounting corniculate cartilages are obvious, and sometimes the cuneiform cartilages also are visible. In a good soft-tissue radiograph the sinus itself, between vestibular and vocal folds, is clearly evident, and leading to this is the *philtrum* of the sinus, *i.e.*, a groove

pipe, though the form of its upper orifice—the laryngeal inlet—varies to conform to the shape of the laryngeal and oral parts of the pharynx where the vowel-sounds in speaking and singing are produced.

In speaking or singing the airway must be maintained unimpeded. It is in this connection that the epiglottic valleculæ (Pl. LXI, p. 696) become of service, for they act as reservoirs for drooling saliva during inhibition of swallowing movements. When the saliva is mixed with a radio-opaque substance, such as barium sulphate, the overflowing vallecula is observed to lose some of its fluid into the lateral gutter or piriform fossa (Fig. 583, Pl. LXIV, Fig. 1, p. 697), flow being directed thither by the slope of the epiglottis.

In mastication, a bolus of food in its semi-solid stage begins to slip past the shepherding veil of the soft palate and slides down the posterior third of the tongue towards or into the valleculæ. When the food has reached the epiglottis and valleculæ, swallowing can no longer be inhibited. The entire laryngeal vestibule can be seen to close, all air being eliminated as far down as the vocal folds. The orifice of the gullet is drawn upwards, and sometimes the column of the palato-pharyngeus (and possibly stylo-pharyngeus) muscle can be clearly seen producing this raising of the throat, by which action the laryngeal inlet, the epiglottis remaining erect, is drawn upwards to be partially overhung by the posterior third of the tongue. At this stage the soft palate rises to permit free passage of the bolus and to close the pharyngeal isthmus. The bolus then tips itself over the epiglottis. Some barium is observed to slip down the lateral food-gutter and some passes right over the closed laryngeal inlet. If, however, there is an inadvertent relaxation of the sphincter of the inlet, barium at once forms a momentary dark shadow, convex downwards in the upper vestibule; but it never descends past the vestibular folds. It is, indeed, immediately ejected by a convulsive cough.

The swallowing of fluid differs in no essential from the swallowing of solid food.

From these observations certain functions of the laryngeal muscles may be inferred :—

(*a*) For service *in swallowing*, there is evidently a sphincter of the laryngeal inlet (ary-epiglottics, oblique arytenoids) which may, in swallowing, be taken off its guard. At a lower level, there is a second sphincter (thyro-arytenoids) which obliterates the cavity of the vestibule and acts as a second line of defence. It is rare, indeed, for any foreign body to pass both guards; if this happens, bronchoscopic intervention is necessary. Also, in swallowing, the raising of the larynx under shelter of the tongue suggests activity of the thyro-epiglottic muscles. It should be noted that, in swallowing, the epiglottis is pressed against the base of the tongue; it does *not* fall backwards as a lid to the laryngeal inlet (Stuart & McCormick, 1892), notwithstanding a recent revival of this old notion (Johnstone, 1942). Indeed, the greater part of the epiglottis can be removed without any noticeable effect on the individual (Negus, 1929).

(*b*) *In breathing*, the size and shape of the rima glottidis are evidently controlled by the posterior and lateral crico-arytenoids and the transverse arytenoid.

(*c*) *In vocalization*, the crico-arytenoids probably fix the arytenoid cartilages. These act as bases from which the vocal muscles (a part of the thyro-arytenoid) produce the proper tension in the vocal folds, and the crico-thyroids tilt the larynx to conform with the adaptation of pharyngeal form to produce the vowel-sounds. Functional changes in the vocal folds have been examined radiographically by Mitchinson & Yoffey (1948).

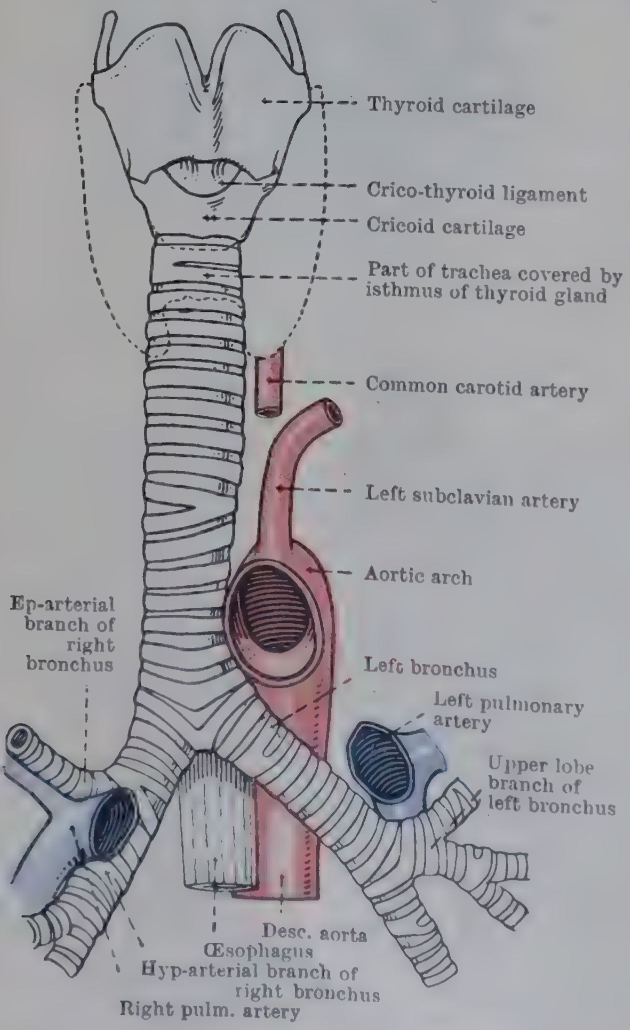

FIG. 592.—TRACHEA AND BRONCHI.
The dotted line gives the outline of the thyroid gland.

TRACHEA

The **trachea** or **windpipe** is kept patent by a series of 16 to 20 **C**-shaped cartilaginous bars embedded in its wall. Behind, where the bars are deficient, the tracheal wall is flattened. In the young child the cartilaginous bars are soft and readily compressible, so that they are felt through the skin with difficulty—a point which must be remembered in tracheotomy. The trachea begins at the lower border of the cricoid

cartilage, opposite the lower border of the body of the sixth cervical vertebra. From here it descends through the neck and the superior mediastinum of the thorax, and it ends, at the level of the upper border of the body of the fifth thoracic vertebra, opposite the sternal angle, by dividing into right and left bronchi. The length of the trachea in men is approximately four and a half inches (11-12 cm.), and in women half an inch less (10 cm.), but its length varies with the movements of the head and neck.

The bifurcation of the trachea is not fixed in position and neither are the roots of the lungs, but they undergo a downward shift during inspiration, as was demonstrated by Macklin (1932). Further, on changing from the recumbent to the upright posture the bifurcation commonly sinks to the level of the body of the sixth thoracic vertebra and it may go lower. In this it shares in the general lowering of the heart and other viscera caused by gravitational pull (Lachman, 1946).

About the middle of its length the trachea exhibits a slight expansion or dilatation, and close to the bifurcation it is again slightly expanded.

The differences in the calibre of the trachea are determined by the surrounding structures. The cervical part is narrowed owing to its being clasped by the thyroid gland, to which in goitre it becomes bound by a rather dense fascia—an attachment which maintains its patency when the cartilaginous bars have become locally absorbed. After operation there is danger of suffocation through collapse of the weak-walled "scabbard" trachea. On the left side of the trachea, near the bifurcation, there is an impression, sometimes strongly marked, due to contact with the aortic arch; on the right side, about its mid-length, there may be an impression for the innominate artery. In the dead subject the lumen of the tube is considerably greater than in the living. (For measurements of the trachea, see p. 704).

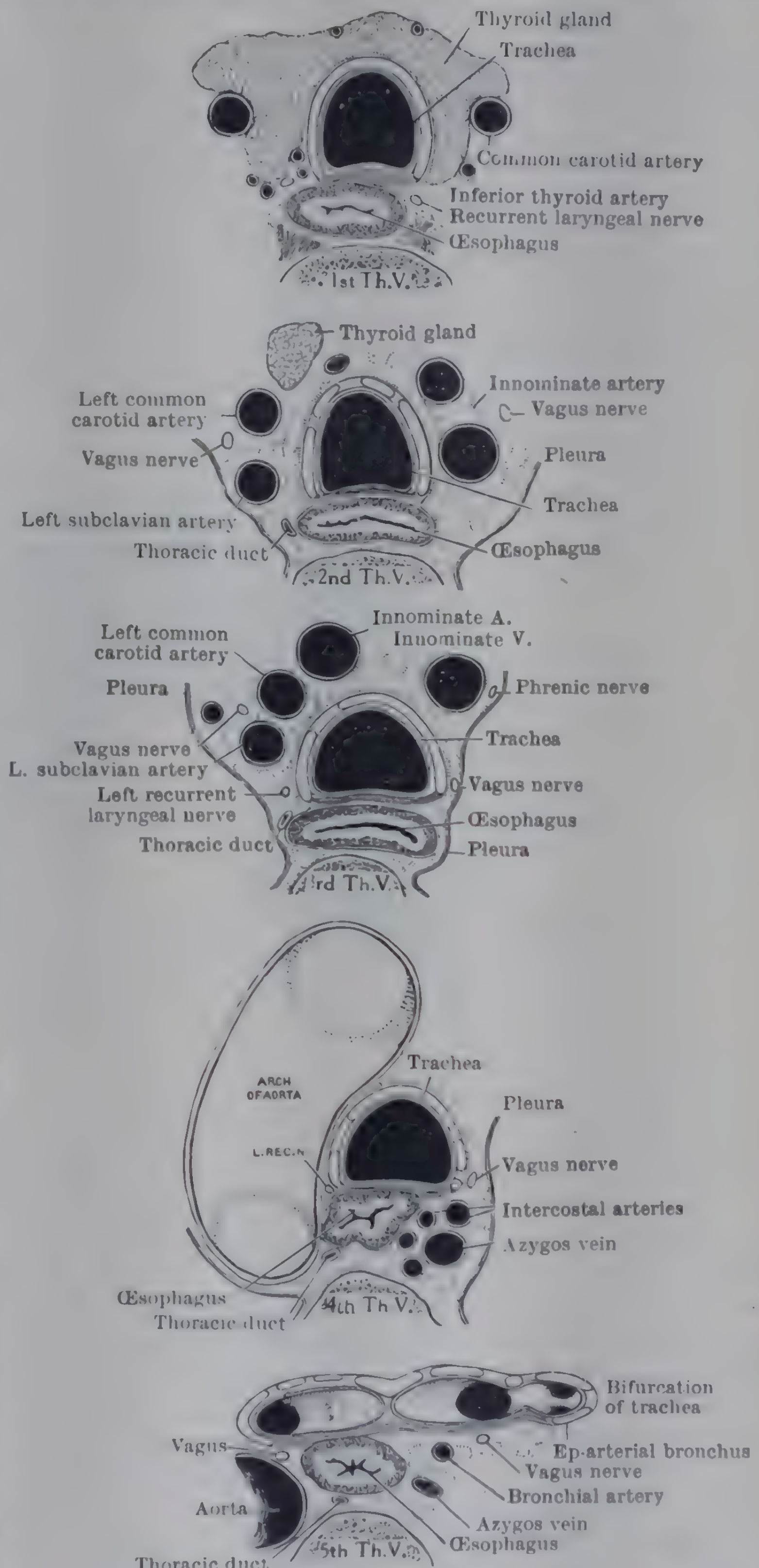

Fig. 593.—Transverse Sections through Trachea and Neighbouring Structures at Levels of Upper Five Thoracic Vertebræ. See also Fig. 509, p. 594.

recedes rapidly from the surface. This is due to its following the curvature of the vertebral column, from which it is separated by the œsophagus.

Relations of Trachea.—The **cervical part** of the trachea measures from 2 to $2\frac{1}{2}$ inches in length when the chin is held so that the face looks directly forwards, but its length is considerably increased when the head is thrown backwards. The thyroid gland clasps this portion of the trachea, the anterior surface of the second, third, and fourth rings being covered by the isthmus, and each side of the trachea as low as the fifth or sixth ring being covered by the lobe of the gland. On each side of the cervical part of the trachea lies the common carotid artery. The recurrent laryngeal nerve passes upwards in the groove between the trachea and the œsophagus. The trachea is separated from the bodies of the vertebræ by the œsophagus, which deviates slightly to the left as it passes downwards.

Overlying the isthmus of the thyroid gland there are two thin muscular strata composed of the sterno-hyoid and sterno-thyroid muscles, as well as the deep

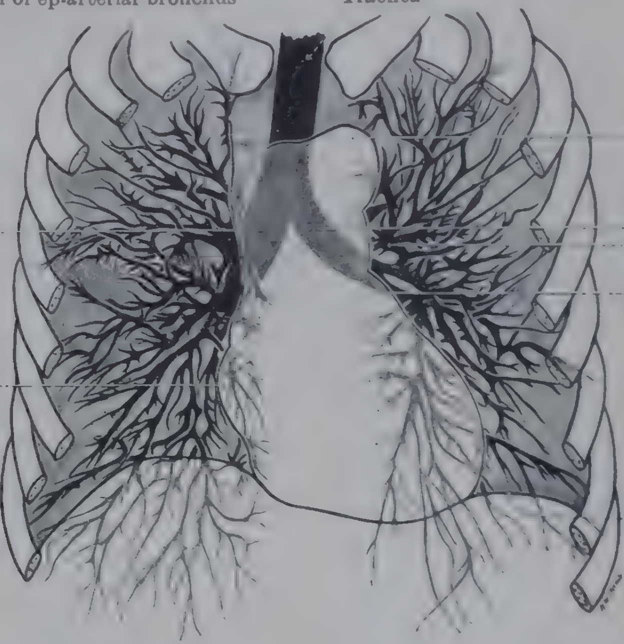

FIG. 594.—TRACING FROM RADIOGRAPH OF CHEST IN FULL INSPIRATION.

and superficial fasciæ and the skin. In the median plane of the neck, between the approximated margins of these muscles, there is a narrow diamond-shaped space within which the trachea is covered merely by the fasciæ and skin. It is important to note that in the lower part of the neck the deep cervical fascia is composed of two layers—a strong stratum applied to the anterior surface of the sterno-hyoid and sterno-thyroid muscles, and a weaker superficial layer stretching across between the two sterno-mastoid muscles. Deep to these muscular and fascial layers the inferior thyroid veins pass downwards and the inconstant thyroidea ima artery passes upwards on the anterior surface of the trachea. At the level of the upper border of the manubrium sterni the innominate artery crosses the trachea obliquely.

The **thoracic part** of the trachea is situated in the hinder part of the superior mediastinum and is separated from the bodies of the vertebræ by the œsophagus. On the anterior and lateral aspects of the trachea immediately above its bifurcation lies the deep cardiac plexus of nerves. At the level of the fourth thoracic vertebra the arch of the aorta clings first to the front of the trachea and then to its left side. The three great branches that spring from the arch ascend in contact with the trachea. Thus, the innominate and the left common carotid arteries lie at first on the front of the trachea, and then, gradually diverging as they proceed upwards, come to lie on its right and left sides respectively. In front of these arteries are the left innominate vein and the remains of the thymus. On the right side, the trachea has the right vagus descending obliquely backwards in contact with it, the azygos vein crossing it at the bifurcation, and the right mediastinal

pleura covering it. On the left side it is separated from the left mediastinal pleura by the arch of the aorta and the left subclavian artery, and the left recurrent laryngeal nerve ascends in the angle between it and the œsophagus.

Structure of Trachea.—The walls of the trachea and extrapulmonary bronchi consist of three not very distinct layers, named from within outwards (1) the mucous coat, (2) the submucous coat, and (3) the supporting coat.

The **mucous coat** is lined with a thick pseudo-stratified columnar *ciliated epithelium* which contains numerous mucus-secreting goblet-cells and rests upon a thick *basement membrane*. The cilia produce an upward movement of the mucus. This basement membrane separates the epithelium from a fibro-elastic *tunica propria*, which contains varying amounts of lymphoid tissue. The elastic fibres of the tunica propria form a dense network in which most of the fibres run longitudinally, and it is these longitudinal fibres that chiefly bring about the recoil of the trachea when stretched (Macklin, 1922). Although the elastic fibres permeate the whole tunica propria, they tend to be concentrated in its outer part and to separate it from the submucous coat.

The **submucous coat** is a fibro-elastic tube that contains numerous tubulo-acinous

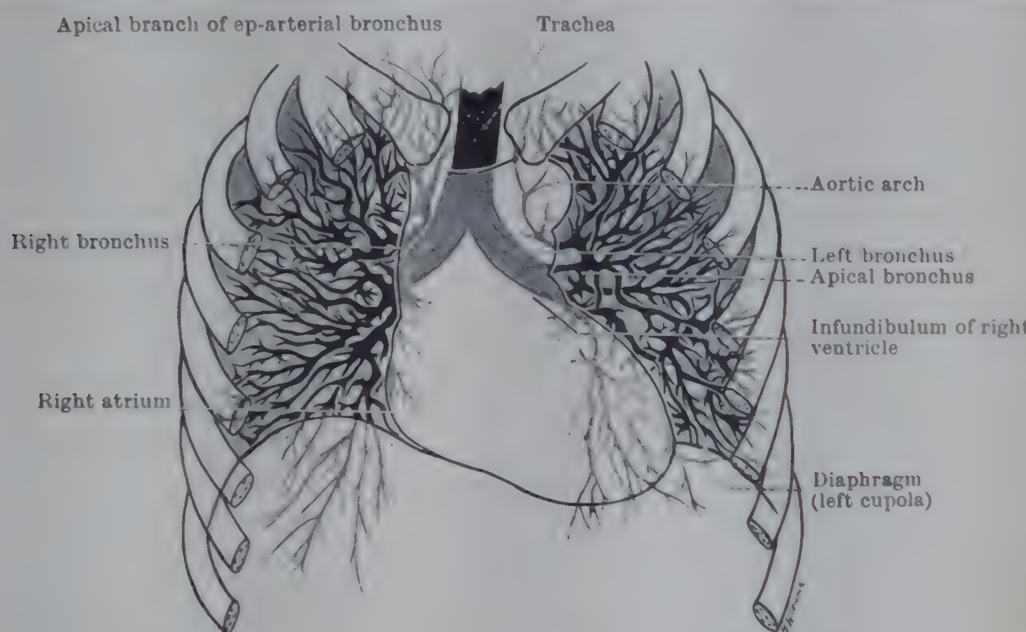

FIG. 595.—TRACING FROM RADIOGRAPH OF CHEST IN FULL EXPIRATION.

glands—both mucous and serous. The glands congregate in the intervals between the tracheal cartilages and also posteriorly; their ducts pass through the tunica propria and open on to the epithelial surface. The elastic fibres of this coat are rather scanty.

The **supporting coat**, though containing a fine network of elastic fibres, is dense and mainly composed of white collagenous fibres. It forms a complete tube which is continuous above with the perichondrium that invests the cricoid cartilage. Embedded in its substance are from 16 to 20 **C**-shaped rings of hyaline cartilage, open posteriorly where applied to the œsophagus and having rounded ends. These *tracheal cartilages* or rings prevent the trachea from collapsing during inspiration. It is common for a ring to branch and perhaps to join an adjacent ring. The coutour of a tracheal ring on cross-section is straight externally and convex internally—the opposite of a wedding-ring—hence each ring bulges slightly into the lumen of the trachea. The intervals between adjacent rings are narrower than the rings themselves. The lowest tracheal cartilage inclines downwards in the median plane in front, and from this median peak a cartilaginous strip is carried backwards in the fork between the two bronchi, forming a ridge called the *carina*. Bands of *plain muscle*, which mostly run transversely internal to the supporting coat, are attached to the inner surface of the tracheal cartilages near their free-ends. Many tubulo-acinous glands grow backwards beyond the submucous coat and come to lie between the muscle-fibres and external to them.

Vessels and Nerves.—The **arteries** of the trachea come chiefly from the *inferior thyroid* but also from the superior thyroid, internal mammary, and bronchial. Its **veins** end mainly in the *inferior thyroid* veins. Its **lymph-vessels** end in the *tracheo-bronchial* and *paratracheal* glands and also in the pretracheal, prelaryngeal, and lower deep cervical glands. Its nerves are the vagi directly and via their recurrent laryngeal branches, and

Measurements of Trachea.—The trachea is 4·0 cm. long at birth; 4·5 cm. between the firs[t] and second years; 5·7 cm. between the sixth and eighth years; 7·2 cm. between the fourteent[h] and sixteenth years; and from 9·0 to 15·0 cm. in the adult. Hence, from birth, through puberty to adult life it increases roughly from 4, through 6, to 12 cm. The sagittal and coronal diameter[s] of the trachea are: 5·7 × 6·0 mm. at birth; 9·4 × 8·8 mm. between the first and second years 10·4 × 11·0 mm. between the sixth and eighth years; 10·7 × 13·5 mm. between the fourteent[h] and sixteenth years; and 16·5 × 14·4 mm. in the adult. Hence, in general, the coronal diamete[r] is greater than the sagittal until adult life.

Until the third or fourth year the cross-sectional area of the trachea is equal to that of th[e] two main bronchi; but from then until the tenth year the bronchi have slightly the larger area after puberty the ratio continues to increase; and in the adult the sectional area of the tw[o] main bronchi is 40 per cent greater than that of the trachea (Engel, 1947).

BRONCHI

The two main or primary **bronchi** proceed obliquely infero-laterally from the bifurcation of the trachea, each towards the hilum of the corresponding lung. Like the trachea, they are kept permanently patent by the C-shaped cartilages in their walls. The two bronchi differ from each other in length, in width, and in direction (Figs. 592, 594, 606).

The first collateral branch of the right bronchus (the upper lobe bronchus) arises 1 inch or more from the trachea; whereas that of the left bronchus arises 2 inches or less from the trachea. There are from six to eight cartilages in the right bronchus and from nine to twelve in the left. The right bronchus is wider than the left in the proportion of 100 to 78·4, and it takes a more vertical course. It therefore lies more in the line of the trachea: and to this, as well as to its greater width, is due the greater tendency of foreign bodies to lodge in the right bronchus. The average angle formed by the right bronchus with the median plane is 24·8°, whereas the average angle formed by the left bronchus is 45·6°. The more horizontal course of the left bronchus is probably determined by the bulging of the heart to the left side of the median plane.

Relations of the Bronchi.—A cluster of tracheo-bronchial lymph-glands occupies the angle between the bronchi, and along each bronchus an irregular chain of glands is carried to the hilum of the lung. On the posterior surface of each bronchus the vagus nerve breaks up into the posterior pulmonary plexus. Arching above the right bronchus, from behind forwards, is the vena azygos; whilst arching above the left bronchus, from before backwards, is the arch of the aorta. In its course laterally and downwards the left bronchus crosses the anterior surfaces of the œsophagus and descending thoracic aorta. The left pulmonary artery crosses in front of the left bronchus above its first collateral branch and, after turning round its lateral side, runs along its posterior surface (Fig. 606). All branches of the left bronchus, therefore, lie below the left pulmonary artery and may, in consequence, be termed **hyp-arterial**. The right pulmonary artery, on the contrary, crosses in front of the stem of the right bronchus below its first collateral branch. This branch may, therefore, be termed the **ep-arterial bronchus**, but all the others are classified as hyp-arterial.

Structure of Extrapulmonary Bronchi.—This is identical with the structure of the trachea.

Vessels and Nerves.—The **arteries** are the bronchial arteries (p. 720). The **bronchial veins** end in the azygos and upper hemiazygos veins. The **lymph-vessels** end in the broncho-pulmonary, tracheo-bronchial, and paratracheal glands. The **nerves** come from the vagus and sympathetic via the pulmonary plexuses.

Radiographic Examination of Bronchi (see p. 721, Pls. LXII, LXIII, p. 696 and Figs. 59[4] and 595).

THORACIC CAVITY

The **cavity of the thorax** is the space above the diaphragm enclosed by the ribs. It contains (*a*) the two lungs, each in its pleural coverings, and (*b*) a thick, median mass of tissue, called the *mediastinum*, interposed as a septum between the lungs and containing the heart. The **thoracic inlet** is the kidney-shaped space bounded by the first thoracic vertebra behind, the manubrium in front, and the first ribs and their cartilages at the sides (Fig. 597). The **thoracic outlet**, closed by the diaphragm, is bounded by the last thoracic vertebra behind, the xiphi-sternal junction in front, and the twelfth ribs and the last six costal cartilages at the sides (p. 147).

PLATE LXV

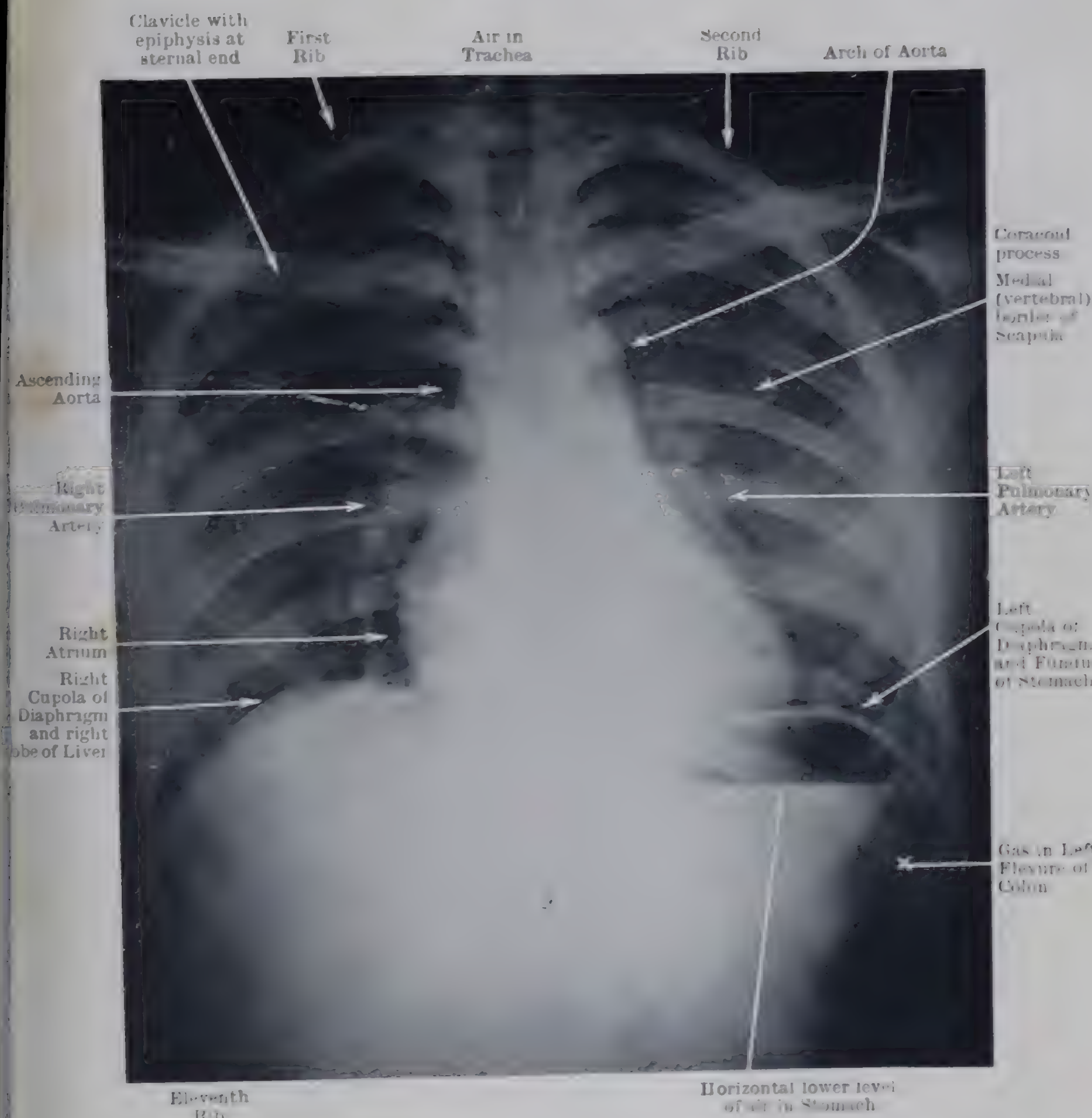

PLATE LXV.—ANTERIOR RADIOGRAPH OF THORAX OF YOUTH AGED 18, IN POSITION OF SEMI-INSPIRATION.

Compare with Plates LXVI, (inspiration) and LXVII, p. 720 (expiration), noting the differences in level of the Diaphragm and in the shape of the Heart. Cf. also Plates LXII, p. 696 and LXVIII, Fig 1, p. 721.

PLATE LXVI

PLATE LXVI.—ANTERIOR RADIOGRAPH OF THORAX OF YOUNG MAN IN POSITION OF FULL INSPIRATION.

Compare with Plate LXVII, p. 720, noting the descent of the Diaphragm, the narrowing and better definition of the whole mediastinal shadow (including the Heart) and the more horizontal position of the Ribs.

The dimensions of the thoracic cavity depend upon the phase of respiration in which they are measured (pp. 354, 454).

MEDIASTINUM

The **mediastinum** is a thick mass of tissue that forms a septum between the lungs and extends from the vertebral column to the sternum. It contains:—the heart enveloped in its pericardium; the thoracic aorta with the great vessels that spring from its arch; the pulmonary trunk; the great veins in the neighbourhood of the heart; the thymus or its remains together with lymph-glands and lymph-vessels; the trachea, œsophagus, and thoracic duct; the vagi, left recurrent laryngeal, cardiac, and phrenic nerves. Owing to the bulging of the heart to the left side and to the position of the thoracic aorta on the left of the median plane, the mediastinum encroaches on that side and the left lung is reduced in width. It is customary to divide the mass of tissue arbitrarily into four parts, termed the superior, anterior, middle, and posterior mediastina, according to their relations to the pericardium.

The **superior mediastinum** is that part which lies above the pericardium. Its boundaries are as follows:—*Anteriorly*, the manubrium sterni, with the attached sterno-hyoid and sterno-thyroid muscles; *posteriorly*, the bodies of the first four thoracic vertebræ; *below*, an imaginary plane which extends from the disc between fourth and fifth thoracic vertebræ to the manubrio-sternal joint; *laterally*, the mediastinal pleura.

The superior mediastinum is crossed by strands of fibrous tissue which bind the manubrium loosely to the pericardium over the roots of the great vessels. This fibrous tissue, termed the *superior sterno-pericardial ligament*, has significance only in persons afflicted with an adherent pericardium (Pick's disease).

The structures in the superior mediastinum are: (1) the aortic arch and the three great arteries that spring from it; (2) the innominate veins and part of the superior vena cava; (3) the trachea, œsophagus, and thoracic duct; (4) the phrenic, vagus, and cardiac nerves, and the left recurrent laryngeal nerve; (5) the thymus or its remains.

The **middle mediastinum** lodges the pericardium and its contents, and also the phrenic nerves with their accompanying vessels which lie outside the pericardium.

The **anterior mediastinum** consists of fibro-areolar tissue between the pericardium and the body of the sternum. It is invaded by the pleural sacs which approach each other on the anterior aspect of the pericardium. In the anterior mediastinum there are a few lymph-glands, some lymph-vessels, and minute twigs from the internal mammary artery. Like the superior mediastinum, it is crossed by fibrous strands which loosely bind the upper end of the xiphoid process to the pericardium. This fibrous tissue is the *inferior sterno-pericardial ligament*—significant only in adherent pericardium.

The **posterior mediastinum** is situated behind the pericardium and the diaphragm. It is a downward prolongation of the hinder part of the superior mediastinum, and many of the structures in the one are continued into the other. It is bounded *anteriorly* by the pericardium and the vertical part of the diaphragm; *posteriorly*, by the bodies of the last eight thoracic vertebræ; and *laterally*, by the mediastinal pleura. It contains the descending thoracic aorta, the posterior intercostal arteries, the azygos and hemiazygos veins, the thoracic duct, and the œsophagus with the two vagi.

Varying and Variable Positions of Mediastinal Viscera.—*In the cadaver* lying on its back in the dissecting room, the thorax is in the position of full expiration, the diaphragm being relaxed is pushed cranially and dorsally by the weight of the abdominal viscera and is pulled in the same directions by the elastic recoil of the lungs. The large arteries of the mediastinum are decreased in length and calibre due to the absence of the dilating force of the blood-pressure. *In life*, however, the positions of the mediastinal viscera as revealed by X-rays, vary with the position of the diaphragm, with the body-build, and with age. Thus, the diaphragm descends during inspiration and the pericardial sac, being attached to it, descends too, taking

with it the heart and the aortic arch, and the bifurcation of the trachea descends also. On changing from the supine to the erect posture there is a similar sequence of descents due to gravitational pull. On the other hand, if the abdominal muscles are in contraction or if the abdomen is distended (*e.g.*, due to a full gastro-intestinal canal, a large liver, or pregnancy) the diaphragm will stand high. Those whose body-build is of the tall, thin, slender type have a low diaphragm; whereas, those who are short, stout, and stocky have a high one. With increasing age the viscera tend to sink lower (Lachman, 1946).

When the living subject stands erect, leans forward, or lies prone, his heart lies close behind the sternum and costal cartilages. The anterior mediastinum is accordingly reduced and the posterior mediastinum increased in the antero-posterior plane, the œsophagus is withdrawn from the vertebral column and the retro-œsophageal pleural recesses (p. 709) are opened. When the subject reclines or is recumbent, his heart recedes from the anterior chest-wall and, in consequence, the anterior mediastinum is increased while the posterior mediastinum is reduced in the antero-posterior plane and the œsophagus is applied to the vertebral column.

For other variations in the shape and position of the heart see page 1240.

PLEURÆ

Each lateral portion of the thoracic cavity is lined with a membrane, called the **pleura**, which extends over costo-sternal, diaphragmatic, and mediastinal surfaces, thereby forming a closed bag or sac around the *pleural cavity.* The lung in embryonic life buds off from the alimentary tract and, as it grows, pushes before it a portion of the mediastinal pleura, which is thus invaginated into the potential pleural cavity and becomes the *visceral* or *pulmonary pleura* in contradistinction to the *parietal pleura*, which lines the bounding walls.

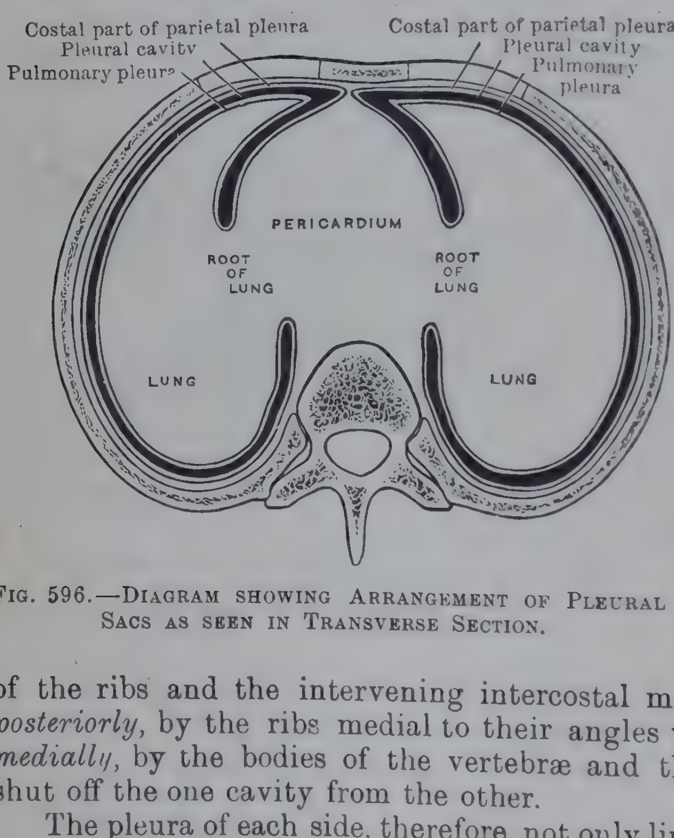

FIG. 596.—DIAGRAM SHOWING ARRANGEMENT OF PLEURAL SACS AS SEEN IN TRANSVERSE SECTION.

Each **pleural cavity** is bounded *inferiorly* by the corresponding cupola of the diaphragm; and as the right cupola rises to a higher level than the left, the right pleural cavity is less deep vertically than the left. *Anteriorly* the wall of each cavity is formed by the costal cartilages and the sternum; *laterally*, by the shafts of the ribs and the intervening intercostal muscles as far as the costal angles; *posteriorly*, by the ribs medial to their angles with the intervening muscles, and *medially*, by the bodies of the vertebræ and the mediastinum, which completely shut off the one cavity from the other.

The pleura of each side, therefore, not only lines the corresponding pleural cavity, but, at the pulmonary root, is prolonged on to the lung so as to give it a complete investment. The inner surface of the pleura (*i.e.*, the free surface facing the pleural cavity) is coated with squamous mesothelium and presents a smooth, glistening, and polished appearance; further, it is moistened with a small amount of serous fluid. In consequence of this, the surface of the lung covered with pulmonary pleura can glide on the wall of the cavity, lined as it is with parietal pleura, with a minimum of friction. In the pathological condition known as pleurisy the inner surface of the pleura is roughened with inflammatory exudate, and "friction sounds" are heard when the ear is applied to the chest.

The **pulmonary pleura** is comparatively thick in man. It lines the fissures of the lungs and thus completely separates the different lobes of the lungs from

one another. A tube or sleeve of pleura connects the pulmonary pleura with the mediastinal pleura. The upper two-thirds of this sleeve envelop the root of the lung; the lower third, with its walls in apposition, forms the pulmonary ligament (Figs. 602, 603).

The **parietal pleura** lines the wall of the cavity in which the lung lies, and is appropriately divided into cervical, costal, diaphragmatic, and mediastinal portions.

The **cervical pleura** (Fig. 597) rises into the root of the neck, through the inlet of the thorax, and forms a dome-shaped roof for the pleural cavity. Its highest point or summit reaches the level of the neck of the first rib; but, owing to the great obliquity of the first costal arch, this point is from one to two inches above its anterior extremity, and from a half to one and a half inches above the medial third of the clavicle. The cervical pleura is protected on the lateral side by the scalenus anterior and scalenus medius muscles, whilst the subclavian artery, arching laterally, lies in a groove on its medial and anterior aspects a short distance below its summit. At a lower level the innominate vein also lies upon its medial and anterior aspects.

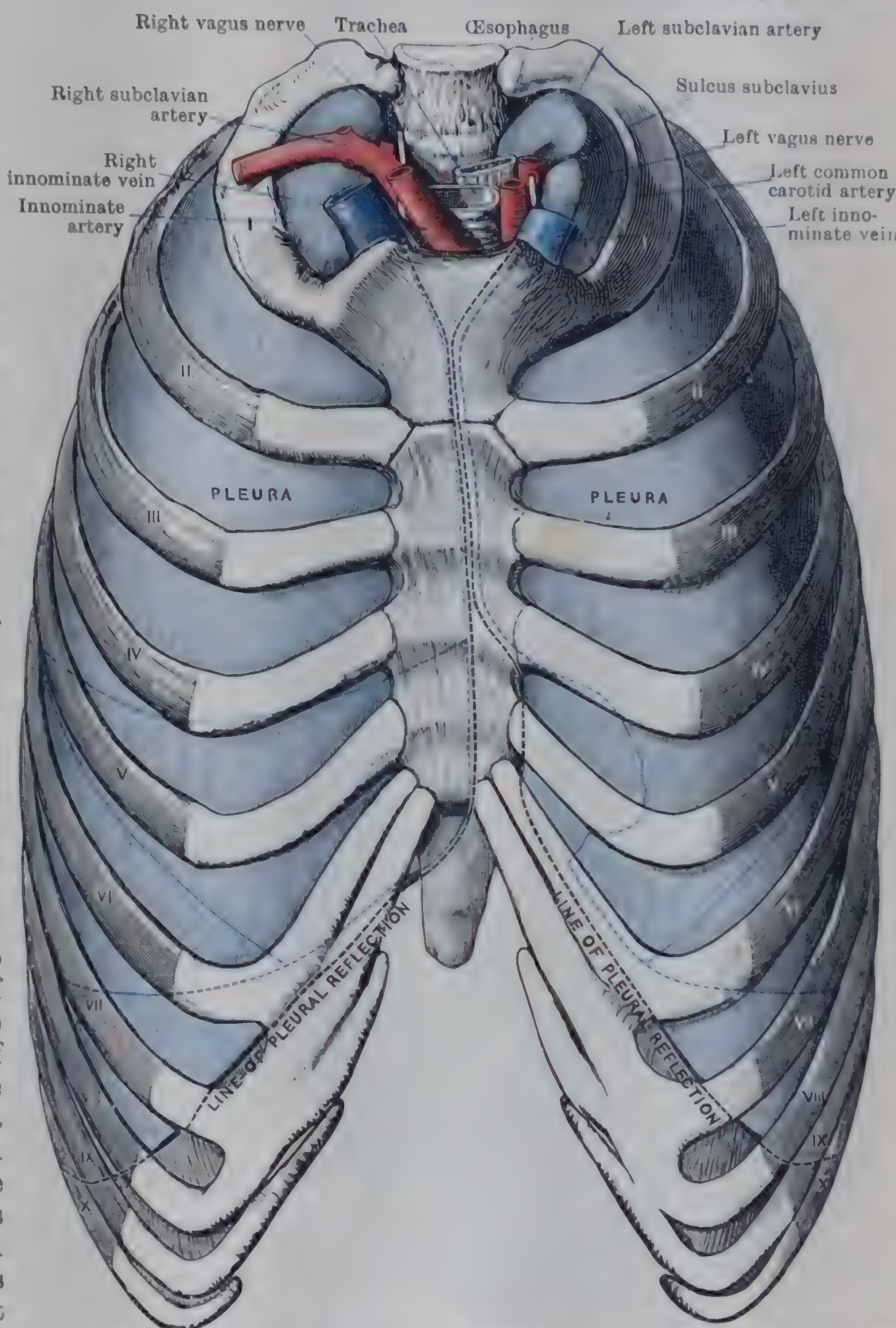

FIG. 597.—PLEURAL SACS IN SUBJECT HARDENED BY FORMALIN INJECTION, TO SHOW THEIR RELATIONS TO THORACIC WALL AND INLET. The anterior and diaphragmatic lines of pleural reflexion are exhibited by black dotted lines, whilst the outlines of the lungs and their fissures are indicated by the blue lines.

The cervical pleura is strengthened by the suprapleural membrane (Sibson's fascia)—an aponeurotic expansion attached to the inner margin of the first rib and derived from a small muscular slip (scalenus pleuralis) that arises from the transverse process of the seventh cervical vertebra.

The **costal pleura** is the strongest and thickest part of the parietal pleura. It lines the inner surfaces of the costal arches (*i.e.*, ribs and their costal cartilages) and

of the intervening muscles. In front it reaches the sternum, whilst behind it passes from the ribs over the sides of the bodies of the vertebræ. It is easily detached from the parts that it lines, except as it passes from the heads of the ribs on to the vertebral column. There, it is rather tightly bound down.

The **diaphragmatic pleura** covers the portion of the thoracic surface of the diaphragm that lies lateral to the base of the pericardium, but it does not dip down to the bottom of the narrow interval between the thoracic wall and the diaphragm. In other words, a strip of the thoracic surface of the diaphragm adjoining its costal attachment is free (Fig. 599).

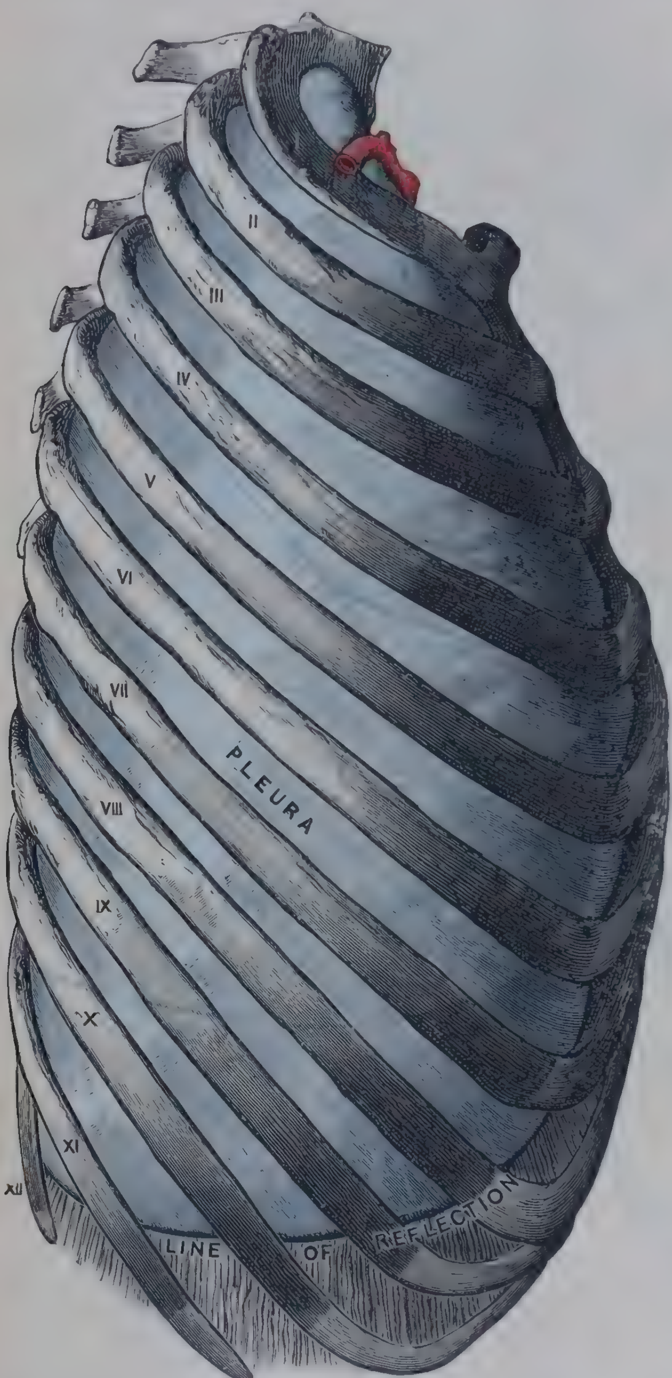

FIG. 598.—LATERAL VIEW OF RIGHT PLEURAL SAC IN SUBJECT HARDENED BY FORMALIN INJECTION. The blue lines indicate the outline of the right lung, and also the position of its fissures.

The **mediastinal pleura** covers the lateral face of the mediastinum and the structures contained in it. It is continuous with the pulmonary pleura around the root of the lung (Figs. 596, 602). It is continuous with the costal pleura both anteriorly and posteriorly—anteriorly, along the abrupt **line of sternal reflexion**; posteriorly, along the bodies of the thoracic vertebræ. Although posteriorly there is no sharp delimitation of mediastinal from costal pleura, the indefinite junction of the two is called the **vertebral line of pleural reflexion** (Fig. 596). Inferiorly the mediastinal pleura is continuous with the diaphragmatic pleura at the base of the pericardium.

Above the root of the lung the mediastinal pleura passes directly from the sternum to the vertebral column. In this region the *left mediastinal pleura* is applied to the arch of the aorta and the left phrenic and vagus nerves; to the left superior intercostal vein and the left common carotid and left subclavian arteries; to the œsophagus and the thoracic duct. The *right mediastinal pleura* is applied, above the root of the lung, to the upper part of the superior vena cava, to the lower part of the right innominate vein and the end of the left; to the innominate artery; to the vena azygos as it hooks forwards above the bronchus; to the right vagus and phrenic nerves; and to the right side of the trachea.

Below and in front of the root of the lung the mediastinal pleura covers the pericardium (pericardial pleura) and is rather firmly attached to it. As the phrenic nerve descends along the side of the pericardium, it also is covered with pleura. As already stated, the mediastinal pleura gives an investment to the root of the lung and becomes continuous with the pulmonary pleura.

The two layers of pleura that invest the root of the lung come into

apposition with each other below the root, and are prolonged downwards as a fold termed the **pulmonary ligament**. This fold stretches from the pericardium to the inferior part of the mediastinal surface of the lung, and ends inferiorly in a free border. Lymph-vessels from the pleura of the lower lobe pass between the layers of this fold to reach the posterior mediastinal lymph-glands.

Behind the root of the lung and the pulmonary ligament the mediastinal pleura on the *right side* passes over the œsophagus to clothe, in part, the anterior aspect of the vertebral bodies, whilst on the *left side* it passes over the descending aorta in order to gain the left side of the vertebral bodies, and just above the diaphragm it covers the left side of the œsophagus. At this level, then, the œsophagus is covered on both sides with a layer of pleura, and the two layers meet between the œsophagus and the aorta to form a thin partition between the right and left pleural cavities. This partition, formed by the meeting of the right and left pleurae behind the œsophagus, commonly extends upwards to the level of the fourth thoracic vertebra. In consequence, there are commonly right and left *retro-œsophageal pleural recesses*, occupied by lung. These are demonstrable by X-rays, particularly during inspiration and with the subject erect, for the recesses deepen then. The right recess may cross the median plane (Lachman, 1946).

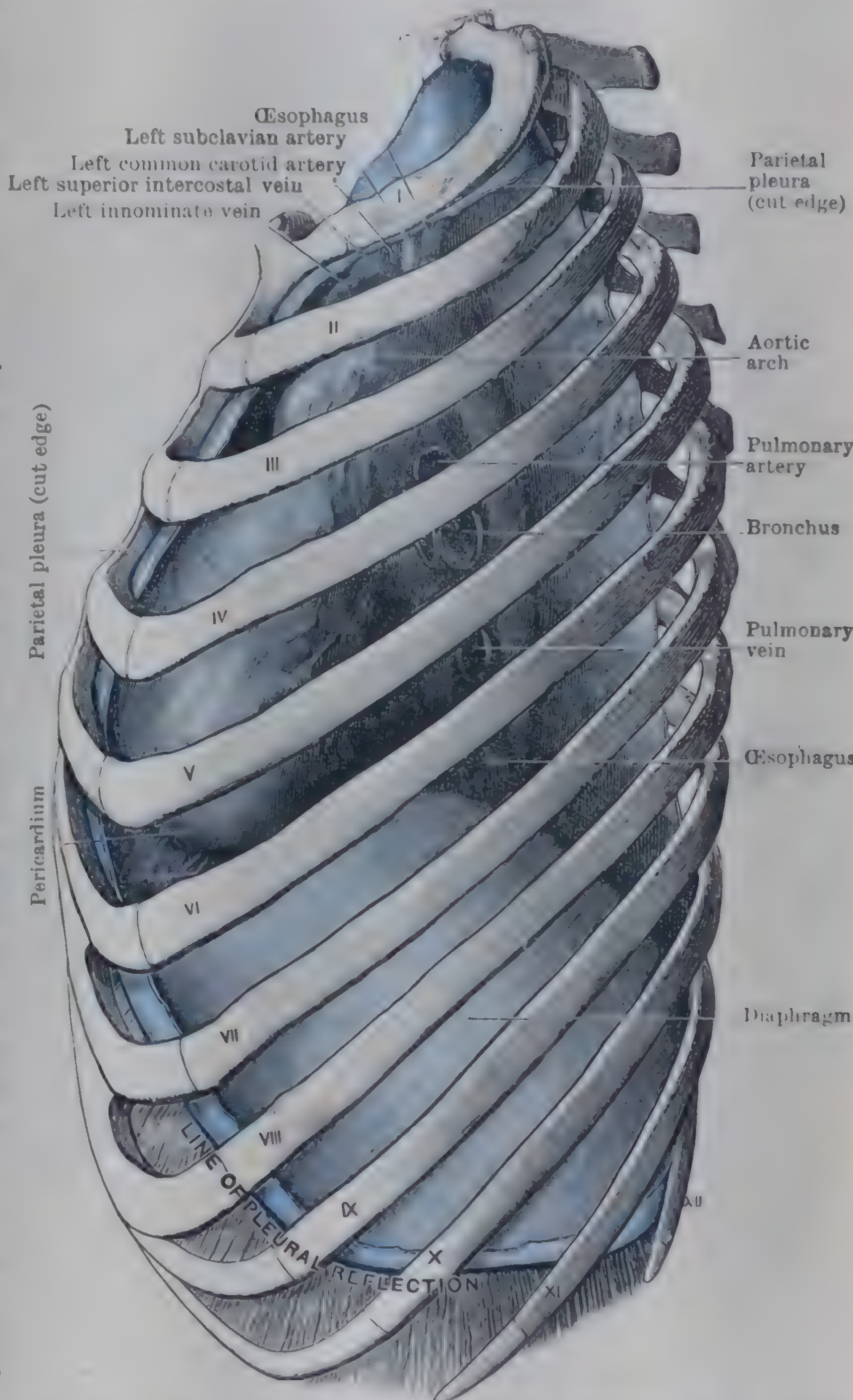

FIG. 599.—LEFT PLEURAL SAC IN SUBJECT HARDENED BY FORMALIN INJECTION. The sac has been opened by the removal of the costal part of the parietal pleura; and the lung also has been removed to display the mediastinal pleura.

Lines of Pleural Reflexion.—The pleural cavities are not symmetrical. The left is narrower than the right, and it thus happens that the lines of pleural reflexion do not accurately correspond on the two sides of the body. The vagueness of the vertebral line of reflexion has been mentioned (p. 708). The sternal and diaphragmatic reflexion-lines are subject to variations in different subjects.

In the vicinity of the manubrium sterni the two pleural sacs are separated from each other by an angular interval. The lines of reflexion at the inlet of the thorax pass behind the sterno-clavicular joints. From these points the lines, as they are traced downwards, converge behind the manubrium, until at last they meet a short distance above its inferior

border. There the two sacs come into contact with each other, and the lines of reflexion coincide. Thence they proceed downwards, on the back of the body of the sternum, with a slight deviation to the left of the median plane, until a point immediately above the level of the sternal attachments of the fourth costal cartilages is reached, and there the two sacs part company. The line of reflexion of the *right pleura* is continued downwards in a straight line to, or just above, the xiphoid process, where the sternal reflexion-line passes into the right diaphragmatic reflexion-line. Opposite the sternal attachment of the fourth costal cartilage, the reflexion-line of the *left pleura*, parting from the right reflexion-line, inclines infero-laterally to a point situated 11 mm. lateral to the sternal end of the 6th intercostal space, and there passes into the left diaphragmatic reflexion-line. In this descent the reflexion-line passes 6 mm. medial to the sternal margin at the level of the 4th intercostal space and 2 mm. lateral to the sternal margin at the level of the 5th intercostal space. The foregoing are average positions: thus, 70 per cent of 95 cases were found to lie within 1 cm. of this line, and the total range of the position of the line at the levels of the 5th and 6th interspaces is 5 cm. (Woodburne, 1947).

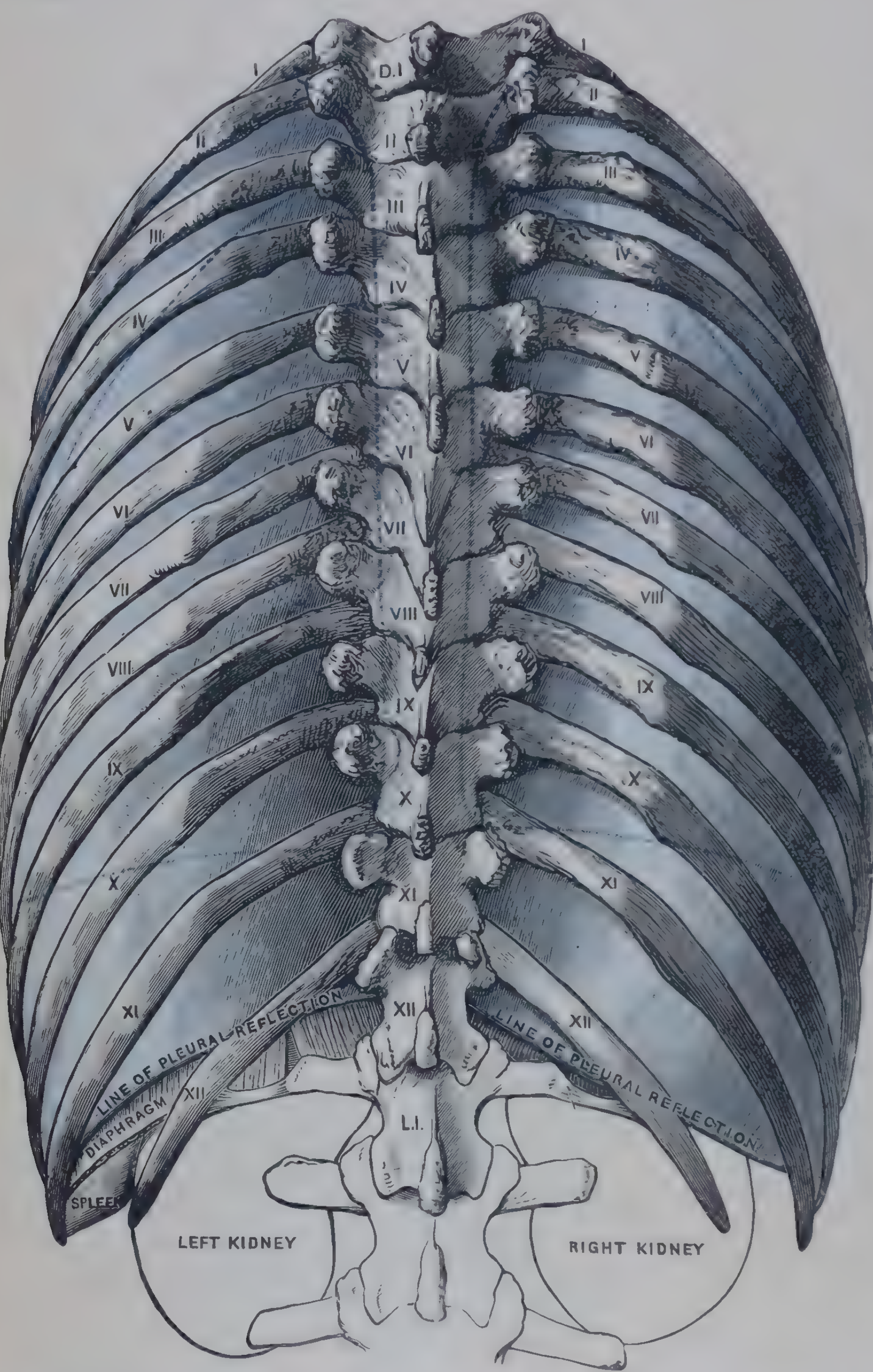

Fig. 600.—Pleural Sacs from Behind in Subject hardened by Formalin Injection. The blue lines indicate the outlines and the fissures of the lungs.

Sternal Line of Pleural Reflexion.—From the back of the sternum the right pleura is reflected, in the upper part of the chest, on to the remains of the thymus, the right innominate vein and the superior vena cava, and, at a lower level, directly on to the front of the pericardium. The left pleura is reflected from the back of the manubrium sterni on to the left common carotid artery and the aortic arch, and, at a lower level, directly on to the front of the pericardium.

Diaphragmatic Line of Reflexion.—From the back of the xiphisternal joint, the diaphragmatic line of reflexion crosses the seventh costal cartilage and reaches the eighth costal arch near its costo-chondral junction, in the mid-clavicular line. Beyond this point the line of diaphragmatic reflexion is carried downwards and laterally across the ninth and tenth ribs near their anterior extremities. As it crosses the tenth rib or, perhaps, as it proceeds across the tenth intercostal space, the line of pleural

reflexion reaches its lowest point, which lies in the mid-axillary line two fingers' breadth above the costal margin. Thence, as it curves backwards towards the vertebral column, it passes slightly upwards, cutting across the eleventh rib and reaching the twelfth rib. Its relation to the twelfth rib varies with the length of that rib: unless the last rib is unusually short the pleura lines its medial half, and the line of reflexion falls below that portion of the rib so as to reach the vertebral column midway between the head of the last rib and the transverse process of the first lumbar vertebra (Fig. 600). There, therefore, the line of diaphragmatic reflexion falls below the inferior border of the thoracic wall; and this is a point of practical importance in operations on the kidney. (See "Pleuræ" in Section on Surface and Surgical Anatomy.) In the living subject, according to radiographic evidence, this most posterior part of the reflexion-line runs either horizontally, or with medial ascent, or upward concavity at any level from the upper margin of the twelfth thoracic vertebra to the lower margin of the second lumbar vertebra (Lachman, 1942).

It is commonly stated that the left pleural sac reaches a lower level than the right, but this is by no means the rule: the right may reach lower than the left.

Along the line of the diaphragmatic reflexion, the **phrenico-pleural fascia** passes from the bare part of the diaphragm and from the costal cartilages to the surface of the costal pleura, so as to hold it firmly in its place.

Pleural Recesses.—Along the sternal and diaphragmatic lines of reflexion the pleura bends so acutely that the two parts come into contact with one another to form **recesses** of the pleural cavity. These recesses are occupied by the anterior and inferior borders of the lung in deep inspiration only, and in some places not even then (pp. 713, 714). They are known as the *costo-mediastinal recess* and the *costo-diaphragmatic recess*; their names sufficiently indicate their positions in relation to the parts of the parietal pleura that bound them. The *retro-œsophageal recesses* are described on page 709.

Structure of Pleura.—The **pulmonary pleura** is the connective tissue capsule of the lung. Its outermost or *serous layer* is a sheet of thin, mesothelial cells. This rests on a *collagenous membrane* which contains some elastic fibres. Deeper still there is an *elastic membrane*. This is separated from the subjacent alveoli of the lung by a *subpleural areolar layer*. Septa from the subpleural layer extend into the lung and partly surround the (secondary) lobules; and through these septa twigs of the bronchial artery, radicles of the pulmonary vein, communicating lymph-vessels, and also nerves are enabled to pass to or from the pleura.

The **parietal pleura**, like other serous membranes, is composed of a stratum of fibrous tissue in which bundles of fibres cross each other in various directions and are intermixed with a considerable quantity of elastic tissue.

On the inner or free surface there is a continuous sheet of mesothelial cells. The pleura so formed is attached to the parts that it lines by a *subserous layer* of areolar tissue.

Vessels and Nerves.—The *intercostal* **arteries** and various branches of the *internal mammary* artery supply the parietal pleura; the **veins** correspond. **Lymph-vessels** are abundant in the subserous layer. **Nerves**: The costal pleura and the peripheral part of the diaphragmatic pleura are supplied by the *intercostal* nerves. The central part of the diaphragmatic pleura and the mediastinal pleura are supplied by the *phrenic* nerve. At operation, probing the costal pleura elicits pain at the point of contact; on probing the peripheral part of the diaphragmatic pleura pain is referred to the lower part of the chest-wall or to the anterior abdominal wall; and on probing the central part of the diaphragm and lower part of the mediastinal pleura (presumably the upper part also) it is referred to the lower part of the neck. The visceral pleura is insensitive to touch.

LUNGS

When healthy and sound each **lung** (pulmo) lies free within the corresponding pleural cavity, and is attached only by its root and the pulmonary ligament. Adhesions between the pulmonary and parietal layers of pleura are due to pleurisy.

The right lung is larger than the left, in the proportion of about 11 to 10. It is also shorter and wider. The difference is due partly to the great bulk of the right lobe of the liver, which forces the right dome of the diaphragm to a higher level than the left dome, and partly to the heart and pericardium bulging more to the left than to the right, thus diminishing the width of the left lung.

The lung is light, soft, and spongy in texture; when pressed between the finger and thumb it crepitates, and when placed in water it floats. Pulmonary tissue is remarkable for its elasticity.

The surface of the adult lung presents a mottled appearance. The ground

colour is a light slate-blue, but scattered over this there are numerous dark patches of various sizes, and also fine, dark, intersecting lines. The coloration of the lung differs considerably at different periods of life. In early childhood the lung is rosy-pink, and the darker colour and the mottling of the surface, which appear later, are due to the pulmonary substance, and particularly its interstitial areolar tissue, becoming more or less completely impregnated with atmospheric dust (see p. 716). Owing to the fact that the upper lobes of the lungs maintain a practically constant relationship to the enclosing ribs and intercostal spaces in inspiration and expiration alike, the pigmentation on the surface of these lobes tends to lie in bands beneath the intercostal spaces. In the lower lobes, which, owing to the action of the diaphragm, expand in a vertical direction across the ribs, this band-like pattern is distinct only on the upper part of the lobes, where vertical expansion is but feeble in extent.

The fœtal lung differs from that of a new-born child who has breathed, for it is firm to the touch, and sinks in water. With the first inspiration, air enters the lung—beginning with the antero-lateral parts. Then, successively, the diaphragmatic, the apical, and the posterior parts come into action until at the end of a fortnight the entire lung is fully functional. It is only when air and an increased supply of blood are introduced into the lung that it assumes its characteristic soft, spongy, and buoyant qualities.

Form of Lungs.—The lungs are necessarily adapted to the walls of the pleural cavities in which they are placed and, when hardened by embalming fluid, they bear on their surfaces the imprint of ribs, vertebræ, and structures in the mediastinum. In this condition, each lung presents an *apex*, a *base* circumscribed by the *inferior border*, *costal* and *medial surfaces* sharply delimited from each other in front by the *anterior border* and less clearly a little behind the hilum by an unobtrusive *posterior border*, which may be rendered more evident by appropriate illumination as in Figs. 602, 603. Curiously enough, this border waited long to be given its name; and the bulky, rounded posterior part of the lung, lying in the deep hollow at the side of the vertebral column was wont to be named the "posterior border".

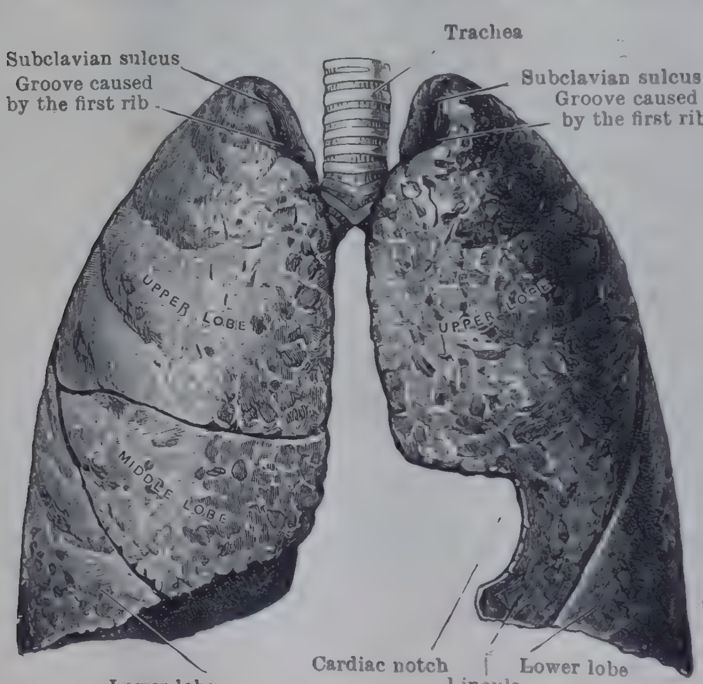

FIG. 601.—TRACHEA, BRONCHI, AND LUNGS OF A CHILD, HARDENED BY FORMALIN INJECTION.

The **apex of the lung** is blunt and rounded. It rises through the thoracic inlet, bounded by the first costal arch, to the full height of the cervical pleura in the root of the neck. The subclavian artery arches laterally across its anterior aspect a short distance below its summit, and there produces a groove called the *subclavian sulcus*. Slightly below this a shallower and wider groove marks the position of the innominate vein, and, on the left lung, the end of the left subclavian vein also. Although those vessels impress the lung they are separated from it by the cervical pleura.

As examined from behind, the apex of the lung usually extends as high as a line drawn from the highest portion of the acromion of the scapula to the tip of the spine of the seventh cervical vertebra. It may, however, be slightly higher or lower than this line.

The lateral limit of the apex of the lung, and consequently of the pleura, is medial to the superior angle of the scapula.

The **base** or **diaphragmatic surface** presents a semilunar outline, being curved around the base of the pericardium. It is adapted to the thoracic surface of the diaphragm, and is consequently deeply concave. As the right dome of the diaphragm lies higher than the left, the basal concavity of the right lung is deeper than that of the left lung. Laterally and behind, the diaphragmatic surface of each lung is limited by a thin salient margin, called the *inferior border*, which extends downwards for some distance into the *costo-diaphragmatic recess* of the pleural cavity. The inferior border of the lung moves freely in a vertical direction during respiration. It is practically horizontal and only approximately fills the costo-diaphragmatic recess in deep inspiration. In the preserved cadaver, the thorax assumes a form approximately midway between that of full inspiration and full expiration; and the inferior border of the lung crosses the sixth rib in the mamillary line; the eighth rib in the mid-axillary line; the tenth rib in the scapular line; and it reaches the vertebral column at the level of the tenth thoracic spine (Figs. 597-600).

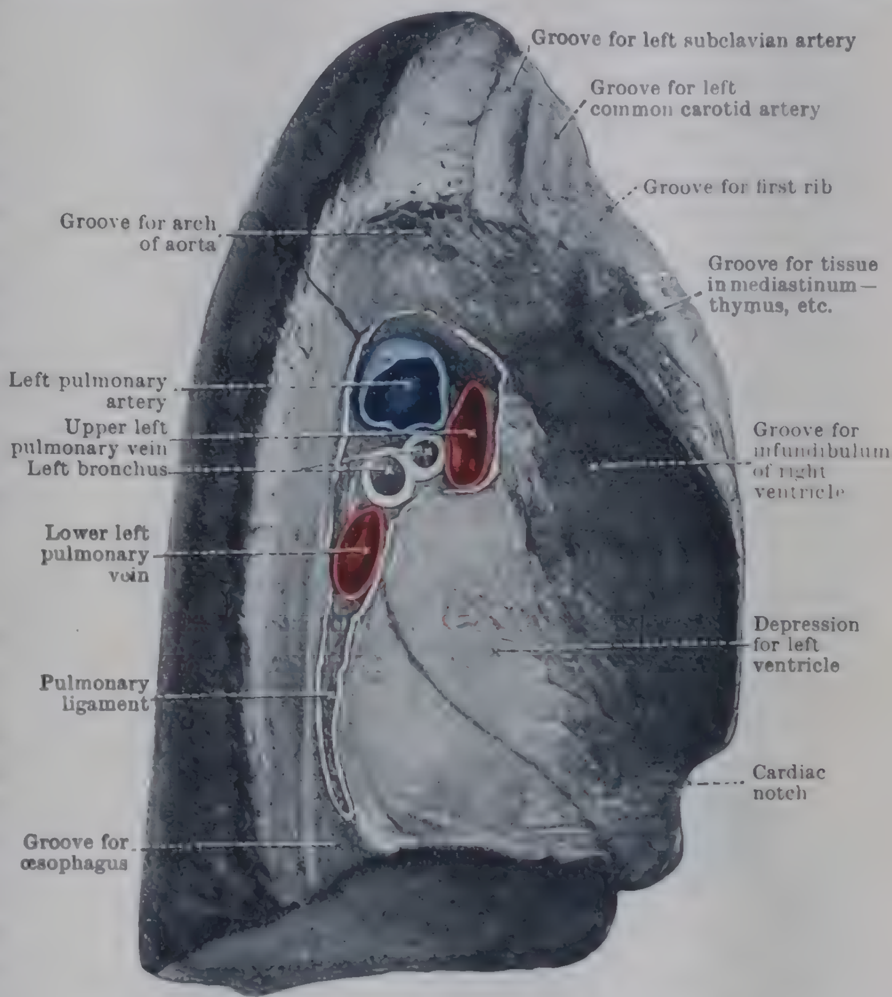

FIG. 602.—MEDIAL SURFACE OF LEFT LUNG HARDENED *IN SITU*.

The diaphragmatic surfaces of the lungs establish important relations with certain of the viscera that occupy the upper part of the abdominal cavity, the diaphragm alone intervening. Thus, the diaphragmatic surface of the right lung rests upon the right lobe of the liver; whilst that of the left lung rests upon the left lobe of the liver, the fundus of the stomach, the spleen, and, in some subjects, the left colic flexure.

The **costal surface** is extensive and convex. It is accurately adapted to the part of the wall of the pleural cavity that is formed by the sternum, the costal arches and the intervening muscles, the imprints of which are left upon it in the preserved cadaver.

The **medial surface** is applied to the sides of the vertebral bodies and to the mediastinal septum. The **mediastinal part** of this surface presents markings in accordance with the inequalities of the septum (Figs. 602 and 603). Thus, it is deeply hollowed out in adaptation to the pericardium. This pericardial hollow or depression comprises the greater portion of the mediastinal part, and, owing to the greater bulging of the heart to the left side, it is much deeper and more extensive in the left lung than in the right lung. Above and behind the pericardial depression is the hilum of the lung. The **hilum** is a wedge-shaped area within which the blood-vessels, nerves, and lymph-vessels, together with the bronchus, enter and leave the lung. Amidst these structures there are some lymph-glands. The hilum is surrounded by the reflexion of the pleura from the lung on

to the pulmonary root. Behind the hilum and the pericardial area, a longitudinal strip of each lung is applied to the posterior mediastinum. On the *right lung* the strip is grooved longitudinally by the right border of the œsophagus; on the *left lung* a broader longitudinal groove is produced by the descending aorta, and, close to the base in front of the aortic impression, a small flattened area makes contact with the left border of the œsophagus immediately above the diaphragm.

The portion of the mediastinal part of the lung that lies above the hilum and the pericardial depression is applied to the superior mediastinum, and the markings are accordingly different on the two sides. On the *left lung* a broad deep groove, produced by the aortic arch, curves backwards above the hilum, and becomes continuous with the aortic groove behind the hilum. From the groove for the aortic arch a narrower, deeper, and much more sharply marked groove runs upwards to become continuous with the groove that arches laterally across the front of the apex. This is the **subclavian sulcus**, and it contains the left subclavian artery when the lung is in place. In front of the subclavian sulcus there is a small area applied to the left common carotid artery and the phrenic and vagus nerves. On the *right lung* also there is a curved groove immediately above the hilum. This groove is narrow and more distinctly curved than the aortic groove on the left lung. It lodges the arch of the vena azygos. From the anterior end of the azygos groove a wide, shallow groove extends upwards to the apex of the lung a short distance below its summit. This is the imprint of the superior vena cava and the right innominate vein. Close to the summit there may be, on its medial aspect, a sulcus for the upper end of the innominate artery.

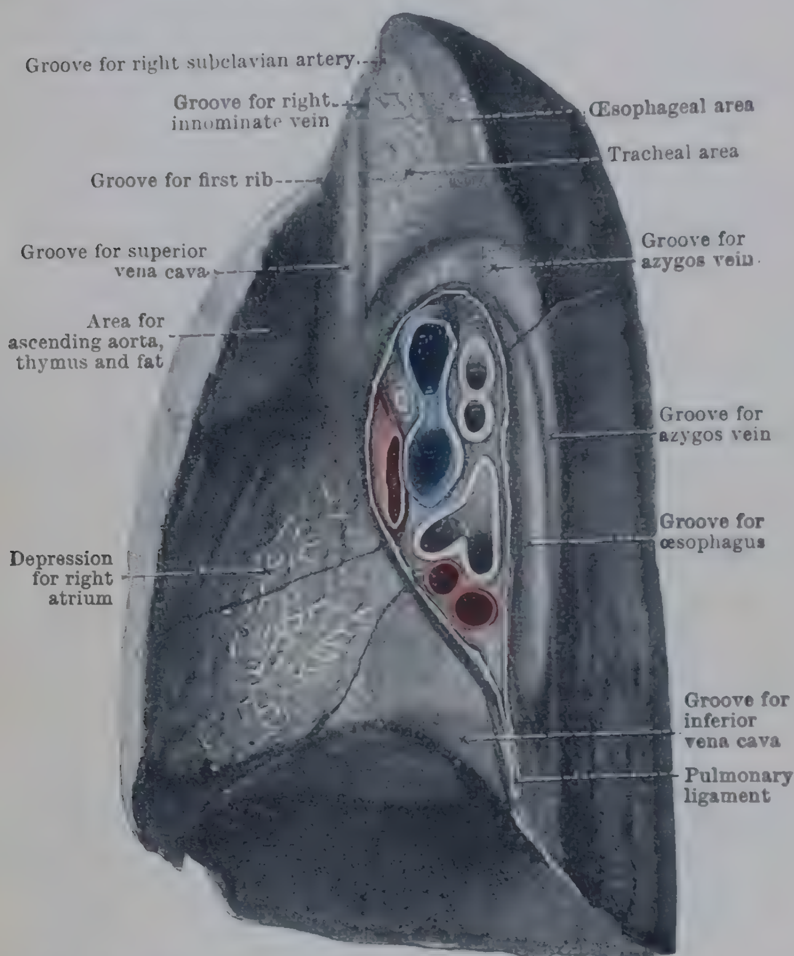

FIG. 603.—MEDIAL SURFACE OF RIGHT LUNG HARDENED *IN SITU*.

In addition to the hilum, it must now be evident that the mediastinal part of each lung presents three districts which correspond respectively to (1) the middle mediastinum (*i.e.*, the pericardial hollow), (2) the posterior mediastinum, and (3) the superior mediastinum; and that in each of these districts impressions corresponding to structures contained within the mediastinum may be noticed.

The **posterior border** of the lung divides the costal from the medial surface; as explained already (p. 712), it is an ill-defined margin.

The **anterior border** of the lung is short and exceedingly thin and sharp. It begins abruptly, an inch or more below the summit, opposite the sterno-clavicular joint, and extends to the base, where it becomes continuous with the inferior border. The thin front part of the lung is carried forwards and medially into the *costo-mediastinal recess* of the pleural cavity. The anterior border of the right lung completely fills this recess (except in deep expiration) and, in the upper part of the chest, is separated from the corresponding border of the left lung only by the two

layers of mediastinal pleura that are reflected from the sternum to the pericardium. The anterior border of the left lung, in its lower part, shows a deficiency of variable size, called the **cardiac notch**, which lies in front of the left side of the heart and pericardium. At the site of the notch, the left costo-mediastinal recess of the pleural cavity is, accordingly, unoccupied by lung. The tongue-like portion of the upper lobe of the lung, situated between the cardiac notch and the oblique fissure, is called the **lingula** (Figs. 601, 606).

In childhood, when the thymus is active and large, the anterior borders of the lungs, in expiration, are pressed apart by the thymus. But in inspiration, owing to expansion of the chest, the anterior borders of the lungs approximate each other and compress the thymus from the sides so that it sinks deeply into the intervening superior mediastinum. After the age of three years, however, the thymic shadow is no longer visible in radiographs of healthy children.

Fissures and Lobes of Lungs.—The *left lung* is divided into two lobes, an *upper* and a *lower*, by a long, deep, **oblique fissure** that penetrates its substance to within a short distance of the hilum. On the upper and lower sides of the hilum this fissure cuts right through the lung and appears on the medial surface. *In the cadaver*, this fissure (Figs. 600, 597), when viewed from the costal surface, is seen to begin behind about two and a half inches below the apex, about the level of the vertebral end of the third rib, and to continue downwards and forwards in a slightly spiral manner to the inferior border, which it reaches a short distance from its anterior end. *In the living subject*, however, the oblique fissure is distinctly lower. Thus, as seen at operations on the chest when healthy lungs have been kept inflated by the anaesthetist, it usually begins at the level of the vertebral end of the fifth rib or fifth interspace and thereafter it follows the line of the sixth rib. It may, however, begin as high as the fourth rib or even at the third interspace, and it is often as low as the sixth rib or sixth interspace (Brock, 1946). The fissure ends near the sixth costo-chondral junction, where it cuts the inferior border of the lung from two to four inches from the mid-sternal line. The **upper lobe** lies above and anterior to the fissure. It is conical in form, with an oblique base; and it includes the apex and the entire anterior border of the lung. The **lower lobe** lies below and behind the fissure. It is the more bulky of the two; and it includes almost the entire base and the greater part of the thick, posterior part of the lung.

The *right lung* is divided into three lobes, an *upper*, a *middle*, and a *lower*, by two interlobar fissures. One of them, the **oblique fissure**, is very similar in its position and relations to the fissure in the left lung. Its upper end, however, is a little farther from the apex; its incline is less steep; and its lower end is a little farther from the anterior border. It separates the lower lobe from the middle and upper lobes. The other fissure, the **horizontal fissure**, begins in the oblique fissure near the mid-axillary line, and proceeds forwards to end at the anterior border of the lung at the level of the fourth costal cartilage. It separates the upper lobe from the **middle lobe**, which is triangular or wedge-shaped in outline and situated anteriorly.

Variations.—The usual *fissures* of the lung may be either incomplete or absent, and supernumerary fissures may be present. Thus, the fissure between the middle and the upper lobe of the right lung was absent in 21 per cent of specimens and incomplete in 67 per cent; the fissure between the middle and the lower lobe was incomplete in 12·5 per cent; and the fissure between the upper and the lower lobe was incomplete, notably at its upper end, in 30 per cent of right and left lungs, according to observations made on 227 lungs (Kent and Blades, 1942). On the other hand, clefts or partial fissures have been observed between most contiguous bronchopulmonary segments (p. 717) and also between certain subsegments; notably, between the superior (dorsal) segment and the remainder of the lower lobe in both lungs; between the lingular segment and the remainder of the left upper lobe, thereby forming a *left middle lobe*; between the lateral and medial segments of the right middle lobe; and partially detaching the medial basal (cardiac) segment of the right lower lobe to form a **cardiac lobe**—a lobe that is constant and large in many of the domestic animals. Rarely, the arch of the azygos vein, suspended within a fold of pleura, cuts downwards into the apical part of the right lung, thereby separating an accessory lobe, the **lobe of the vena azygos** (see Stibbe, 1919), which is detectable on X-ray examination (Fig. 2, Pl. LXVIII, p. 721). (For abnormalities, see Foster-Carter, 1946.)

Weight.—The right adult lung, when filled with blood, weighs about 22 ounces, the left 20 ounces. In the nearly bloodless condition after electrocution the right lung weighs only about 8 ounces and the left 7 ounces.

Pigmentation.—Although at every breath foreign material is inhaled, little reaches the

alveoli of the lungs. Most is entangled in the mucus of the respiratory passages and washed by ciliary action upwards to the pharynx. Fine particles which succeed in reaching the alveoli are believed to be engulfed by alveolar phagocytes (dust-cells), which convey them to the nearest lymph-vessels, in the walls of the alveolar ducts and respiratory bronchioles. Having entered these, the phagocytes are swept on to the lymph-glands at the hilum. It is presumed that many die on the way, since pigments are usually found in and around the walls of the lymph-vessels. During expansion, the upper lobe maintains almost unchanged its relation to the overlying costal arches and intercostal spaces. Consequently, the pigmentation beneath the visceral pleura rather sharply defines the intercostal spaces. The lower lobe, following the diaphragm in its descent, modifies its relation to the overlying thoracic wall, and its subpleural pigmentation is therefore more diffuse. In certain disease-processes (*e.g.*, congestive heart-failure) alveolar phagocytes containing hæmoglobin pigment are coughed up. At birth, the surface of the lung is pinkish-white, but later in life it acquires a mosaic pattern of black lines which demarcate the bases of the (secondary) lobules of the lung. Hence, it would appear that some phagocytes, laden with foreign material obtained from the more peripheral alveoli, are carried by the vessels in the interlobular septa in the reverse direction (*i.e.*, away from the hilum) to the subpleural lymph-vessels and there deposited. The colour of the lung is determined largely by the colour of the inhaled pigment: in coal-miners the surface of the lung may be very nearly uniformly black, in hæmatite-miners red, and in zinc-oxide workers white.

Expansion of Lung in Respiration.—Although the texture of the lung is uniform throughout, the presence of the great blood-vessels and bronchi in the part around the hilum prevents that area from taking any active part in respiration. The middle zone of the lung, surrounding the hilar area, has but limited functional value. It is the outer zone, near the visceral pleural surface, that is most active in respiration. Probably only about 3 mm. depth of the superficial zone is active in quiet respiration and about 30 mm. depth in forced breathing. The walls of the pleural cavity are not uniformly expansile. The costo-sternal and diaphragmatic walls obviously move most freely; whereas, the region bounded above by the cupola, posteriorly by the vertebral ends of the ribs, and medially by the bodies of the vertebræ and the adjacent part of the mediastinum displays almost no expansile movement. Hence, the parts of the lung most free to expand are the costo-sternal and the diaphragmatic. During inspiration the root of the lung moves downwards and forwards, and it is this root movement that makes it possible for the apical and postero-medial parts of the lung to expand. Indeed, if for any pathological reason the root of the lung is fixed, the latter regions can hardly expand. During inspiration the bronchi (cf. Figs. 594 and 595) and the pulmonary vessels elongate and increase in calibre (Macklin, 1932). Further, the bronchi undergo a slight rotatory movement which can be recognized in cinematographic films.

Roots of Lungs.—The term **root of the lung** is applied to a number of structures which, enveloped in a tube of pleura, pass from the mediastinum to the hilum and constitute a pedicle for the lung. The phrenic nerve passes downwards a short distance anterior to the pulmonary root, whereas the vagus nerve breaks up into the posterior pulmonary plexus on its hinder aspect under the investing pleura. The anterior pulmonary plexus is placed in front of the root of the lung under the pleura. From the inferior border of the root of the lung the pulmonary ligament extends almost to the diaphragm. These relations are common to the roots of both lungs, but there are others which are peculiar to each lung. On the *right* the superior vena cava lies in front of the pulmonary root, and the vena azygos arches over it. On the *left* the aorta arches over the root, and the descending thoracic aorta passes behind it.

Contents.—The large structures in each pulmonary root are: (1) the two pulmonary veins; (2) the pulmonary artery; (3) the bronchus. There are also one or more small bronchial arteries and veins, the pulmonary nerves and lymph-vessels, and some broncho-pulmonary lymph-glands.

Relations.—The **bronchus** in the root of the lung lies behind the pulmonary vessels. The **pulmonary artery** is differently situated on the two sides. On the right it gives off a branch corresponding to the ep-arterial bronchus but itself lies below that bronchus. On the left, where there is no ep-arterial bronchus, the pulmonary artery enters the hilum above the bronchus. On both sides the **lower pulmonary vein** lies at a lower level than the artery and the bronchus, whereas the **upper** lies in front of the artery and slightly below it (Figs. 602 and 603).

The Bronchial Tree and Broncho-Pulmonary Segments.—The trachea bifurcates into a right and a left primary or *main bronchus*, one for each lung. The main bronchi divide into secondary or *lobar bronchi*, of which there are three on the right side (upper, middle, and lower) and two on the left side (upper and lower) for the respective lobes of the lungs. Each lobar bronchus divides into two or more tertiary or *segmental bronchi* for the supply of the subdivisions or segments of the lobes of the lungs. Of these segments, ventilated by tertiary bronchi, there are characteristically ten in the right lung and eight in the left (Fig. 604), and they are called **broncho-pulmonary segments.** Their number is not absolute, because of minor variations in the pattern of branching. Hence, in more general terms, a broncho-pulmonary segment may be described as the portion of lung served by a principal branch of a lobar bronchus (Foster-Carter & Hoyle, 1945). The pattern is, however, fundamentally identical in both lungs; but in the left lung the apical and the posterior segmental bronchi arise by a common stem, and so do the anterior basal and the medial basal (cardiac) segmental bronchi, thus accounting for the reduced number of segmental bronchi in the left lung. The segmental bronchi continue to divide into smaller and still smaller subsegmental bronchi until finally they end in lung units, described below.

For the anatomy of the bronchial tree, see Neil, Gilmour & Gwynne (1939); Neil & Gilmour (1946, 1949), Brock (1946), and Boyden (1949); and for the older views on the manner of the intrapulmonary branching of the bronchi, consult Aeby (1880), Ewart (1889) and Huntington (1920), summarized and illustrated by Smyth (1949).

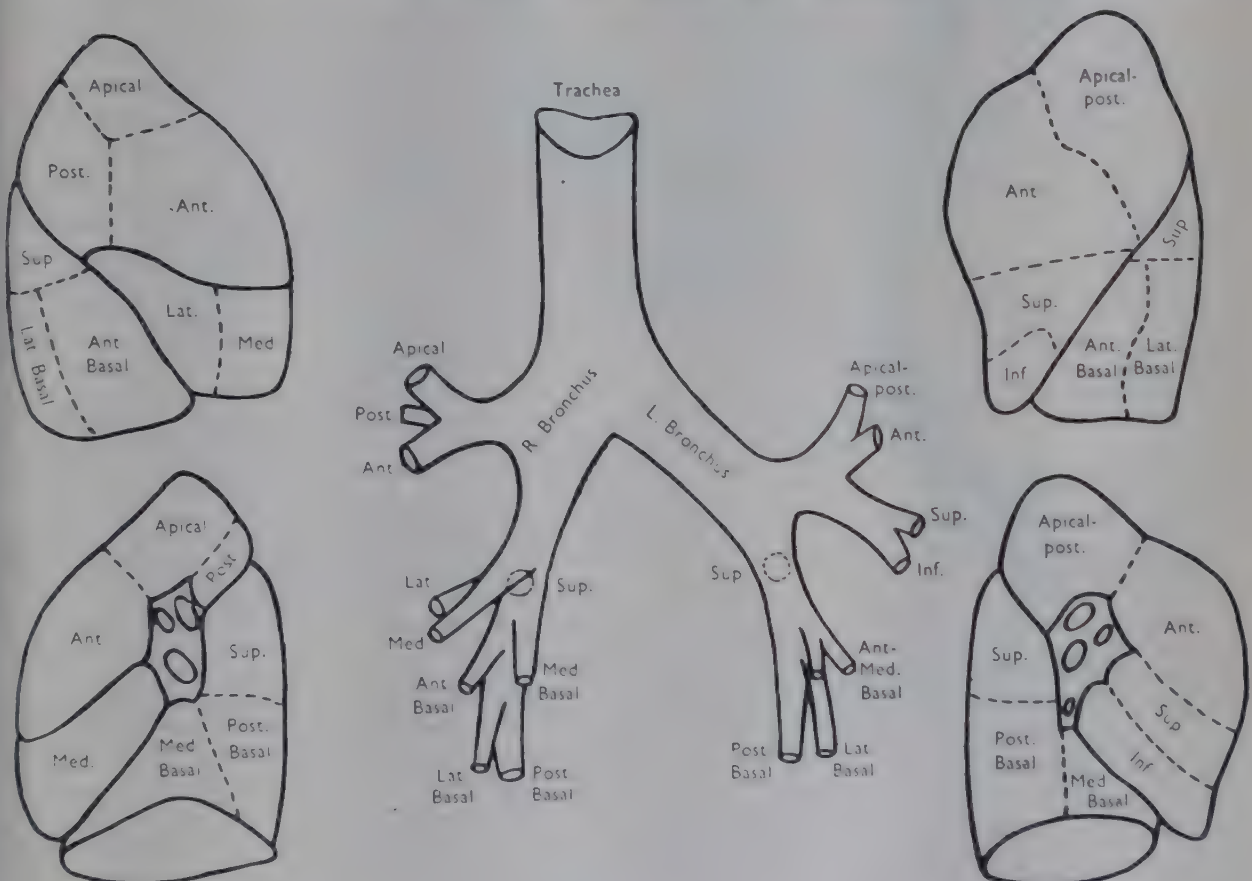

FIG. 604.—THE BRONCHO-PULMONARY SEGMENTS. (After Jackson & Huber, 1943.)
Each bronchial branch is designated by the name of the subdivision of the lung supplied by it.

Clinical Significance.—Within recent years the broncho-pulmonary segments have acquired an increased clinical significance to the physician in making a differential diagnosis of pulmonary disease, to the bronchoscopist in locating and removing a foreign body from a bronchus, and to the surgeon about to drain a localized abscess of the lung or to excise one or more diseased segments (Brock, 1946).

Nomenclature.—The recent revival of interest has naturally been accompanied by an evolving nomenclature to which many have contributed and in which there are many synonyms. This seems to have reached its simplest, most concise, and most easily remembered form in the terms suggested by Jackson & Huber (1943) and employed here, where each segment is referred to its position in its own lobe. No term is duplicated. The term *anterior* is preferred to the synonym *pectoral*; *lateral* to *axillary*; *superior* to *dorsal*; and *medial basal* to *cardiac* (cf. Brock, 1946).

The three right and two left lobar bronchi arise as the main bronchus approaches the

hilum of the lung. The right upper lobe bronchus arises nearly an inch from the trachea; whereas the left upper lobe bronchus arises about twice that distance from the trachea. The relation of the pulmonary artery to the upper lobe bronchus is different on the two sides: for, as the artery turns backwards to reach the posterior surface of the bronchus, it passes below the right upper lobe bronchus but above the left one. Hence, the right upper lobe bronchus has been called the *ep-arterial bronchus* (Aeby, 1880); all other bronchi on both sides being *hyp-arterial bronchi*. The ep-arterial bronchus is to be regarded as a branch that has migrated cranialwards on the main bronchial stem.

Just as the inferior lobe bronchus appears to be the direct continuation of the main bronchus, so the posterior basal bronchus appears to be the direct continuation of the inferior lobe bronchus and, therefore, to be the terminal and tapering part of the main stem of the bronchus, other bronchi being collateral branches. In its descent in the lung the stem curves postero-medially to the base of the lung, in conformity with the moulding of the lung by the heart.

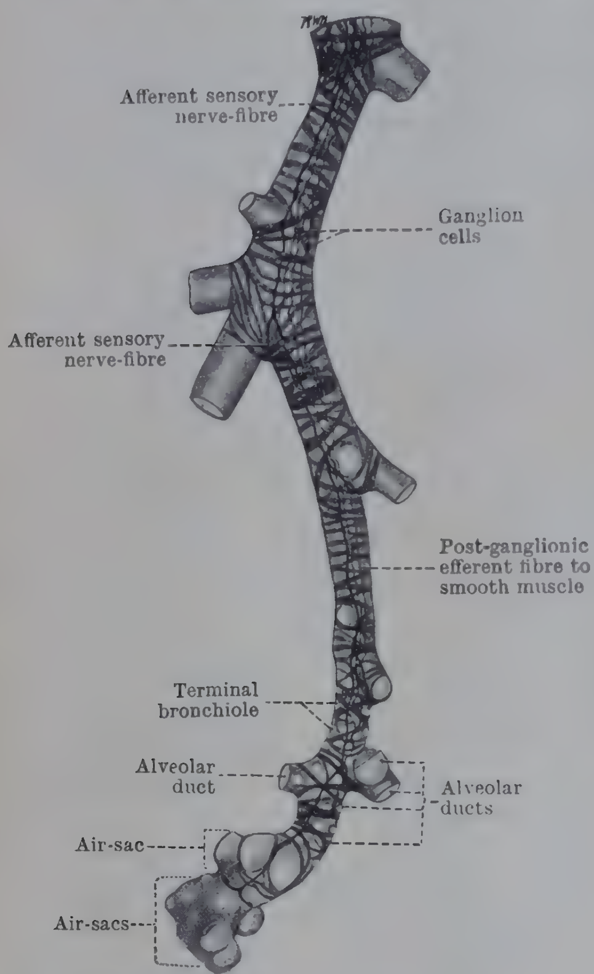

Fig. 605.—Reconstruction of a Bronchus, expanded in Inspiration, with its Muscles and Nerves. (After W. Snow Miller, 1921, 1947.)

Structure of Lung.—The lung is so constructed that the blood that reaches it through the pulmonary artery is brought into the most intimate relation with the air that enters it through the trachea and bronchi. An interchange of materials between the blood and the air is thus made possible, and the object of respiration is attained. As a result of the interchange, the dark, impure blood that flows into the lung through the pulmonary artery becomes bright red and arterial before it returns to the heart through the pulmonary veins.

The lungs are lobed, each lobe being an elastic, spongy mass enclosed in a capsule of pulmonary pleura and subpleural areolar tissue. From this subpleural layer fine areolar septa penetrate into the substance of the lung, and these, with the areolar tissue that enters at the hilum upon the vessels and bronchi, constitute a supporting framework for the organ.

A branching tree of tubes permeates the lung and constitutes the **conducting part of the lung**. The main tube and the first few generations of its branches are termed *bronchi*; the succeeding and smaller branches are termed *bronchioles*. The **respiratory part of the lung** consists essentially of a capillary network supported by elastic and reticular fibres and partitioned like a honeycomb. The pulmonary artery brings blood to the network; the pulmonary veins return it to the heart. The bronchioles divide ultimately within the lung substance into a number of tubules, called *alveolar ducts*, which branch, and even re-branch, and end in rounded cavities, called *alveolar sacs* (air-sacs), on whose walls there are outpouchings or *alveoli*. Alveoli occur also on the alveolar ducts and on the bronchioles that immediately precede them, which are accordingly called *respiratory bronchioles*. The name *terminal bronchioles* is applied to the precursors of the latter.

Lobules of Lung.—The lobes of the lung are made up of a number of broncho-pulmonary segments, each of which, by the progressive branching of its bronchus, is divisible into smaller and still smaller subsegments until areas called *secondary lobules* are reached, each of which is subdivided into many smaller *primary lobules* or *lung-units*. On the surface of the lung, black lines, resulting from pigment deposited in the interlobular septa, enclose polygonal areas, 1 cm. or more in diameter, which are the bases of secondary lobules. These polygonal areas are indefinitely marked off by finer black lines into smaller polygonal areas, 2 or 3 mm. in diameter, which are the bases of primary lobules. Although no pigment is present in the fœtal lung, the lobular character

of the lung is particularly well marked in the fœtus, and with a little care one can separate its surface lobules from one another by gently tearing through the intervening areolar tissue. The lobules thus isolated are pyramidal. The bases of the pyramids abut against the subpleural areolar tissue, whilst each apex, directed towards the hilum, receives a bronchiole. This bronchiole branches several times, the last generation of branches being respiratory bronchioles. The portion of lung, including its vessels and nerves, supplied by a respiratory bronchiole is a *primary lobule* or **lung-unit** (Snow Miller, 1947).

Structure of Intrapulmonary Bronchi.—When the large bronchi enter the lung, they become cylindrical and lose the posterior flattening which is characteristic of the extrapulmonary bronchi. They possess the same coats as the trachea and extrapulmonary bronchi (p. 703); but as the tubes become smaller by repeated divisions, the coats become thinner and differently arranged.

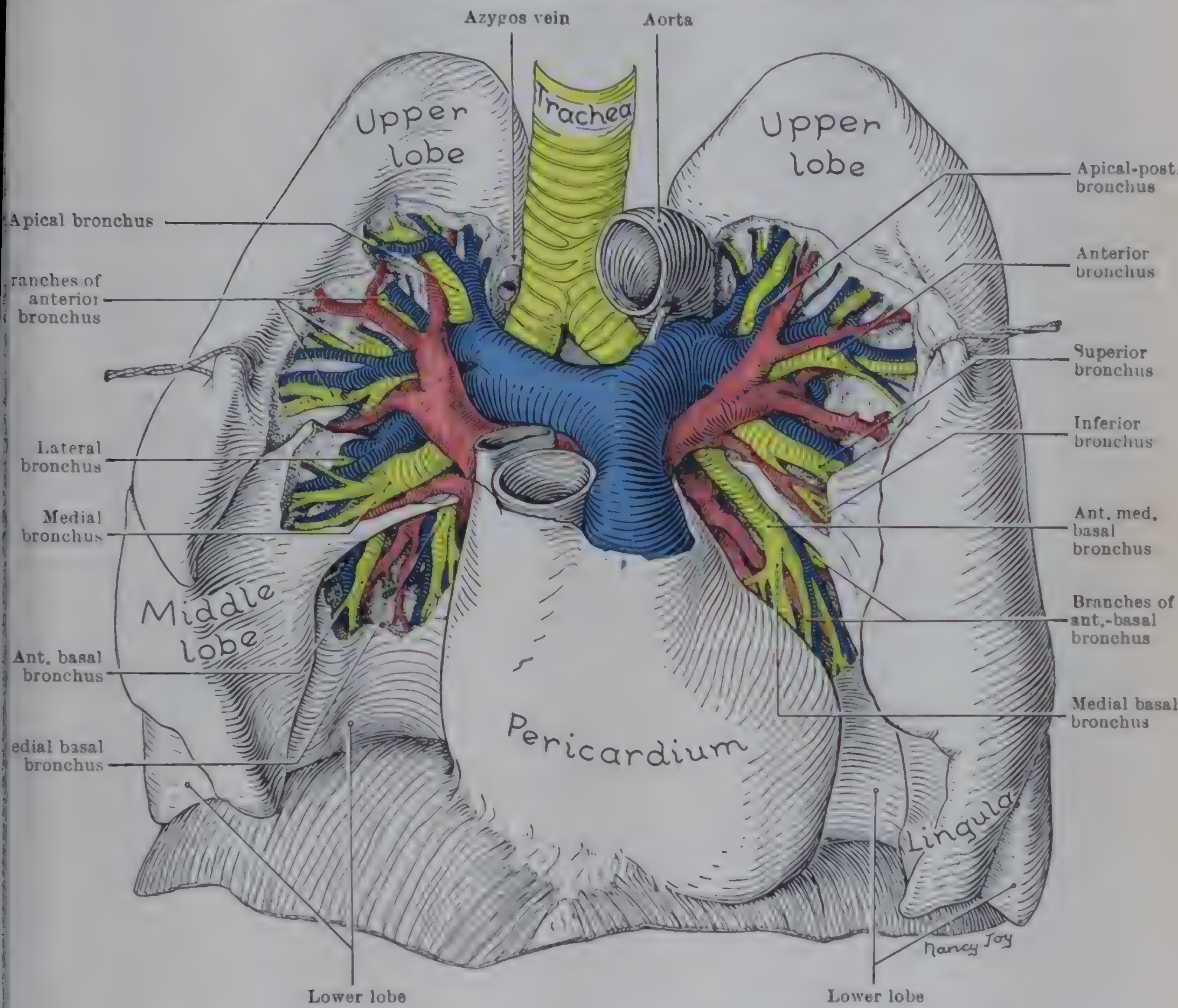

FIG. 606.—DISTRIBUTION OF BRONCHI AND PULMONARY BLOOD-VESSELS IN THE LUNGS.
(From a dissection by Miss A. I. Scott.)

In the *supporting coat* the **C**-shaped cartilages, characteristic of the trachea and extrapulmonary bronchi, give place to a mosaic of irregular plates which completely surround the bronchus. They become progressively fewer and correspondingly smaller in the smaller tubes until, in bronchi of 1 mm. diameter, they disappear altogether. The glands cease to exist about the same point. The *muscle-fibres* form a continuous lattice work in the bronchi; this becomes relatively more conspicuous in the non-cartilaginous bronchioles, and may be traced to the ends of the alveolar ducts, where it forms sphincters. Spasm of these sphincters accompanies asthmatic attacks. The *mucous coat* becomes greatly thinned in the smaller bronchioles. It contains numerous longitudinally arranged elastic fibres and is disposed in longitudinal folds, so that when the tube is cut across the lumen presents a stellate appearance. The mucous coat is lined with ciliated columnar epithelium as far as the beginning of the respiratory bronchioles, where it becomes non-ciliated and cuboidal. The ciliated epithelium, however, extends beyond the last goblet-cell. There is controversy whether or not the epithelium of the bronchial tree is continued into the respiratory portion of the lung. Certainly no continuous epithelial lining can be seen in the alveoli, though isolated cells (septal cells or alveolar phagocytes) are apparent

here and there on the alveolar wall amid the capillary network. Fine perforations in the septa, called *alveolar pores,* that bring contiguous alveolar sacs into communication with each other are described by some and denied by others (Engel, 1947).

Vessels and Nerves of Lung.—The bronchial arteries, usually one on the right side (of variable origin) and two on the left from the aorta, accompany the intrapulmonary bronchi as two or three longitudinal anastomosing branches, dividing when these divide and extending to the respiratory bronchioles. The function of the bronchial artery is to supply oxygenated blood, under high pressure, to the conducting part of the lung and to the other non-respiratory tissues (*i.e.*, bronchial tree, areolar tissue, lymph-glands, and, *via* the interlobular septa, the pulmonary pleura) for their nourishment. (See Cauldwell *et al.*, 1948.)

The **pulmonary artery**, on the other hand, brings venous blood under low pressure to the respiratory parts of the lung (*i.e.*, the parts that possess alveoli) to be oxygenated. The bronchial and pulmonary arteries effect capillary anastomoses on the respiratory bronchioles, but the branches of the pulmonary artery do not anastomose with each other. The terminal divisions of the artery join a dense capillary plexus which is spread over the alveoli. This vascular network is so close that the meshes are barely wider than the capillaries that form them. In the partitions or septa between adjacent alveoli there is only one layer of the capillary network, and thus the blood flowing through the network is exposed on both aspects to the air in the alveoli. There is a principal artery (or arteries) for each broncho-pulmonary segment. Ten arteries are to be identified in each lung and they are best named after the segments they supply. For the most part, the arteries follow the peripheral distribution of the bronchi, but their sites of origin and their proximal courses (*i.e.*, in the hilar region) are liable to certain variations (described in elaborate detail by Appleton, 1944, 1945, and by Boyden *et al.*, 1945, 1946, 1948).

The **pulmonary veins** return to the heart the blood delivered both by the pulmonary artery and by the bronchial artery, excepting the bronchial blood to the first one or two divisions of the bronchi; this blood is returned by **bronchial veins** to the azygos, hemiazygos, or intercostal veins. The radicals of the pulmonary vein, therefore, arise in the capillary plexus over the alveoli, in the walls of the alveolar ducts, in the pulmonary pleura, and in the areolar tissue.

Ten principal veins are to be identified in each lung. In their peripheral course, the veins do not lie with the arteries but occupy intersegmental planes and receive tributaries from the adjacent segments. Hence, to remove a segment at operation one set of tributaries must be ligated. In their proximal course, the veins accompany the bronchi and are named after the bronchi that lie superior and adjacent to their stems, excepting the first two veins of the right upper lobe which are called the apical anterior and the inferior vein. Certain veins run subpleurally in the interlobar fissures and on the mediastinal surface.

When fissures are incomplete it is common to find a vein passing from one lobe to the other. Arteries also not uncommonly cross intersegmental planes. Hence, a broncho-pulmonary segment should not be regarded as a broncho-vascular unit.

Variations.—The arteries are more variable than the bronchi, and the veins than the arteries. For details, Appleton and Boyden in particular, should be consulted.

The upper and lower pulmonary veins of either lung sometimes unite to form a single trunk which opens into the left atrium; the vein of the middle lobe may open independently. Again, one or both pulmonary veins of one or both sides may open into the right atrium or into one of its tributaries, *e.g.*, the superior vena cava, left innominate vein, left superior intercostal vein, coronary sinus, or inferior vena cava, or into an adjacent vein; but, unless 50 per cent or more of the pulmonary blood can find its way to the left atrium, life is not sustained for many weeks (*i.e.*, unless the interatrial septum is absent or the foramen ovale and the ductus arteriosus are patent—Brody, 1942; Brantigan, 1947).

The **lymph-vessels** of the lung are numerous, and they are divided into two groups—superficial and deep.

The *superficial lymph-vessels* are comparable to the lymph-vessels found in the capsules of other organs. They form a network which outlines the bases of the (secondary) lobules, and they are abundantly supplied with valves. Lymph-vessels in the interlobular septa bring the superficial network into free communication with the deep vessels—though these septal vessels occasionally have valves or valve-like structures, it is questionable whether they function as valves. In general, valves are so arranged in the lymph-vessels of the adult human lung that the lymph-flow is always directed towards the hilum (Harvey & Zimmerman, 1935).

Of the *deep lymph-vessels*, one set, beginning at the alveolar ducts, accompanies the bronchial tree; a second set accompanies the pulmonary artery; a third accompanies the pulmonary vein; and a fourth lies in the septa between the (secondary) lobules of the lung and communicates with the superficial network. These deep vessels have few valves; they intercommunicate freely, and they run to the hilum, where they end in the broncho-pulmonary lymph-glands situated either just outside the lung or within the lung substance. The blood-capillaries over the alveoli, being respiratory in function rather than nutritive, have no corresponding lymph-vessels.

From the broncho-pulmonary glands, the lymph-flow passes to the superior and inferior tracheo-bronchial glands, and from these it continues upwards through the paratracheal lymph-glands on each side of the trachea to the mediastinal lymph-trunk. One or two vessels from the lower lobe of each lung pass through the pulmonary ligament to end in the posterior mediastinal glands.

Further, lymphoid tissue is scattered throughout the lung-substance at the sites of division of bronchi and bronchioles, on the alveolar ducts, and where venous radicles arise beneath the

PLATE LXVII

PLATE LXVII.—ANTERIOR RADIOGRAPH OF THE SAME THORAX AS IN PLATE LXVI, IN POSITION OF FULL EXPIRATION.

Compare with Plate LXVI, p. 705, noting the rise of the Diaphragm, the broadening of the whole mediastinal shadow (including the Heart) and the greater density of the Lungs.

PLATE LXVIII

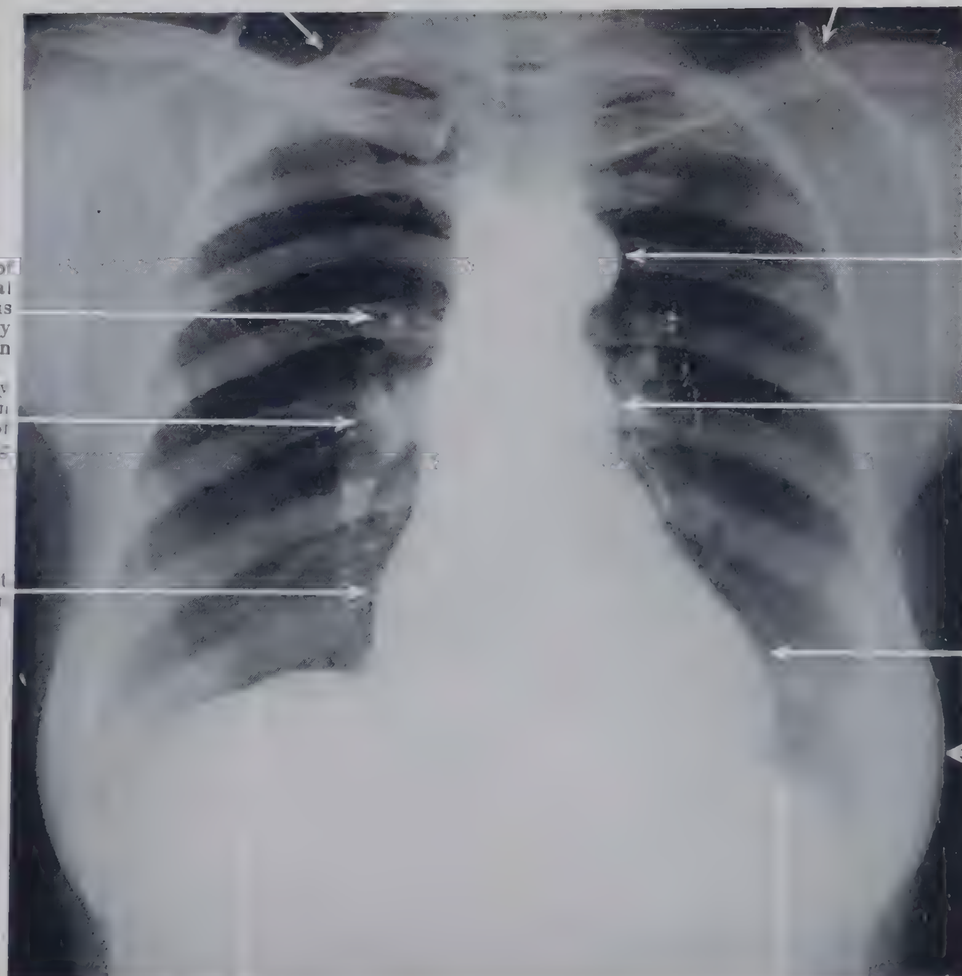

FIG. 1.—ANTERIOR RADIOGRAPH OF THORAX, OF WOMAN AGED 32, SHOWING GENERAL FORM OF MEDIASTINAL AND LUNG-ROOT SHADOWS AND SHADOWS OF BREASTS.

Note the position of the breast-shadows and compare with Plates LXII, p. 696, and LXV, p. 704.

FIG. 2.—RADIOGRAPH OF RIGHT CERVICO-THORACIC REGION, OF WOMAN AGED 35, SHOWING, IN ADDITION TO CERVICAL RIB, THE SHADOWS OF VENA AZYGOS AND PLEURAL FOLD THAT INDICATE THE PRESENCE OF A "LOBE OF THE VENA AZYGOS" IN THE RIGHT LUNG.

Cf. Plate IV, Fig. 1, p. 105, and see pp. 715, 1333.

[Facing p. 721

pleura. This lymphoid tissue is increased in old age, when it forms sheaths for the bronchial tree and pulmonary vessels, and also becomes diffused in the bronchial walls between the epithelium and the plain muscle.

The **nerves** of the lung come from the anterior and posterior pulmonary plexuses, and they comprise both efferent and afferent **vagal** and **sympathetic** fibres. The preganglionic fibres of the sympathetic issue from the upper three or four thoracic segments of the spinal cord, and the postganglionic fibres leave the middle cervical, inferior cervical, and upper four thoracic sympathetic ganglia. The afferent sympathetic fibres take the reverse course.

The fibres of the **pulmonary plexuses** are distributed along (*a*) the bronchial tree, and (*b*) the pulmonary vessels. The *plexus along the bronchial tree* includes ganglion-cells (postganglionic neurones of the vagus) which provide constrictor fibres to the muscles of the bronchial tree and secretory fibres to the glands; postganglionic fibres of the sympathetic have the opposite effects. Afferent vagal endings ("plain muscle-spindles"), present throughout the entire bronchial tree, are excited by the stretching of the lung during inspiration (Hering-Breuer reflex); afferent vagal fibres, having free nerve-endings in the epithelium throughout the bronchial tree, are concerned in the cough-reflex. The *plexus along the pulmonary vessels* brings vagal and sympathetic efferent fibres (postganglionic) to the vessels—most of the vasodilator fibres being vagal and most of the vasoconstrictor fibres being sympathetic. Afferent fibres, having free nerve-endings in the pulmonary pleura, pass *via* the interlobular septa to this plexus. Their central connexions are unknown. The pulmonary pleura is, nevertheless, insensitive to touch.

Radiographic Examination of Thorax.—In radiographs of the chest the ribs are clearly visible as they sweep round from the vertebral column to the costal cartilages. The posterior portions of the ribs are more compact than the anterior portions and therefore cast a denser shadow. The costal cartilages are not visible unless they are calcified. The clavicles are clearly seen, and the scapulæ and the shoulder joints may be included in whole or in part, depending on the size of the film used. When the chest is radiographed, the film is usually placed in front of the patient and the shoulders are displaced forwards so that the shadows of the scapulæ do not obscure the lung-fields.

In addition to the bony structures of the thoracic wall, some of the soft tissues may be visible. Thus, the lower end of the sterno-mastoid and the fold of the skin as it passes over the clavicle may be seen. The female breast casts a shadow, the density of which varies with the development of the organ (Pls. LXII, p. 696, LXVIII, Fig. 1); the nipple may be visible in both sexes. In the male, the lower margin of the pectoralis major, if well developed, may cast a shadow.

In health, the **lungs**, because of their air-content, do not absorb radiation to any extent, and in consequence the lung-fields, on each side of the shadow of the mediastinum, appear dark in radiographs. The translucency of the lungs is distinctly greater at the end of inspiration because of the increase of their air-content; and, for the same reason, the lung-fields appear specially dark in *emphysema*—a pathological condition in which the alveoli are permanently dilated. On the other hand, anything that diminishes the relative amount of air in the lung (congestion, pneumonia, etc.) reduces its permeability to the passage of the rays.

The lung-fields are not homogeneous, however, for the beam, while it passes easily through the substance of the lung, is absorbed to some extent by the blood-vessels. The **blood-vessels** give rise to the X-ray "pattern" of the lung; and they can be seen as white shadows ramifying from the hilum, branching and becoming narrower as they extend out to the periphery of the field (Pl. LXV, p. 704).

When a vessel is seen end-on it casts a circular shadow that is homogeneously dense; it should never be confused with the shadow of a calcified lymph-gland, which is irregular in both outline and density. The vessel that accompanies the ep-arterial bronchus is often seen end-on near its origin (Pl. LXVIII, Fig 1). Where the shadow of one vessel crosses that of another, an area of increased density is produced; this superimposition of the shadows of blood-vessels occurs throughout the lung-field and is a main factor in the production of the "lung-pattern".

The white shadows cast by the blood-vessels are often attributed to bronchi; but **bronchi**, since they are filled with air, do not absorb radiation and therefore, in general, they merge into the dark lung-field. When bronchi are, in fact, recognizable, it is not because they cast a shadow but because their air-content makes them *more* radio-translucent than the surrounding tissues, so that they appear as darker areas in contrast to the white shadows of the blood-vessels (Pls. LXVI, p. 705, LXVII). In this connection it is interesting to note that the **trachea** is easily recognized as a median, dark area passing from the neck into the superior mediastinum (Pl. LXV). The fact that the trachea is radio-translucent makes it obvious that bronchi, with thinner walls, cannot produce the ramifying white shadows in the lung-field. Occasionally a bronchus—particularly the

ep-arterial bronchus—is visible end-on, and it is then recognized as a circular dark area surrounded by a white line (Pl. LXVIII, Fig. 1). The white line is produced by the wall of the bronchus which, because of its direction, can absorb sufficient radiation to enable it to cast a shadow.

The bronchi can be rendered plainly visible by the injection of an iodized oil through the trachea. This procedure—harmless to the patient, provided too much oil is not used—makes the relation of the bronchi to the blood-vessels evident; and, by its means, not only the main bronchi and their primary branches but even the **bronchioles** may be displayed (Pls. LXII, LXIII, p. 696). During inspiration the main bronchi and their primary intra-pulmonary branches are lengthened and spread out a little; in expiration they shorten and tend to come together as the volume of the lung diminishes. Figs. 594 and 595 give a general impression of the respiratory alternation in the form of the lungs and of the bronchial tree. (See also Peirce & Stocking, 1939.)

The **broncho-pulmonary lymph-glands** are not visible unless they are enlarged by disease. Even small glands, however, if calcified, may be recognized as irregular, mottled shadows near the hilum of the lung.

The **pleura**, unless it is thickened by disease, is hardly visible in an ordinary radiograph. The cervical pleura, however, may cast a recognizable shadow as the X-ray beam passes tangentially through it; and the pulmonary pleura also may be seen in the interlobar fissures when its double layer presents an edge to the beam. Thus, in the usual anterior radiograph of the chest, only the horizontal fissure of the right lung is visible, but in lateral views the oblique fissures also may be recognized. Thickening of the pleura by disease increases the density of its shadow, and it may then appear as a double line. Pleural effusions also may be recognized by an increased density of the lower lateral part of the lung-field, and the fluid in the pleural cavity may obscure the costo-diaphragmatic recess and the outline of the diaphragm.

The domes of the **diaphragm** delimit the lower margins of the lung-fields. The right dome is higher than the left. When the radiograph has been taken with the patient erect, the air-bubble in the fundus of the stomach (p. 620) is usually conspicuous under the left dome (Pl. XLVIII, p. 599).

Foreign bodies in the accessible bronchi may be seen by direct view through a broncho-scope, but radiography is required to locate them if they have passed into the smaller bronchi or, as in the case of bullets or shell-fragments, if they are embedded in the lung-substance.

The radiography of the **mediastinum** (heart and great vessels) is dealt with after the description of the heart in the Section on the Blood-Vascular System.

DEVELOPMENT OF RESPIRATORY SYSTEM

The larynx, trachea, bronchi, and lungs all arise from a median longitudinal groove, called **the laryngo-tracheal groove**, which makes its appearance in the ventral wall of the primitive pharynx at its œsophageal end when the embryo is about 3·0 mm. in length. The groove is soon pinched off from the fore-gut by lateral constrictions and is thus converted into the primitive respiratory tube (Fig. 607). This conversion begins at the caudal end and proceeds headwards, but it leaves the cephalic end of the tube in communication with the fore-gut.

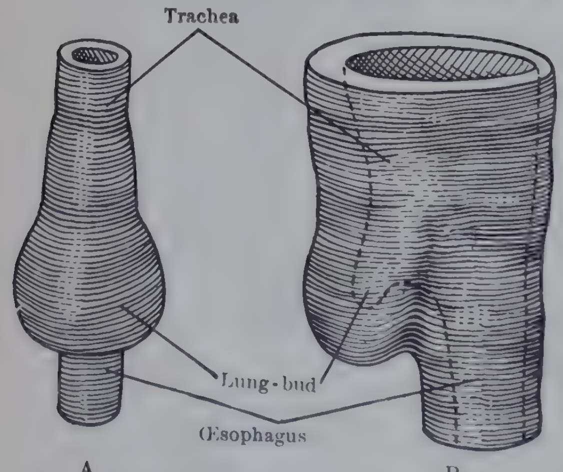

FIG. 607.—DEVELOPMENT OF RESPIRATORY TUBE IN 4·25 MM. HUMAN EMBRYO. (After Grosser, 1912.) A, ventral view; B, lateral view.

The cephalic end of the primitive respiratory tube forms the larynx; the succeeding portion forms the trachea; whilst the caudal end—the 'lung-bud'—bifurcates into two bulbous swellings called the pulmonary diverticula. These grow tailwards, one on each side of the heart, into mesodermal masses derived from the dorsal attachment of the septum transversum. The epithelium of the respiratory tube and of its future branches is of entoderm derived originally from the fore-gut; the remaining elements of the lungs are derived from the mesodermal masses.

Larynx. At first the cephalic end of the laryngo-tracheal groove lies caudal to the fourth pair of pharyngeal arches in a region representing the fifth and sixth arches; but these soon move headwards to a position between the ventral ends of the fourth pair of pharyngeal arches. The *laryngeal muscles*, however, are

derived from the sixth pair of arches and, hence, are supplied by the nerves of these arches, namely, the recurrent laryngeal nerves. The slit-like opening of the primitive respiratory tube becomes the *rima glottidis* of the fully-developed larynx, whilst the parts of the larynx above this level are pharyngeal upgrowths (Fig. 608).

In embryos of about 5 mm. in length, a median elevation bulges headwards from the ventral wall of the pharynx and receives the ventral ends of the third and fourth pharyngeal arches. The opening of the primitive respiratory tube is immediately dorsal to this elevation, while upgrowths, in which the fifth and sixth arches are represented, bound the opening laterally. The median elevation gives rise to the *epiglottis*, and the lateral upgrowths become the *ary-epiglottic*

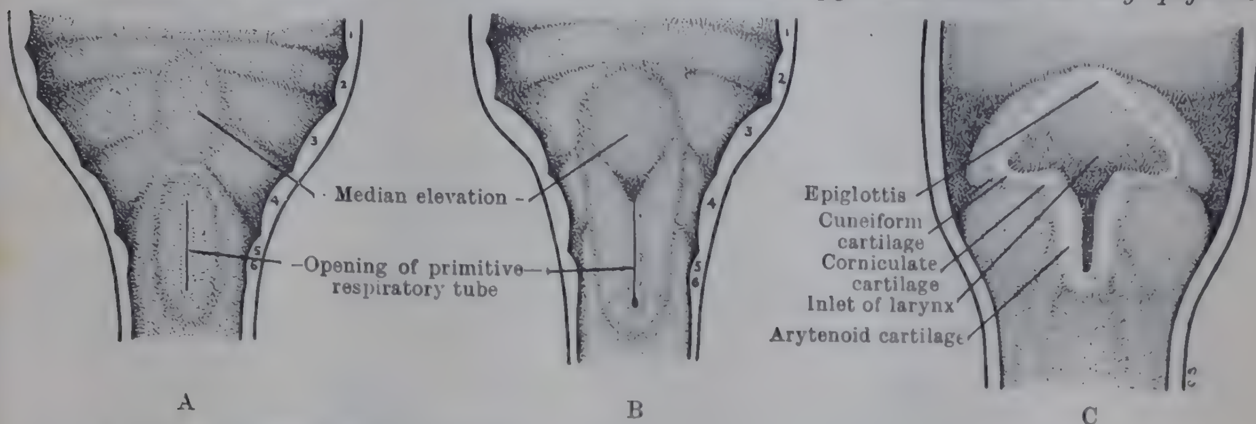

FIG. 608.—DEVELOPMENT OF LARYNX. (A and B, after Frazer, 1940 ; C, after Arey, 1946.)
A, 6 mm. human embryo ; B, 8·5 mm. human embryo ; C, 40 mm. human embryo.

folds. About the fourth month, excavation of the medial side of each of these folds begins and gives rise to the corresponding *sinus* (ventricle) of the larynx. The lower margin of each sinus becomes a *vocal fold.*

At the end of the fourth week the cartilaginous framework of the larynx is indicated by mesodermal condensations, though actual cartilage does not appear until the seventh week. The arytenoid and corniculate cartilages, which form in the upgrowths above the level of the glottis, the cricoid cartilage, and the cartilages of the trachea are all continuous at first. The *epiglottic* and *cuneiform cartilages* develop in the median elevation and likewise are originally continuous.

The *thyroid cartilage* first appears as a pair of separate mesodermal plates, one on each side of the larynx, connected ventrally by dense mesoderm. Some time after chondrification has begun in the plates, a cartilaginous element arises in this dense ventral mesoderm and above it two smaller nodules of cartilage appear. As chondrification proceeds, the thyroid cartilage is formed by the fusion of all these initially separate components. The cartilages of the fourth pair of pharyngeal arches are represented in the plates, and perhaps those of the fifth pair. A foramen in the fully developed thyroid lamina is the result of incomplete chondrification, probably attributable to the passage of a small blood-vessel. The superior horn of the thyroid cartilage is at first continuous with the greater horn of the hyoid bone, and part of the connecting bar remains as the *cartilago triticea.*

The precartilaginous rudiments of the *cricoid* and *arytenoid cartilages*, though at first continuous with each other, become differentiated by the appearance of a separate cartilaginous centre for each arytenoid and an incomplete ring (for a time deficient behind) for the cricoid. The cricoid thus resembles developmentally a tracheal ring, to which it probably corresponds morphologically. Chondrification proceeds in the cricoid from two centres, one on each side. These centres soon unite ventrally, but chondrification proceeds more slowly into the posterior lamina. The *corniculate cartilages* are merely detached portions of the arytenoid cartilages.

Trachea.—The trachea is developed from the intermediate portion of the respiratory tube.

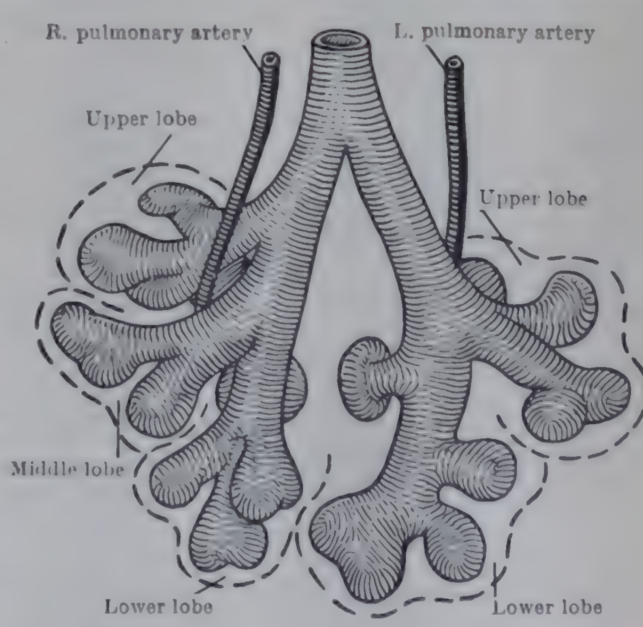

FIG. 609.—DEVELOPMENT OF LOBES OF LUNGS IN 14 MM. HUMAN EMBRYO. (From Arey, 1946, after Ask.)

Lungs.—The bronchi and lungs are developed from the two diverticula at the caudal end of the laryngo-tracheal groove and from the mesodermal tissue into which these grow. Both diverticula elongate, and almost immediately subdivide into vesicles—the right into three

and the left into two - thus early indicating the lobes of the respective lungs (Fig. 609). As the primitive respiratory tube lies in the median plane in the posterior attachment of the septum transversum, each pulmonary diverticulum grows laterally and backwards into the corresponding pleural canal (pericardio-peritoneal canal), *i.e.*, the future pleural cavity, carrying before it a covering of mesoderm. From this mesoderm are derived the blood-vessels and other tissues which build up the lung; from the entodermal lining of the primitive respiratory tube the epithelial lining of the air-passages is derived. The entodermal pulmonary diverticula branch and re-branch and push their way into the pulmonary mesoderm until the complete bronchial tree is formed (Fig. 610).

When the ramification is complete, the bulbous ends of the various branches represent alveoli clustering around the alveolar ducts into which each terminal bronchiole divides.

At first the lung is devoid of air-cells, but between the sixth month and full-term the alveoli make their appearance on the alveolar ducts. By the close of the fourth month of intra-uterine life the columnar cells which line the trachea and bronchi have become ciliated.

Growth of the lung is not interrupted at birth, but since the terminal branches are now expanded by air there must be a new form of budding. At any stage of post-natal growth the terminal branches bear evidence, in the alveoli projecting from them, that they were once alveolar ducts. These alveoli become obliterated by the advance of the muscle-sheet which extends over the length of the alveolar duct (Fig. 605).

It was the general belief that the cuboidal cells, which at one stage of fœtal life form a

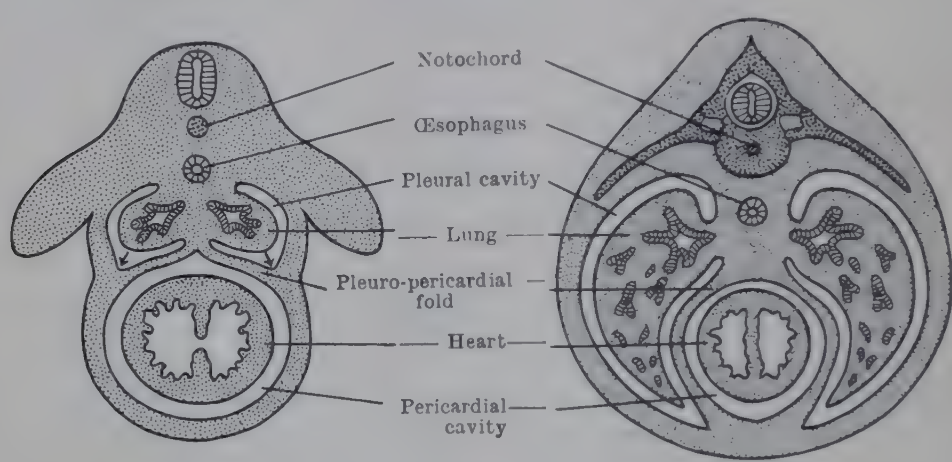

FIG. 610.—VENTRAL EXTENSION OF PLEURAL CAVITIES DURING DEVELOPMENT. (Schematic ; after Patten, 1946.)

continuous lining for the alveoli of the lungs, become flattened at birth but remain in continuity. Recent studies, however, indicate (*a*) that towards the end of fœtal life the cells that line the last two generations of the entodermal tree become discontinuous and that capillaries push their way between these cells and help to line the alveoli; (*b*) that at the time of birth the alveolar ducts, the air-sacs, and the alveoli are lined with a capillary network —the epithelial cells persisting only singly or in isolated groups; and, further, (*c*) that in late fœtal life the lungs are not gland-like and completely unexpanded but have an opened-up appearance (which is reasonable, since respiratory movements take place during fœtal life) and though they sink in water, it is because they contain amniotic fluid, not air.

Pleural Cavities.—In the embryo there is a continuous body-cavity or cœlom. Its head-ward part, which becomes the pericardial cavity, communicates by means of a right and a left pleuro-pericardial opening with the pleural passage (pericardio-peritoneal canal) on each side, and these lead tailwards into the peritoneal cavity.

When the heart and pericardium are carried ventro-caudally, the pleural passages become greatly elongated, and their cephalic ends now open into the dorsal part of the pericardial cavity by the pleuro-pericardial openings, and their caudal ends open into the peritoneal cavity by the pleuro-peritoneal openings. As the common cardinal vein (duct of Cuvier) runs ventrally towards the septum transversum to enter the heart, it crosses lateral to the pleural passage.

The growing lung-bud pushes the medial wall of the pleural passage laterally, immediately caudal to this vein, and, after passing lateral to the vein, the bud expands within the body-wall in three directions: *headwards*, on the lateral side of the common cardinal vein, to form the apical part of the lung; *ventrally*, to form the anterior part, which thus detaches or dissects the pericardium and phrenic nerve from the body-wall (Fig. 610); and *tailwards*, to form the base of the lung. (See also p. 93 and Figs. 108-110.

The pleural cavity enlarges within the body-wall to keep pace with the ever-growing lung, and its openings into the peritoneal and pericardial cavities become closed. The pleuro-peritoneal opening is closed by the pleuro-peritoneal membrane which grows across it from the dorsal mesentery and septum transversum to a ledge formed on the body-wall caudal to the base of the lung—in post-natal anatomy its site is the vertebro-costal trigone (p. 452). Closure occurs earlier on the right side, and the liver covers the right opening: hence congenital diaphragmatic hernia, due to failure to close, is rare on the right side but not on the left.

The pleuro-pericardial opening is closed by the pleuro-pericardial membrane which grows medially across it, from the laterally situated ridge which contains the common cardinal vein to the medial wall of the opening just cranial to the lung-bud. Closure is assisted by adhesion of the surfaces of the pleural passage. The opening is at first caudal to the common cardinal vein, but, with the descent of the heart and septum transversum, it later lies dorsal. In post-natal anatomy its site is between the superior vena cava and the root of the lung. As the phrenic nerve lies alongside the vein, it also is ventral to the opening. Failure of the right opening to close is unknown in Man, due presumably to the persistence of the right superior vena cava, but the left opening occasionally remains widely open; in fact, it may be so dilated that the whole left side of the heart is in contact with the lung.

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UROGENITAL SYSTEM

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The **Urogenital System** is divided into:—(*a*) the *urinary organs* proper, which are concerned with the secretion, temporary storage, and discharge of the urine; and (*b*) the *reproductive* or *genital organs*, which arise from the same embryonic tissues as the urinary organs and retain an intimate relationship to them.

URINARY ORGANS

The urinary organs are:—the **kidneys**, where the urine is elaborated from the blood, the **ureters**, which convey the urine from the kidneys to the urinary bladder, the **urinary bladder**, where the urine is temporarily stored, and the **urethra**, by which it is voided.

KIDNEYS

Form and Size.—The kidneys are a pair of bean-shaped organs, brownish-red when fresh, and of a glistening appearance due to the fact that each of them is covered with a delicate fibrous capsule which is close-fitting though easily stripped off. They are approximately symmetrical in size and shape. Each kidney is about $4\frac{1}{2}$ inches (11 cm.) long, 2 inches (5 cm.) wide, and about $1\frac{1}{4}$ inches (3 cm.) thick; and it weighs about $4\frac{1}{2}$ ounces. It possesses an *upper* and a *lower end* or pole (of which the upper is generally the more bulky), an *anterior* and a *posterior surface*, and a *medial* and a *lateral border*. The lateral border is uniformly convex from the upper to the lower pole; the medial border is convex above and below but in the middle it forms a deep concavity which leads into a hollow that extends almost half-way through the kidney. This hollow is known as the **sinus** of the kidney; and the entrance into the sinus is called the **hilum**. The renal artery enters the sinus through the hilum; the renal vein and the upper, expanded part of the ureter leave the sinus by the same route.

Position.—Each kidney lies against the medial and posterior walls of a deep depression on the posterior wall of the abdomen near the vertebral column. In this region the vertebral column, partly covered by the psoas major muscle, projects forwards into the abdominal cavity leaving a deep gutter on each side. As these gutters pass downwards, they slope slightly forwards and laterally because the posterior abdominal wall itself slopes forwards and the psoas major muscles increase in bulk from above downwards. The gutters therefore are deep and fairly close together above but are shallow and farther apart below (Figs. 612 and 615). Consequently, the long axis of each kidney is not quite vertical but slopes laterally and slightly forwards from above downwards. Moreover, as the kidneys lie against the medial walls as well as the posterior walls of the gutters, they are slightly rotated on their long axes; their anterior surfaces are directed, therefore, laterally as well as forwards and their posterior surfaces medially as well as backwards. Likewise, the medial border of each kidney really faces medially and forwards, and the lateral border faces laterally and backwards (Fig. 612).

The two kidneys are not quite symmetrical in position; almost always the left is about half an inch higher than the right; and it is therefore slightly more medial, on account of the slope of the gutters in which they lie (Fig. 615). The

level of each kidney, however, varies slightly both with the respiratory movements and with posture, but the range of this normal physiological movement does not exceed an inch. During quiet respiration in the recumbent attitude, the hilum of the left kidney is approximately in the transpyloric plane about $1\frac{1}{2}$ inches from the median plane of the body, or about a finger's breadth medial to the tip of the ninth costal cartilage, and the hilum of the right kidney is about half an inch below this point. The lower pole of the kidney is about 2 inches from the median plane—the left in the subcostal plane and the right half an inch below this plane.

With reference to the posterior surface of the body the hilum of the left kidney is at the level of the spine of the first lumbar vertebra, or at the level of the line where the lateral border of the sacro-spinalis muscle meets the twelfth rib, and the lower pole is 2 inches or less above the highest point of the iliac crest (Fig. 614). Corresponding points on the right kidney are about half an inch lower.

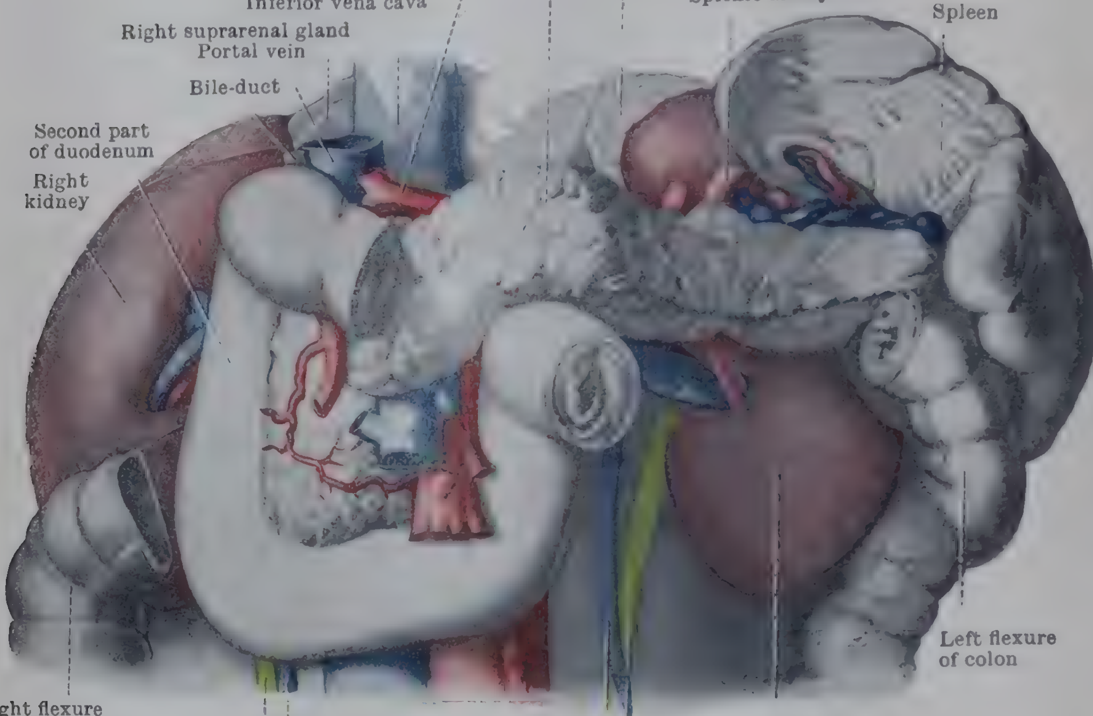

FIG. 611.—DISSECTION TO SHOW THE RELATIONS OF THE KIDNEYS. The greater part of the stomach has been removed by an incision made close to the pylorus. The transverse colon has been taken away, and the small intestine has been cut across close to the duodeno-jejunal flexure. (From a model by Birmingham.)

Renal Fascia and Fat.—Each kidney has a peculiarly intimate relationship to the corresponding suprarenal gland and is enclosed with it in a common investment of weak fascia, known as the **renal fascia**, one layer of which covers the front and the other the back of the enclosed organs. Outside this investing fascia and between it and the kidney (surmounted by the suprarenal gland) there is a variable amount of fat called the **renal fat**. The fat outside the renal fascia is known as *pararenal fat*; it is most abundant behind the lower end of the kidney. The fat within the fascia is called *perirenal fat* and is most abundant at the margins of the organ; it is traversed by weak fibrous strands which connect the renal fascia with the capsule of the kidney.

The two layers of the renal fascia fuse together a short distance above the suprarenal gland and join the fascia on the under surface of the diaphragm; lateral to the kidney also they fuse together and join the transversalis fascia. Below the kidney the two layers remain separate, the anterior gradually fading into retroperitoneal areolar tissue and the posterior joining the fascia over the iliacus muscle. The posterior layer, passing over the quadratus lumborum, is attached medially to the fascia of the psoas major at its posterior border. As it approaches the medial border of the kidney it then splits into two laminae: one turns laterally into the hilum of the kidney and is attached to the back

of the pelvis of the ureter; the other lamina blends with the psoas fascia and thereby gains an attachment to the bodies of the vertebræ just in front of the muscle. The anterior layer of the renal fascia extends across the aorta and inferior vena cava as a thin layer as far up as the origin of the superior mesenteric artery; above this level it loses itself in the connective tissue around the coeliac axis. From the anterior layer a distinct lamina also passes backwards medial to the kidney and blends with the anterior lamina of the posterior layer. This lamina is pierced by the renal vessels and the ureter (Martin, 1942); and its presence accounts for the limitation of perirenal effusions to one side of the body and for the explanation given by Mitchell (1939) that the anterior layer as well as the posterior is attached to the bodies of the vertebræ. See also the description in the Surface and Surgical Section (p. 1508), based on Mitchell (1950), and compare Figs. 612 and 1224.

Posterior Relations of Kidneys (Figs. 612-615).—If the kidney, together with the corresponding suprarenal gland and surrounding fascia and fat, is removed from the posterior abdominal wall, the boundaries of the gutter in

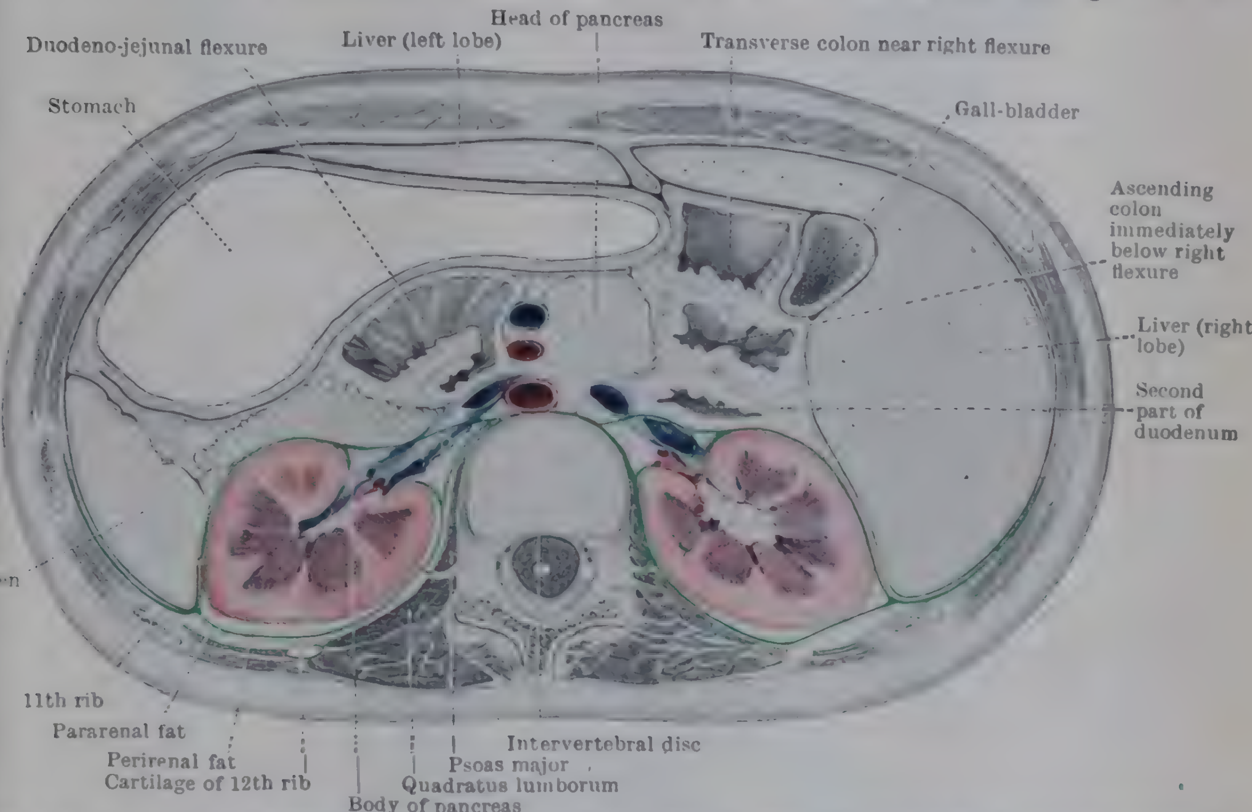

FIG. 612.—TRANSVERSE SECTION THROUGH ABDOMEN OF A CHILD. The position and the general relations of the kidneys are well seen, and the arrangement of the renal fascia is indicated. Cf. Fig. 1224, p. 1507. The fascia is coloured green.

which it lay can be seen. The medial boundary is formed by the psoas major muscle; and the medial part of the kidney overlaps the lateral side of this muscle. Lateral to this, and forming the posterior relation of most of the kidney, lies the quadratus lumborum muscle, and lateral to this again the aponeurosis of the transversus abdominis muscle, on to which the lateral part of the kidney extends for a short distance. But towards the upper end of the gutter the medial and lateral arcuate ligaments cross the psoas major and quadratus lumborum respectively, and above this line the diaphragm, arising from the ligaments, forms the uppermost part of the walls of the gutter. The supero-lateral third of the kidney therefore lies in front of the diaphragm.

Emerging from under the lower border of the lateral arcuate ligament and running downwards and laterally across the front of the quadratus lumborum muscle is the subcostal nerve accompanied by its vessels; and a little lower down the ilio-hypogastric and, below it, the ilio-inguinal nerve both emerge from the lateral side of the psoas major and run a parallel course. The subcostal and ilio-hypogastric nerves pierce the aponeurosis of the transversus abdominis a short distance lateral to the quadratus lumborum, and the ilio-inguinal nerve pierces it a little farther forwards (Fig. 615).

In this region, some bony structures can easily be felt through the diaphragm

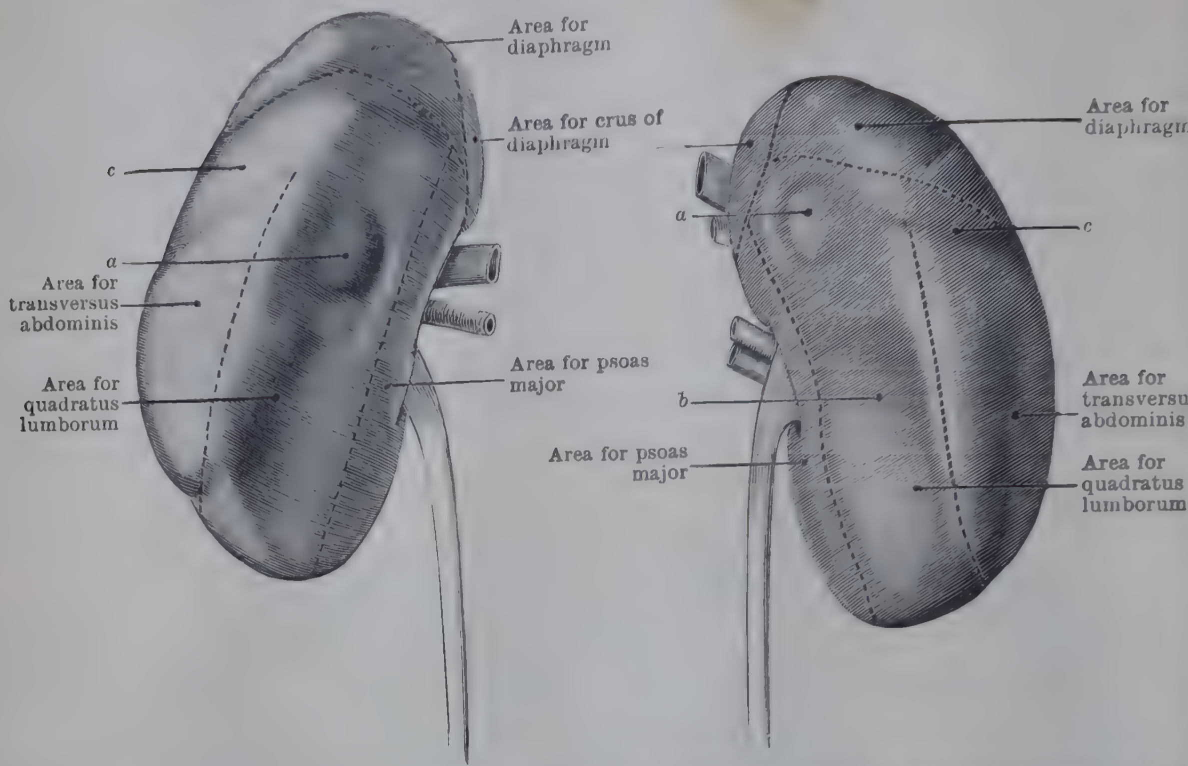

Fig. 613.—Posterior Surfaces of the Kidneys. The dotted lines mark out the areas in contact with muscles of the posterior abdominal wall.

a and *b*. Depressions corresponding to transverse processes of first and second lumbar vertebræ.
c. Depression corresponding to the twelfth rib.

and quadratus lumborum. The twelfth rib runs downwards and laterally behind the diaphragm, and its lateral part passes for a variable distance into the abdominal

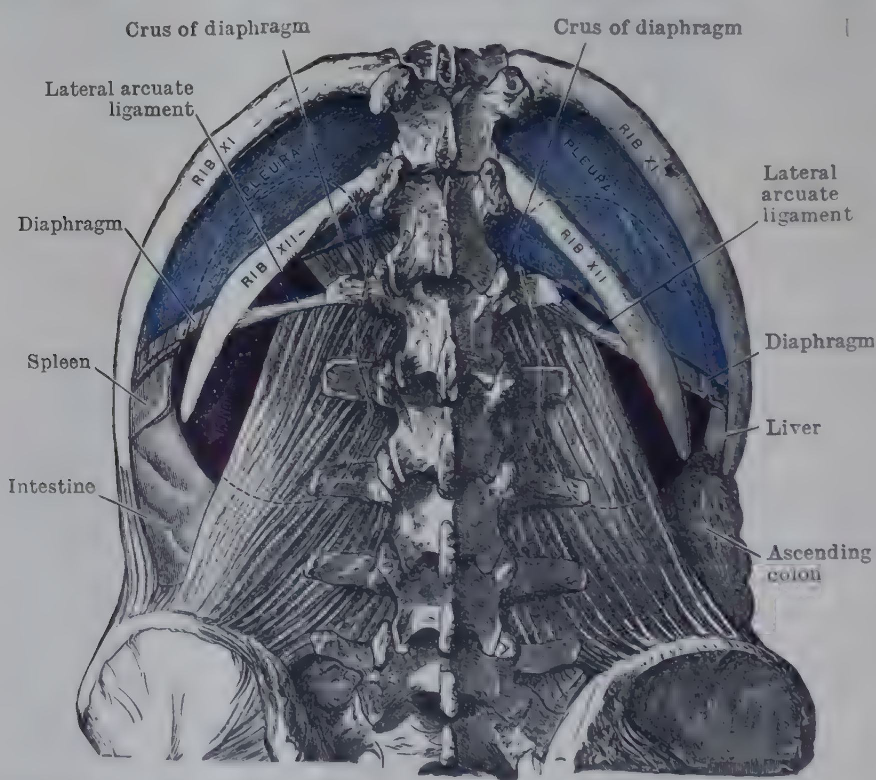

Fig. 614.—Dissection from Behind to show the Relation of the Two Pleural Sacs to the Kidneys. The outline of the concealed portions of the kidneys (which are more alike in level than usual) is indicated by dotted lines.

wall just lateral to the upper end of quadratus lumborum: the transverse process of the first lumbar vertebra lies at the level of the junction of the medial and

lateral arcuate ligaments, and those of the other vertebræ at correspondingly lower levels—their tips being behind the medial edge of the quadratus lumborum. If the kidneys have been hardened *in situ* shortly after death in a thin subject, their posterior surfaces are generally moulded by the muscles and bony structures against which they lay (Fig. 613), but stress should not be laid on this fact, for it is merely a post-mortem phenomenon and can easily suggest that the kidneys are less mobile than they are. Moreover, it is of the utmost importance to realize that the part of the twelfth rib which lies behind the diaphragm is separated from the diaphragm by the costo-diaphragmatic recess of the pleura, which extends down as far as a line drawn from the middle of the twelfth rib to a point midway between

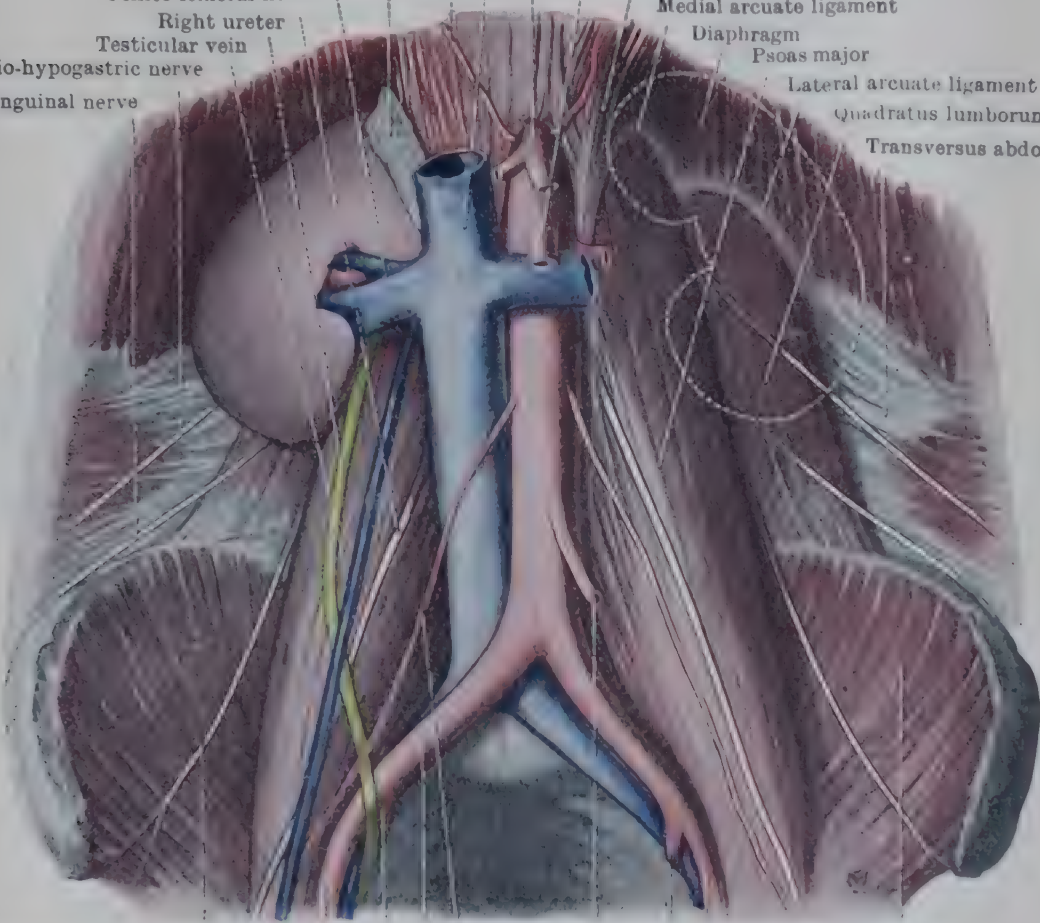

FIG. 615.—DISSECTION TO SHOW THE RELATION OF KIDNEY AND URETER TO THE POSTERIOR ABDOMINAL WALL. The dotted outline indicates the position of the left kidney

the head of the twelfth rib and the transverse process of the first lumbar vertebra (Fig. 614). The pararenal fat behind the upper part of the kidney is therefore separated from the pleura by only a very thin sheet of diaphragm; and as this part of the diaphragm is often partly deficient in the vertebro-costal trigone, especially on the left side of the body, the pararenal fat and the pleura may be in direct contact.

More remote posterior relations of the kidneys are as follows:—The middle layer of the lumbar fascia extends medially behind the quadratus lumborum as far as the tips of the transverse processes of the lumbar vertebræ; the upper three lumbar arteries run laterally behind the quadratus lumborum and then pierce the aponeurosis of transversus abdominis (the fourth lumbar artery usually passes in front of the quadratus lumborum but at a level that is below the position of the dead and immobile kidney found in dissecting-room material). Farther back

still, the sacro-spinalis muscle covers the transverse processes of the lumbar vertebræ and overlaps the quadratus lumborum; and it in its turn is covered behind by the posterior layer of the lumbar fascia giving origin to the serratus posterior inferior and the latissimus dorsi muscles.

Anterior Relations of Kidneys (Figs. 611 and 616).—A small portion of each kidney, near the upper pole, is covered by the corresponding suprarenal gland, part of which lies on its anterior aspect and extends downwards for a short distance along its medial border, the left generally to a slightly greater extent than the right. The other anterior relationships of the two kidneys are quite different; and, as already pointed out, all other organs in front of the kidney have a less intimate relationship to it, for they all lie outside the renal fascia, whereas the suprarenal gland is enclosed along with the kidney inside this fascia.

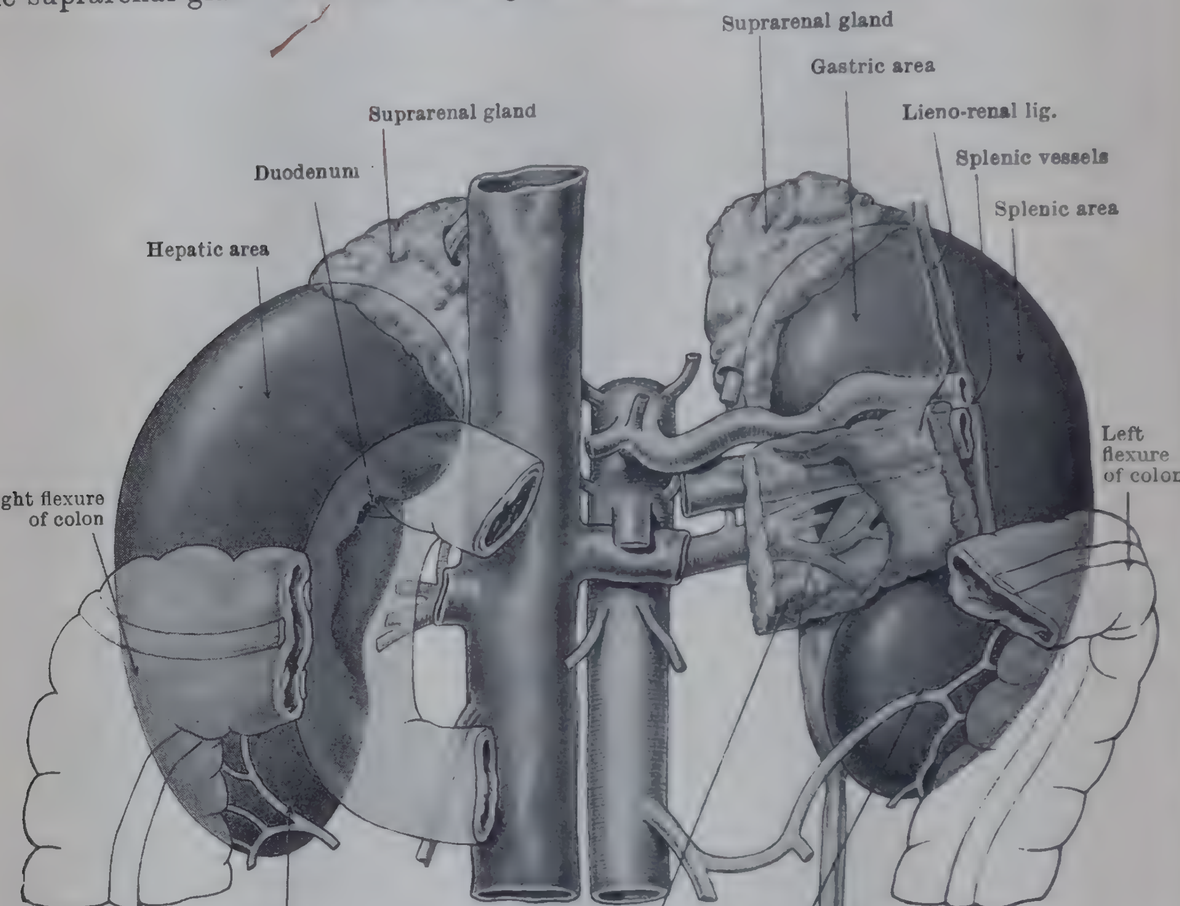

FIG. 616.—DIAGRAM OF ANTERIOR RELATIONS OF KIDNEYS.
The pancreas and certain other parts are shown as if transparent.

Anterior Relations of Right Kidney.—Below the area covered by the suprarenal gland, the anterior surface of the right kidney for about two-thirds of its extent is in relation with the back of the right lobe of the liver. The uppermost part of this hepatic area is usually related to the bare area of the liver, from which it is separated by some loose areolar tissue, but most of the hepatic area is covered by peritoneum of the greater sac which is reflected from the back of the liver on to the front of the kidney. Below the hepatic area, the region adjacent to the lower pole is in relation with the right flexure of the colon, and the region adjoining the hilum is covered to a variable extent by the second part of the duodenum, both these organs being separated from the kidney by loose areolar tissue. Below and medially, the peritoneum is reflected forwards from the hepatic area to cover the colon and the second part of the duodenum. At the extreme lower end of the kidney there is sometimes a small gap between the colic and duodenal areas, and, when this is present, it is covered with peritoneum of the greater sac that passes up from the posterior abdominal wall on to the front of the kidney and separates this small area from coils of small intestine.

Anterior Relations of Left Kidney.—Below and lateral to the area covered by the suprarenal gland there is a small triangular region covered with peritoneum of the lesser sac which passes down from the front of the suprarenal gland, and this region is separated from the posterior surface of the stomach by the lesser sac of the peritoneum. Below, this gastric area is bounded by the body of the pancreas, which lies across the middle of the kidney; and laterally the area is bounded by the line of attachment of the lieno-renal ligament, which runs approximately from the upper pole of the kidney to the junction of the middle and lower thirds of its lateral border. The peritoneum which covers the gastric area passes downwards on to the front of the body of the pancreas; from the pancreas it passes downwards and forwards as the anterior layer of the transverse mesocolon, while laterally it is reflected forwards as the medial layer of the lieno-renal ligament. The body of the pancreas is separated from the kidney by loose areolar tissue in which the splenic vein runs medially, while the artery runs its tortuous course along the upper border of the pancreas. The area lateral to the line of attachment of the lieno-renal ligament is separated from the spleen by the peritoneum of the greater sac which passes on to it from the posterior abdominal wall and is then reflected forwards as the lateral layer of the lieno-renal ligament. Below the pancreatic area, the lateral part is covered by the left flexure of the colon and the upper part of the descending colon—separated by loose areolar tissue—and the medial part by the peritoneum of the greater sac which passes up from the posterior abdominal wall to be reflected forwards and downwards as the posterior layer of the transverse mesocolon and to pass laterally on to the left flexure and the descending colon. This medial area is in relation to coils of jejunum in front of the peritoneum and to the ascending branch of the superior left colic artery, which crosses it behind the peritoneum. The obliquity of the anterior surface of the kidney has already been pointed out; and, if this is borne in mind, it will be realized that though the spleen and left flexure of the colon are described as anterior relations of the left kidney, they are really more lateral than anterior.

Medial Relations of Kidneys (Figs. 612 and 615).—Medial to each kidney is the corresponding psoas major muscle and psoas minor (if present); and along the medial margin of the psoas lies the abdominal part of the sympathetic trunk. On a more anterior plane, each kidney is related medially to the corresponding suprarenal and renal vessels, ovarian or testicular vein, and upper end of ureter. More anteriorly still there is the inferior vena cava on the right side and the abdominal aorta on the left.

Sinus of Kidney (Figs. 617 and 619).—The sinus is the hollow within the kidney, and its long axis corresponds to that of the kidney itself. Its walls are thick, being formed by the substance of the kidney, and, except where they are covered by the calyces of the ureter, they are lined with a continuation of the capsule of the kidney, which is reflected into the sinus over the lips of the hilum. The floor of the sinus is not even but presents a series of small conical elevations, called **renal papillæ**, which vary from six to fifteen in number. Radiating from each papilla there are several small ridges of kidney substance separated by depressed areas. The blood-vessels and nerves enter and leave the kidney by piercing the depressed areas. On the summit of each renal papilla there are many minute openings, which are the terminal apertures of the secretory tubules of which the kidney is mainly composed; the urine escapes through these foramina into the calyces of the ureter. The cavity of the sinus is filled with fat, embedded in which lie the calyces of the ureter, branches of the renal artery and tributaries of the renal vein. The artery usually branches and the tributaries of the vein unite a short distance outside the hilum; and, within the sinus, the tributaries of the vein are most anterior, while farther back are the calyces of the ureter, with branches of the artery both in front and behind.

Fixation of Kidneys.—The kidneys are held in position partly by the renal vessels and the surrounding fat and fascia, but mainly by the tension of the muscles of the anterior abdominal wall transmitted through the other abdominal viscera and acting against the inclined plane formed by the posterior abdominal wall.

Kidney in Section.—Sections through the kidney (Figs. 617 and 619) show that it is composed to a large extent of a number of conical masses—known as **renal pyramids**. The pyramids constitute, collectively, the **medulla** of the kidney, and are arranged with their bases directed towards the surface and their apices projecting into the lesser calyces of the pelvis of the ureter in the renal sinus, where they form the renal papillæ. The pyramids are more numerous than the papillæ, two or three usually ending in each papilla in the middle part of the kidney, and sometimes as many as six or more in each papilla near its ends. The bases of the pyramids are separated from the surface by a layer called the **cortex** of the kidney. The cortex not only covers over the bases of the pyramids, but also sends in prolongations, known as **renal columns**, between the pyramids, towards the sinus. In section, both parts have a striated appearance, but the cortex is less markedly striated and is usually different in colour. The **basal part** of each pyramid appears to be composed of alternate dark and light streaks, while the **papillary part** is often of a lighter colour, and is very faintly striated.

The larger blood-vessels are seen between the pyramids; and some of their main branches are visible passing across the bases of the pyramids.

In the fœtus and young child, and sometimes, though much less distinctly, in the adult, the surface of the kidney is marked by a number of grooves that divide it into polygonal areas (Fig. 679, p. 802) The areas represent the **lobes** or **reniculi** of which the kidney is originally composed, and each corresponds to one papilla with its pyramids and surrounding cortex.

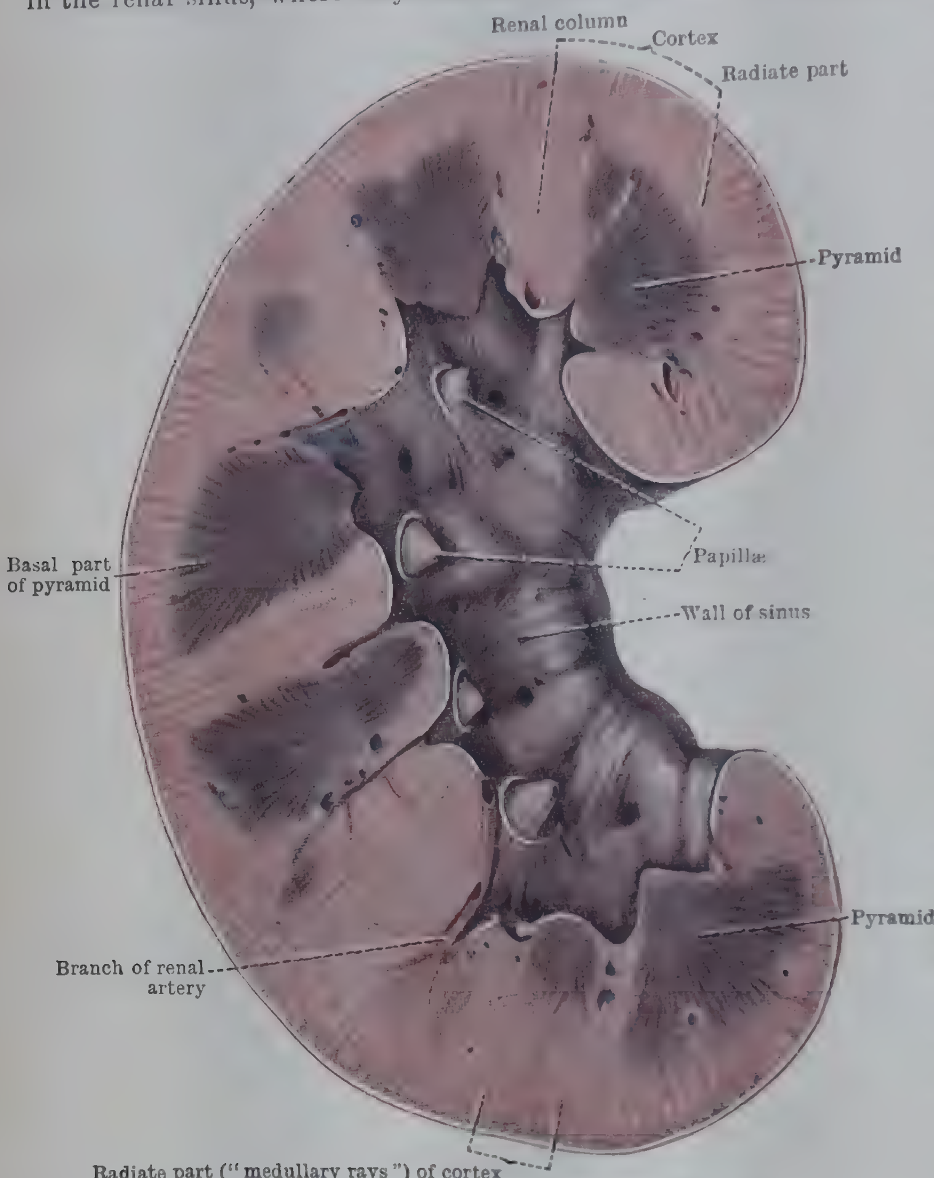

FIG. 617.—LONGITUDINAL SECTION THROUGH THE KIDNEY.

The vessels and fat have been removed to show the wall of the sinus of the kidney. The points where the vessels enter the substance of the kidney are seen as holes in the wall of the sinus.

An examination with an ordinary pocket lens shows that it is the lighter striæ of the bases of the pyramids which are continued into the cortex. As they pass through the cortex towards the surface of the kidney the striæ become less distinct, and appear, when cut longitudinally, as separate ray-like prolongations carried outwards from the bases of the pyramids. The parts of the cortex which seem in this way to be continuations of the medulla are called "medullary rays" or the **radiate part** of the cortex. The part of the cortex which intervenes between them is darker in colour and forms what is known as the **convoluted part** or "labyrinth". The appearance presented by the cortex in section varies much according to the plane in which the section has been taken. If the section is parallel to the axis of a pyramid, the medullary rays will appear as isolated streaks directed from the base of the pyramid towards the surface of the kidney, and separated from one another by narrow strips of the convoluted part. In sections made at right angles to the axis of a pyramid, or cutting this axis obliquely, the convoluted part presents the appearance of a continuous net the meshes of which are occupied by the rays, and the rays now exhibit circular or oval outlines. In a similar manner sections through the bases of the pyramids differ much in appearance according to the plane in which they are cut.

Kidney-Tubules.—The glandular substance of the kidney is composed of a vast number of minute **renal tubules**, each of which has an exceedingly complicated course (Fig. 618). The wall

of each tubule consists throughout of a basement membrane and of an epithelial lining, but the lumen of the tubule and the character of the epithelium vary much in its different parts. Every tubule begins in a thin-walled spherical dilatation, known as a **glomerular capsule**, into which a complicated loop of capillary blood-vessels or **glomerulus**, covered by a reflexion of the delicate wall of the capsule, is invaginated (Fig. 618). The capsules with their enclosed capillaries are called **renal corpuscles**, and they are all placed in the convoluted portion of the cortex, where they may be recognized as minute red points just visible to the unaided eye and best marked when the renal vessels are congested. The part of the tubule that leads from the capsule—*first convoluted tubule*—is very tortuous and lies within the convoluted part of the cortex. Passing from the convoluted part, the tubule enters a medullary ray, in which its course becomes less complicated, and here it receives the name of *spiral tubule*. Leaving the medullary ray, the tubule enters the basal portion of the pyramid, and, diminishing in diameter, it pursues a straight course towards the apex of the pyramid, forming the so-called *descending limb of Henle's loop*. Within the apical portion of the pyramid the tubule suddenly bends upon itself, forming the *loop of Henle*, and, reversing its direction, it passes back again through the base of the pyramid into a medullary ray of the cortex as the *ascending limb of Henle's loop*. The ascending limb exhibits a slight spiral twisting. Leaving the medullary ray again, the tubule once more enters the convoluted part of the cortex, where its outline becomes so uneven that the name *irregular* or zigzag *tubule* is applied to it. While still within the convoluted part, its contour having acquired a more uniform appearance, the tubule receives the name of *second convoluted tubule*; this tubule finally ends in a short *junctional tubule*, which passes back into a medullary ray and joins a *collecting tube*. Each collecting tube receives numerous renal tubules, and pursues a straight course through a medullary ray of the cortex and the pyramid. Finally, several collecting tubes, uniting together, form an *excretory tube*, which opens on the summit of a renal papilla into a calyx of the ureter by one of the minute foramina already described. In microscopic sections the various portions of the renal tubule may be distinguished by the position which they occupy and by the character of the lining epithelium.

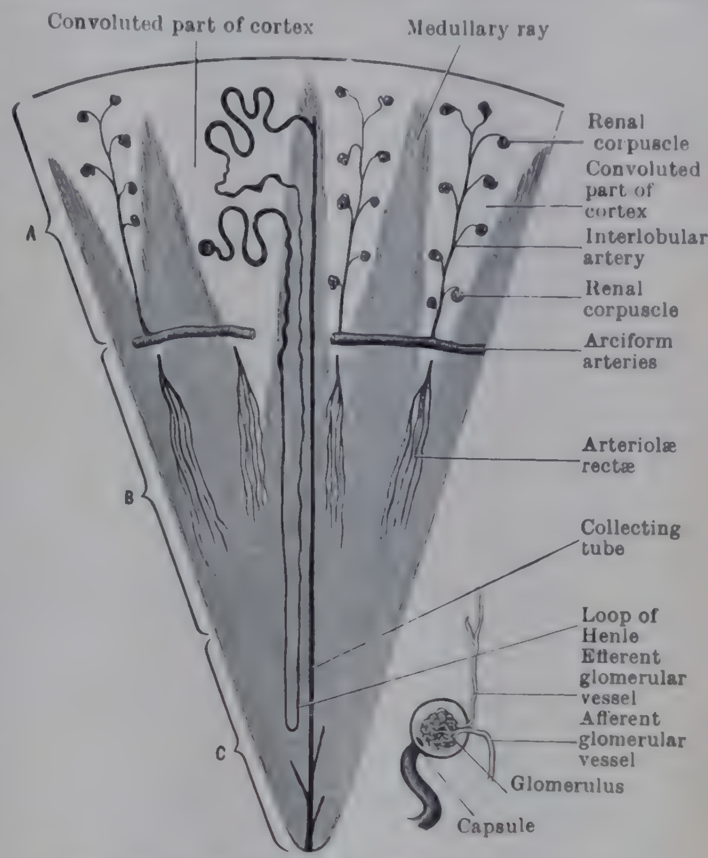

Fig. 618.—Diagrammatic Representation of the Structures forming a Kidney-Lobe.

In the middle part of the figure the course of one of the renal tubules is indicated, and, on each side of that, the disposition of the larger arteries. A, Cortex; B, Basal portion, and C, Papillary portion of pyramid.
The small diagram illustrates the connexions of the structures that compose a renal corpuscle.

Supporting Tissue of Kidney.—The tubules and the blood-vessels are all united together by a very small amount of areolar tissue which completely surrounds each tubule and blood-vessel and binds it to its neighbours. It has been found possible to obtain an accurate idea of the arrangement of this areolar tissue by submitting thin sections of the kidney to the action of certain digestive fluids. When that is done the tubules and blood-vessels are removed, and the areolar tissue stroma is left behind. The areolar tissue thus revealed is seen to form a continuous network, the spaces in which faithfully reproduce the outlines and the arrangement of the renal tubules. The network of the stroma is continuous with the capsule of the kidney.

Vessels and Nerves of Kidney.—The **renal arteries**, one on each side, arise directly from the aorta. The left is usually slightly higher than the right and they are both large vessels relative to the size of the kidneys. Each artery lies behind the corresponding renal vein, and at or just outside the hilum of the kidney it divides into three or four branches, one of which passes behind the upper, expanded part of the ureter while the others lie in front of the ureter, between it and the renal vein. Within the sinus each branch divides further. Having entered the substance of the kidney, the larger arteries lie in the intervals between the pyramids and are called **interlobar arteries**. These vessels divide and form a series of incomplete arterial arches—the **arciform arteries**—which pass across the bases of the pyramids. Although we speak of arterial arches, it must be understood that no anastomosis between the branches of the interlobar arteries actually takes place, but that each artery which enters the wall of the kidney-sinus is an 'end-artery' with an isolated distribution. The arterial arches give off a number of vessels which pass through the convoluted part of the cortex towards the surface

of the kidney; they are known as the **interlobular arteries**, and they lie at very regular intervals. From them a number of short branches arise, termed **vasa afferentia**, each of which proceeds to the dilated extremity, or capsule, of a renal tubule. There, the vas afferens breaks up into a much-convoluted capillary mass, called a *glomerulus*, which is contained within the invagination of the capsule. The little vessel—**vas efferens**—which issues from the glomerulus, instead of running directly into a larger vein, breaks up, after the manner of an artery, into capillaries which supply the convoluted tubules of the labyrinth and the longitudinal tubules of the medullary rays. At the bases of the pyramids, where the longitudinal tubules pass into the pyramids, the efferent vessels of some of the glomeruli do not break up immediately into capillaries but pass as fine arterioles into the pyramids and then break up into a capillary network around the tubules of the pyramid. These fine arterioles, known as the **arteriolæ rectæ**, are just visible to the naked eye, and they give the bases of the pyramids their striated appearance (Fig. 618). It has recently been shown that near the base of the pyramids there are some large glomeruli in which the afferent and efferent vessels are of equal calibre. These glomeruli are apparently non-functional and from their efferent vessels the arteriolæ rectæ arise. In certain conditions the renal blood-flow can be shunted through the vessels of these non-functional glomeruli and the arteriolæ rectæ directly from the renal artery into the renal veins without passing through the functional glomeruli of the cortex proper (Trueta *et al.*, 1947). Franklin (1949) gives an account of the history of research on the renal circulation.

The fibrous capsule of the kidney receives minute branches from the interlobular arteries, some of which pierce the capsule and communicate by capillaries with the vessels of the renal fat.

Veins corresponding to the interlobular arteries and arteriolæ rectæ collect the blood from the capillaries around the tubules and unite to form a series of complete arches across the bases of the pyramids. From the venous arcades, vessels arise which traverse the intervals between the pyramids and reach the sinus of the kidney, where they unite to form the tributaries of the renal vein. Some small veins in the superficial part of the cortex communicate through the fibrous capsule with minute veins in the renal fat. The main tributaries issue from the sinus and unite to form the **renal vein**, which runs a direct course to end in the inferior vena cava.

Variations in the renal vessels are common. Supernumerary arteries and veins or supernumerary branches of the renal artery and vein are frequent. The abnormal vessel may enter or leave the kidney within the sinus or at some other point. Small accessory renal veins from the lower pole of the kidney are especially common.

The **lymph-vessels** of the kidney end in the aortic lymph-glands (p. 1416).

The **nerves** of the kidney are derived from the renal plexus and accompany the branches of the artery. Their branches form regular plexuses on the walls of the arteries and renal tubules, and the terminations of the nerves among the epithelial cells of the tubules have been demonstrated.

From clinical evidence it would appear that the afferent nerve-fibres which supply the kidney are connected with the tenth, eleventh, and twelfth thoracic nerves.

Variations.—A marked difference in the size of the two kidneys is sometimes observed, a small kidney on one side of the body being usually compensated for by a large kidney on the opposite side. Congenital absence of one or other kidney is recorded. A few cases are on record in which an extra kidney was found on one or other side.

Traces of the superficial lobulation of the kidney, present in the fœtus and young child, are often retained in the adult.

Horseshoe-kidney is a not infrequent abnormality. In such cases the two kidneys are united at their lower ends across the median plane by a connecting piece of kidney-substance. The amount of fusion between the two kidneys varies much; it is sometimes very complete, while in other cases it is but slight, the connexion being composed chiefly of fibrous tissue. The hilum of each kidney looks forwards, and the ureters always pass in front of the connecting piece.

Very rarely the kidney appears to be almost entirely surrounded by peritoneum and to be attached to the abdominal wall by a kind of mesentery which encloses the vessels and nerves passing to the hilum. The condition is believed to be congenital.

One or both kidneys may be at a much lower level than usual—in the iliac fossa or even in the pelvic cavity. When congenital, this is associated with an arrest in the normal change in position, relative to surrounding structures, which the kidney experiences during development. In such cases the kidney does not receive its blood-supply from the usual source but from vessels which arise from the lower end of the aorta, or from an iliac artery, or the middle sacral artery. Such congenital abnormally situated kidneys do not usually possess the typical outline of the normal organ but vary much in shape, and the hilum is often malformed and misplaced.

In some mammalian animals, such as the bear, the kidneys are composed of a number of completely isolated lobes, each of which corresponds to one papilla with its pyramids and surrounding cortex; while in others, such as the horse, the fusion of the lobes is more complete than in the human kidney, and a single mass represents the united papillæ.

URETERS

The **ureters** are the ducts that lead from the kidneys to the urinary bladder. Each ureter begins above in a thin-walled, funnel-shaped expansion, called the **pelvis of the ureter**, which is placed partly inside and partly outside the sinus

of the kidney. Towards the lower end of the kidney the part of the pelvis which lies outside the sinus diminishes in calibre, and forms a tube-like duct which conveys the urine to the bladder.

Pelvis of Ureter.—Within the sinus of the kidney the pelvis lies among the larger renal vessels (Fig. 619). It is formed by the junction of two (or, more rarely, three) thin-walled tubes—the **greater calyces**—each of which has a number of branches. The branches, called **lesser calyces**, are short, and increase in diameter as they approach the wall of the sinus, to which they are attached. Their wide, funnel-like ends enclose the renal papillæ and receive the urine. The lesser calyces are usually about eight in number, one calyx sometimes surrounding two or even three papillæ. The portion of the pelvis that lies outside the kidney has in front of it, in addition to the renal vessels, on the *right side*, the second part of the duodenum, and on the *left side*, a part of the pancreas and the peritoneum of the posterior abdominal wall (Figs. 611, 616) or, sometimes, the duodeno-jejunal flexure.

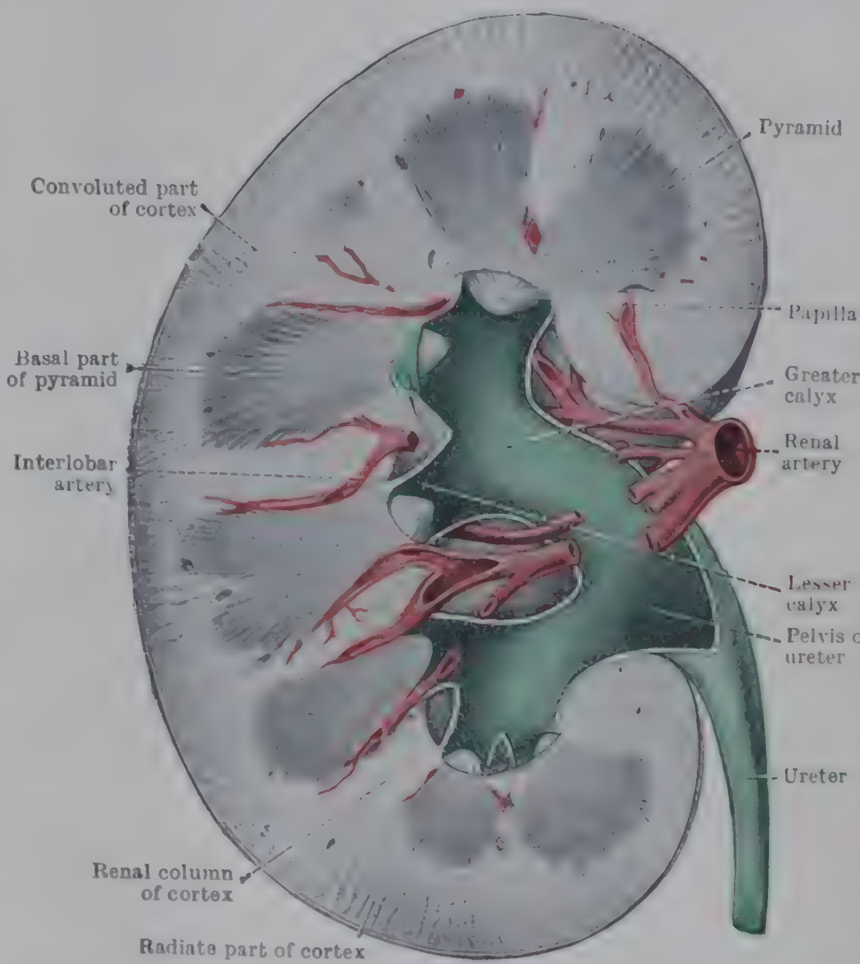

Fig. 619.—Longitudinal Section of Kidney and Pelvis of Ureter to show the Relations of the Calyces to the Renal Papillæ.

Ureter Proper.—The ureter proper is a pale-coloured, thick-walled duct with a small lumen. When *in situ* it has a total length of about ten inches, and lies throughout its whole course in the extra peritoneal tissue behind the peritoneum, to which it is closely adherent. The upper part of the ureter lies in the abdominal cavity, and the lower part in the true pelvis (Figs. 611 and 620).

The **abdominal portion** of the ureter, about five inches in length, is directed downwards and slightly medially, and lies on the psoas major muscle (Fig. 615). Certain structures are related to the ureters in a similar manner on both sides of the body; for instance, the abdominal portion of each ureter is crossed very obliquely, in front, by the testicular or ovarian vessels, and behind each ureter the genito-femoral nerve passes downwards and laterally. Other structures are related to the duct of the right or left side alone. On the *right side*, the second part of the duodenum lies in front of the upper part of the ureter, and the line of attachment of the mesentery crosses it lower down, shortly before the ureter enters the true pelvis. The right colic and ileo-colic arteries also are anterior relations. On the *left side*, the left colic vessels and the line of attachment of the pelvic mesocolon cross the ureter.

Crossing the common iliac or the external iliac artery, the ureter enters the true pelvis. Usually the left ureter crosses the common iliac artery, and the right ureter the external iliac; but that arrangement is by no means constant.

The **pelvic portion** of the ureter is about five inches in length; it passes backwards and downwards on the side-wall of the pelvis under cover of the

peritoneum, describing a curve which is convex backwards and laterally (Fig. 639), the most convex point being close to the deepest part of the greater sciatic notch.

In its course within the pelvis the ureter lies below and in front of the internal iliac artery, and crosses the medial side of the obturator nerve and vessels and of the umbilical artery. About the level of the ischial spine, the ureter is crossed from before backwards by the vas deferens, and from that point onwards it is not so intimately related to the peritoneum. It then bends slightly medially and forwards to reach the lateral angle of the bladder, and comes into relationship with the upper end of the seminal vesicle, in front of which it lies (Fig. 626). The vas deferens having crossed the ureter also turns medially, and as it does so it lies on a plane posterior to the ureter. The lower end of the ureter is surrounded by a dense plexus of veins which brings the vesical plexus into communication with the internal iliac vein. The largest of the nerve-cords which connect the hypogastric plexus with the pelvic plexus divides to pass on each side of the ureter in the region where the ureter is crossed by the vas deferens (Fig. 639).

When the right and left ureters reach the bladder they are a little more than two inches apart. They pierce the wall of the bladder very obliquely, and are embedded within its muscular tissue for nearly three-quarters of an inch. Finally, they open into the bladder by a pair of minute, slit-like apertures which are of a valvular nature and prevent a backward passage of fluid from the bladder. It is probable, however, that an exaggerated idea of the valvular nature of the openings of the ureters into the bladder is obtained by an examination of the parts in the dead subject. When the bladder is empty the openings of the ureters are placed about one inch apart, but when the bladder is distended they may be two inches apart, or more. As the ureter pierces the wall of the bladder the muscular fibres of the bladder and ureter remain quite distinct, and so the ureter, remaining a thick-walled tubular structure, appears to pass through a gap in the muscular wall of the bladder. The mucous coat of the ureter becomes continuous with that of the bladder.

The lumen of the ureter proper is not uniform throughout; it is slightly constricted near its pelvis and where it crosses the iliac artery; and it is narrowest where it passes through the bladder-wall.

In the female, the ureter, near its termination, passes below the root of the broad ligament of the uterus, and lies about three-quarters of an inch lateral to the cervix uteri above the lateral fornix of the vagina, and finally inclines medially to lie in front of the lateral margin of the vagina (Fig. 661). The upper end of the vagina usually deviates to one side, more often the left, and hence much more of one ureter than of the other may come to lie in front of the vagina (Brash, 1922). Its lower part is accompanied by the uterine artery, which crosses above and in front of it not far from its termination. Higher up it lies in the peritoneal ridge which forms the posterior boundary of the fossa ovarica (Fig. 653).

Structure of Ureter.—The wall of the ureter proper, which is thick and of a whitish colour, is composed of mucous, muscular, and fibrous coats. The **mucous coat** is covered with an epithelium composed of many layers of cells, those nearest the lumen being of large size. When the canal is empty the mucous coat is thrown into numerous longitudinal folds, and so its lumen has a stellate outline in transverse section. The submucous tissue varies much in thickness in different parts of the ureter, and contains some elastic fibres. The **muscular coat** consists of plain muscle-fibres collected into bundles which are separated by a considerable amount of fibro-areolar tissue, and are arranged, some longitudinally, some circularly. In the upper part of the ureter a relatively large amount of fibro-areolar tissue is present deep to and among the bundles of muscle-fibres, which are arranged in three distinct strata—an inner longitudinal, middle circular, and an outer longitudinal. In the middle part of the tube the same layers may be recognized, but the circularly disposed bundles of fibres are more numerous than higher up. In the lower part of the ureter the fibro-areolar tissue is relatively scanty and the inner longitudinal fibres lie close to the mucous coat; in this region also the longitudinal folds of the mucous coat become fewer and less marked. A short distance above the bladder, a number of coarse bundles of longitudinally arranged muscle-fibres are applied to the outer surface of the muscular coat. These form the so-called "sheath of the ureter", and are continuous with the superficial part of the muscular wall of the bladder. In the portion of the ureter which traverses the wall of the bladder nearly all the fibres of the muscular coat are disposed longitudinally. The muscle-fibres lie immediately outside the epithelium, and end just where the mucous coats of the bladder and ureter become continuous. The outer, **adventitious coat** of fibrous tissue varies in thickness at different levels, and in its lower part blends with the fibro-areolar tissue which lies among the muscle-fibres of the sheath of the ureter just mentioned.

The mucous coat of the calyces and of the pelvis of the ureter has an epithelium like that of the ureter proper. Where each renal papilla projects into one of the calyces a deep, circular recess is formed between the wall of the calyx and the papilla; at the bottom of this recess the epithelium of the calyx becomes continuous with that covering the papilla. At the apex of the papilla the epithelium joins that of the renal tubules. The muscular fibres in the wall of the calyces and of the pelvis are collected into loosely arranged bundles separated by wide intervals occupied by fibrous tissue. As in the ureter proper, the outermost and innermost fibres are longitudinal, and the middle ones are circular. The circular fibres alone form a distinct layer.

Vessels and Nerves of Ureter.—The abdominal part of the ureter receives its **blood-supply** from the renal and the testicular or ovarian arteries; the pelvic portion is supplied by the vesical and middle rectal vessels, and it may receive a direct branch from the common iliac or the internal iliac artery.

The **nerves** of the ureter are derived from the renal, testicular or ovarian, and hypogastric plexuses. The afferent fibres reach the spinal cord through the eleventh and twelfth thoracic and first lumbar nerves.

Variations.—The ureter is sometimes represented by two tubes in its upper portion. In rarer cases it is double throughout the greater part of its extent, or even in its whole length with two openings into the bladder. Asymmetry in such abnormalities is very common.

Variations in the form of the pelvis of the ureter are of frequent occurrence. Most usually the pelvis divides into two greater calyces—an upper and a lower. In some cases the two calyces spring directly from the ureter without the intervention of a pelvis, or a marked subdivision may lead to the formation of two pelves.

Methods of Clinical Anatomical Examination.—A kidney of normal size and occupying its normal position cannot be palpated in the living subject, but, if the organ is much enlarged or abnormally mobile, it can usually be felt at the end of a deep inspiration. To search for a palpable kidney, place the patient on his back, pass one hand behind him and press forward below the last rib and with the other hand press backwards on the anterior abdominal wall opposite the fingers of the first hand. If the kidney is palpable it can be felt slipping between the opposed fingers when the patient takes a deep breath. The outline of the kidney cannot be defined by percussion as the organ is deeply placed and adjacent to other organs of a similar consistency to itself.

In the angle between the lateral border of the sacro-spinalis muscle and the lower border of the twelfth rib, the kidney lies fairly close to the posterior surface of the body, for there it is separated from the surface only by relatively thin structures—the quadratus lumborum, the layers of the lumbar fascia, the serratus posterior inferior, and the latissimus dorsi. Lesions, *e.g.*, an abscess in the region of the kidney, can cause tenderness and swelling in this area. The close relationship of the psoas major muscle and the kidney is important as, owing to it, extension of the thigh may increase pain due to lesions in the kidney region.

Radiographic Examination of Kidney and Ureter.—The outline of the **kidney** can usually be seen faintly in ordinary radiographs, and it can be made obvious by preliminary injection of air or oxygen into the perirenal fat (Pl. LXIX, p. 744). The position of the kidney may be determined also by the use of the opaque media that are employed in X-ray examination of the ureter.

There are two methods of examining the **ureter**. (1) In *descending pyelography* ("excretion urography") an organic compound of iodine is given intravenously. This substance is opaque to X-rays, is rapidly excreted by the kidneys, and it outlines the pelvis and ureter as it passes down to the bladder. The kidney itself is increased in density during the period of excretion (Pl. LXXI, Fig. 1, p. 745). (2) In ascending or *retrograde pyelography* a solution of sodium iodide is injected directly by means of a catheter introduced into the ureter from the bladder with the aid of a cystoscope. Sodium iodide, in the concentration employed, is more opaque to X-rays than the organic compounds used in descending pyelography; and the whole length of the ureter, including the pelvis and calyces, is rendered clearly visible by its use. The catheter itself may be radio-opaque and may be recognized on the film even after the injection of sodium iodide (Pl. LXX, p. 744).

In radiographs taken after these procedures the pelvis of the ureter is usually seen lying immediately below the shadow of the twelfth rib, and the shadow cast by the ureter proper is seen to fall on the tips of the transverse processes of the lower lumbar vertebræ and on the sacro-iliac joint. In retrograde pyelography the catheter may cause some displacement of the ureter from its normal position (Pl. LXX).

URINARY BLADDER

Position.—The urinary bladder is a hollow muscular organ situated below the peritoneum on the anterior part of the pelvic floor above and behind the pubic symphysis. The space in which it lies is three-sided. On each side, it is bounded

above by the obturator internus and lower down by the levator ani muscles; and these two side-walls meet in front at the pubic symphysis. As the two levator ani muscles slope downwards, backwards and medially they form the walls of a gully which is deeper behind than in front owing to the slope of its floor; this floor is defective in front because of the slight gap that exists between the two levator ani muscles, but the deficiency is bridged over by the medial pubo-prostatic ligaments (pubo-vesical in the female) and partly compensated for at a lower level by the fascia on the sphincter urethræ muscle. The space is bounded behind by the fascial tissue which stretches across the back of the bladder and is

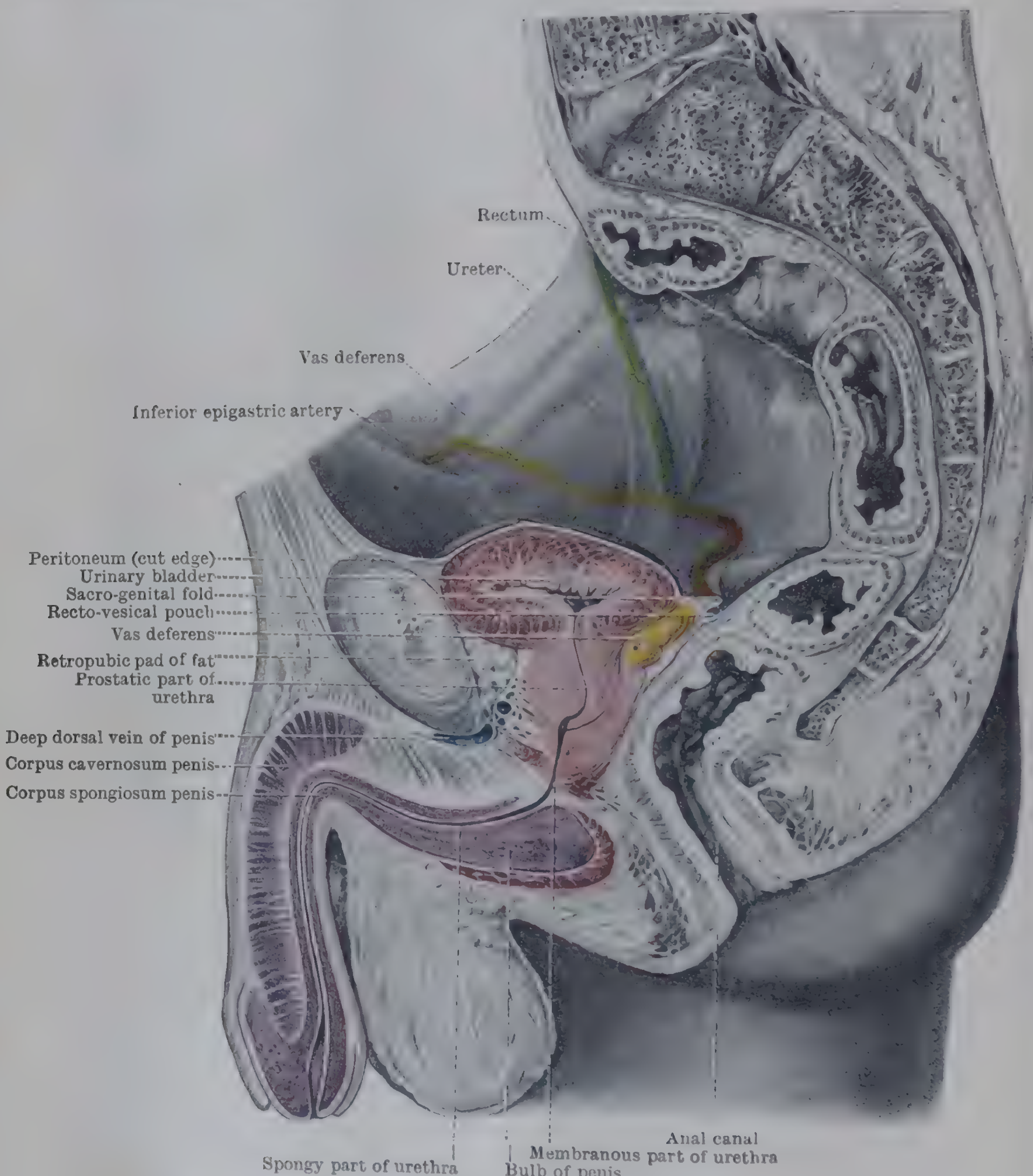

FIG. 620.—MEDIAN SECTION OF PELVIS OF ADULT MALE SUBJECT.
The urinary bladder is empty and firmly contracted; compare with Fig. 621.

thickened and condensed as it passes from the bladder to be connected with the fascia of the levator ani on each side.

Shape and Parts (Fig. 624).—The empty adult bladder lies completely or almost completely within the above-mentioned space, and in dissecting-room fixed specimens it is usually moulded by the walls of the space and by the pressure of overlying viscera. It is therefore usual to describe the empty adult bladder as possessing four surfaces:—a *superior surface* looking straight upwards, a pair of *infero-lateral surfaces* facing downwards, laterally, and forwards, and a *posterior*

surface directed backwards and slightly downwards. The posterior surface is called **the base**; the anterior end of the bladder, where the superior and the two infero-lateral surfaces meet, is known as the **apex**; and the lowest part of the organ, where the base and the two infero-lateral surfaces come together, is termed the **neck**. But deductions made from an examination of such dead and relaxed bladders appear to be inapplicable to the living organ. The bladder almost always

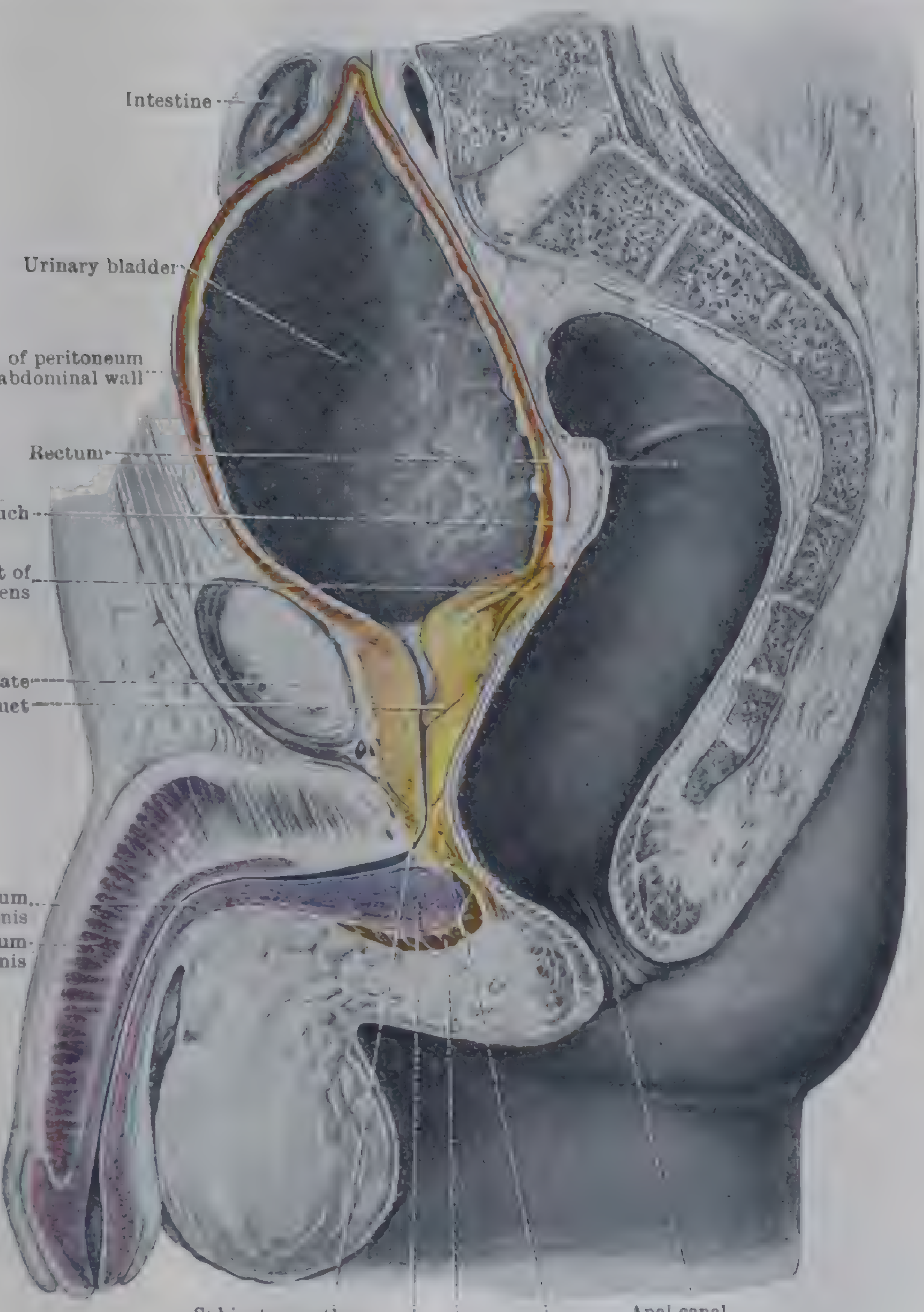

FIG. 621.—MEDIAN SECTION OF PELVIS OF ADULT MALE SUBJECT.
The urinary bladder and rectum are both distended. Compare with Fig. 620.

contains a little fluid and is physiologically closed except at intermittent intervals; and its walls are always in some degree of tonic contraction. These facts alone ensure that the living bladder is always more or less rounded, though its spherical shape may be slightly altered either by pressure of surrounding organs or by its attachment to surrounding structures. Hence, radiographs of the bladder in living subjects show it as a rounded organ, with its upper aspect frequently flattened by the weight of overlying viscera, or even slightly depressed by a heavy overlying viscus, *e.g.*, a gravid uterus. It would therefore probably be more correct to speak of the various *aspects* of the bladder than of its *surfaces*; for its true shape appears

to be that of a sphere or a spheroid, though this conformation may be temporarily modified by pressure of surrounding structures.

The distended bladder rises above the three-sided space already described and projects upwards into the true abdominal cavity.

Attachments.—In both sexes the **neck** is the most firmly fixed part of the bladder. In the male it is held in place chiefly by the pubo-prostatic ligaments and by its firm connexion with the prostate, with which it is structurally continuous. Each side of the neck gives attachment to the *lateral pubo-prostatic ligament*, which is merely the fascia on the anterior part of the levator ani muscle. The *medial pubo-prostatic ligaments* are a pair of thick, short, strong bands that lie side by side over the anterior part of the gap between the two levatores ani in front of the neck of the bladder and attach it firmly to the back of the pubic bones; these ligaments contain bundles of plain muscle-fibres which are continuous with the muscular coat of the bladder and are named, therefore, the *pubo-vesical muscle.* The prostate lies in the posterior part of the gap between the two levator ani muscles and is itself enclosed in a strong fibrous sheath which also is firmly connected with the pubo-prostatic ligaments and is attached inferiorly to the fascia on the sphincter urethræ muscle. In the female the neck of the bladder and upper part of the urethra are connected with the pubis and the levator ani by similar fascial bands which, in the absence of a prostate, are named *pubo-vesical* ligaments; and these parts are also directly connected with the fascia which covers the sphincter urethræ.

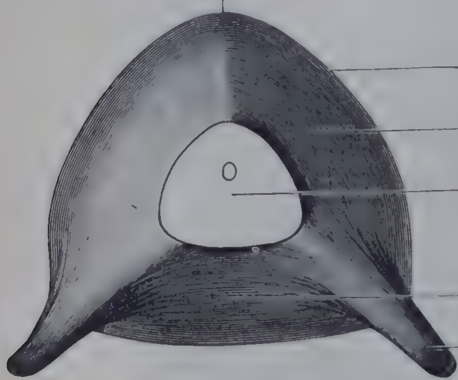

FIG. 622.—INFERIOR ASPECT OF EMPTY MALE URINARY BLADDER. From a subject in which the viscera had been hardened *in situ.*

The **apex** of the bladder is continuous with the median umbilical ligament, which extends up on the posterior surface of the anterior abdominal wall to the umbilicus. This ligament is the fibrous remnant of the *urachus*—the passage which in the embryo connects the developing bladder with the allantois.

The **base** of the bladder is attached by means of the condensation of fascia which, on each side, blends with the fascia on the levator ani muscle. The whole condensation is really a collection of fibrous tissue around the internal iliac artery and its branches, and it passes medially to be attached to the base of the bladder and seminal vesicles in the male, and the base of the bladder and the sides of the vagina and cervix uteri in the female.

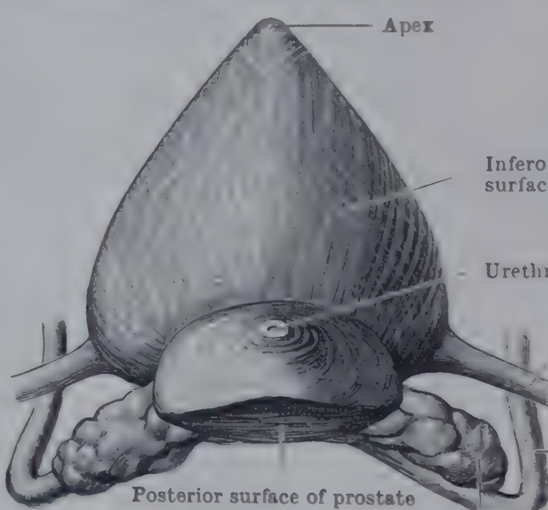

FIG. 623.—URINARY BLADDER, PROSTATE, AND SEMINAL VESICLES, VIEWED FROM BELOW.

Taken from a subject in which the viscera were hardened *in situ.* Same specimen as Fig. 624, A. The bladder contained a very small amount of fluid.

In addition to these connexions, the base is attached by areolar tissue loosely to the anterior wall of the vagina in the female, but firmly to the seminal vesicles and ampullæ of the vasa deferentia in the male.

The ureters enter the bladder at the upper and lateral aspects of the base, the points of entrance being about two inches apart; and the urethra leaves the bladder at its lowest point—that is the neck.

In dissecting-room specimens, once the median umbilical ligament has been

cut, the whole anterior part of the bladder is very mobile but the base and neck remain fixed.

Relations of Male Bladder.—The **superior surface** of the bladder (Figs. 620 and 625) is covered with peritoneum, which separates it from coils of small intestine or from the pelvic colon. The peritoneum passes from the upper surface of the bladder forwards on to the posterior surface of the anterior abdominal wall at the level of the pubic crest; laterally it passes slightly downwards and then upwards on to the side-wall of the pelvis, thus forming a shallow *paravesical fossa* on each side of the bladder; and posteriorly it passes backwards for about half an inch forming a prominent shelf-like fold—the *sacro-genital fold*—and then turns abruptly downwards for about an inch to be reflected on to the front of the rectum, thus forming the recto-vesical pouch (Fig. 625). As the peritoneum turns downwards it may, in the median plane, cover a small portion of the base of the bladder but more laterally it is separated from the base by the vas deferens and the upper end of the seminal vesicle. When the bladder is completely empty, the peritoneum on its upper aspect may be thrown into a transverse fold—the *plica vesicalis transversa*.

The two **infero-lateral surfaces** and the border between them are separated

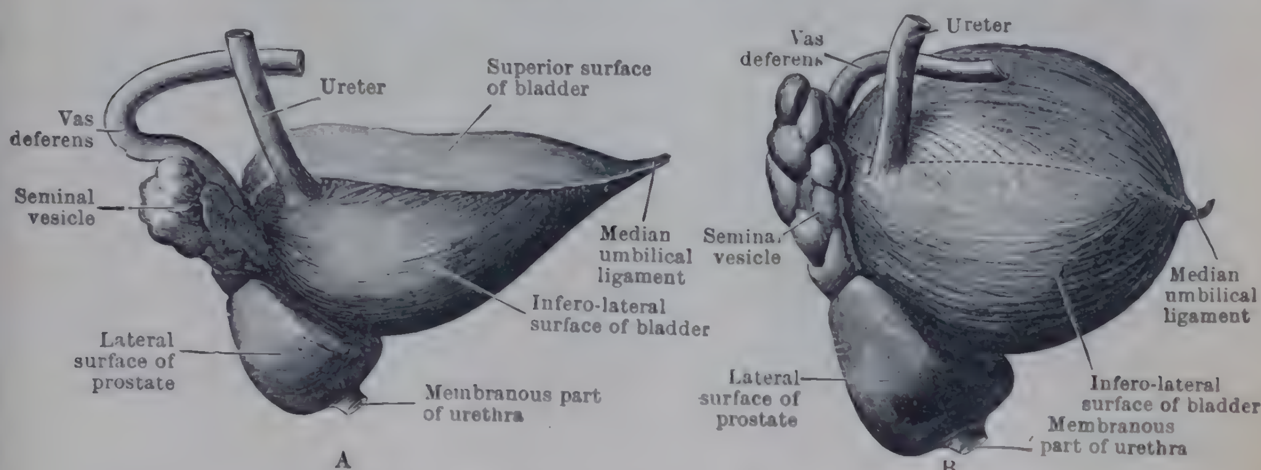

FIG. 624.—URINARY BLADDER, PROSTATE, AND SEMINAL VESICLE VIEWED FROM THE RIGHT SIDE.

Drawn from specimens in which the viscera were hardened *in situ*. In A the bladder contained a very small quantity of fluid; in B the quantity was a little greater. In A the peritoneum is shown covering the superior surface of the bladder, and its cut edge is seen where it is reflected along the lateral border. In B the level of the peritoneal reflexion is indicated by a dotted line.

from the surrounding firm structures by a space—the *retropubic space*—which is filled with loose areolar tissue, fat and a plexus of veins (Fig. 620). This mass of tissue, adapted as a packing to fill the gaps between the bladder and the neighbouring, rather rigid, pelvic walls, is known as the *retropubic pad of fat*. The retropubic space is bounded in front by the back of the pubis, at each side by the levator ani muscle below and the obturator internus muscle above, inferiorly by the pubo-prostatic ligaments, and posteriorly by the fascial condensation which passes from the base of the bladder to the side-walls of the pelvis. Superiorly, it is bounded by the peritoneum which passes from the upper surface of the bladder to the anterior wall of the abdomen and the side-walls of the pelvis. As the bladder fills and expands, it lifts the peritoneum upwards as far as the line of the lateral umbilical ligaments (obliterated umbilical arteries), and the retropubic space therefore potentially extends upwards on to the back of the anterior abdominal wall and on to the side-walls of the pelvis as far as these ligaments. The obturator nerve and vessels extend into the posterior and upper part of the side-wall of the retropubic space even when the space is unexpanded; and as the bladder fills and the space enlarges the vas deferens also may be included. The plexus of veins in the retropubic pad of fat is especially rich in the neighbourhood of the neck of the bladder.

The **base** of the bladder faces backwards and slightly downwards (Figs. 620 and 624). Its infero-lateral parts are in contact with the seminal vesicles, which diverge from each other at rather more than a right angle as they pass laterally

and upwards from the back of the neck; medial to each seminal vesicle, the base

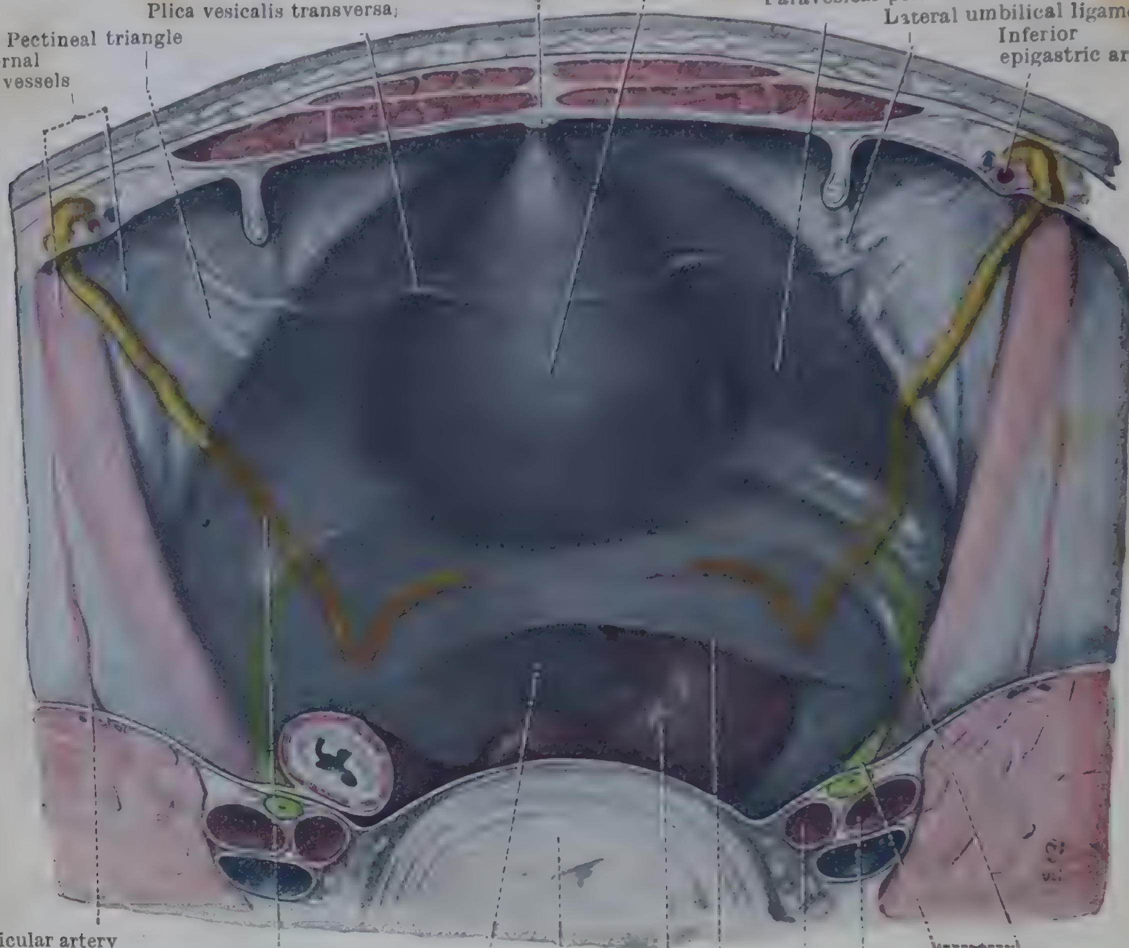

FIG. 625.—CAVITY OF MALE PELVIS SEEN FROM ABOVE AND BEHIND.

From a specimen in which the bladder was firmly contracted and contained but a small amount of fluid. The peritoneal pouch in front of the rectum is bounded on each side by the sacro-genital folds, which meet together in the median plane some distance behind the posterior border of the bladder.

is in contact with the ampulla of the vas deferens of the same side; between the two vasa it is separated by some loose areolar tissue from the front of the rectum, but the uppermost part of that interval may be covered with peritoneum.

The **neck** is firmly attached to the prostate, or, rather, structurally continuous with it; and a well-marked groove runs round the junction of the two organs.

Relations of Female Bladder (Figs. 627, 657, and 659).—The bladder occupies a slightly lower position than in the male. The **superior surface** is covered with peritoneum, which, as in the male, passes forwards on to the back of the anterior abdominal wall, and also laterally to the side-wall of the pelvis, forming, as

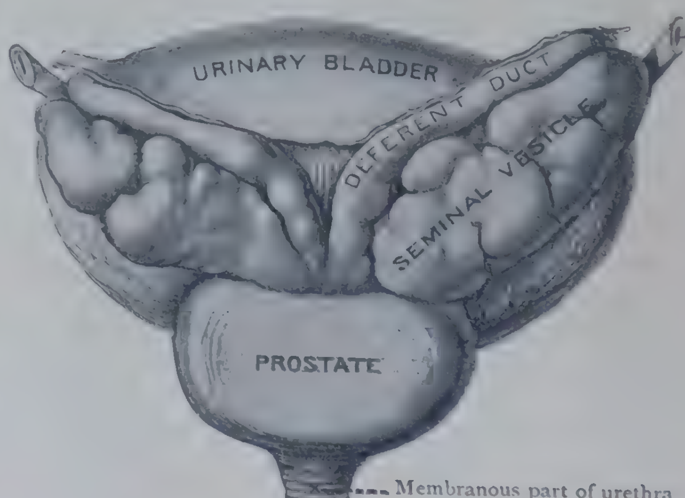

FIG. 626.—URINARY BLADDER, SEMINAL VESICLES, AND PROSTATE, VIEWED FROM BEHIND.

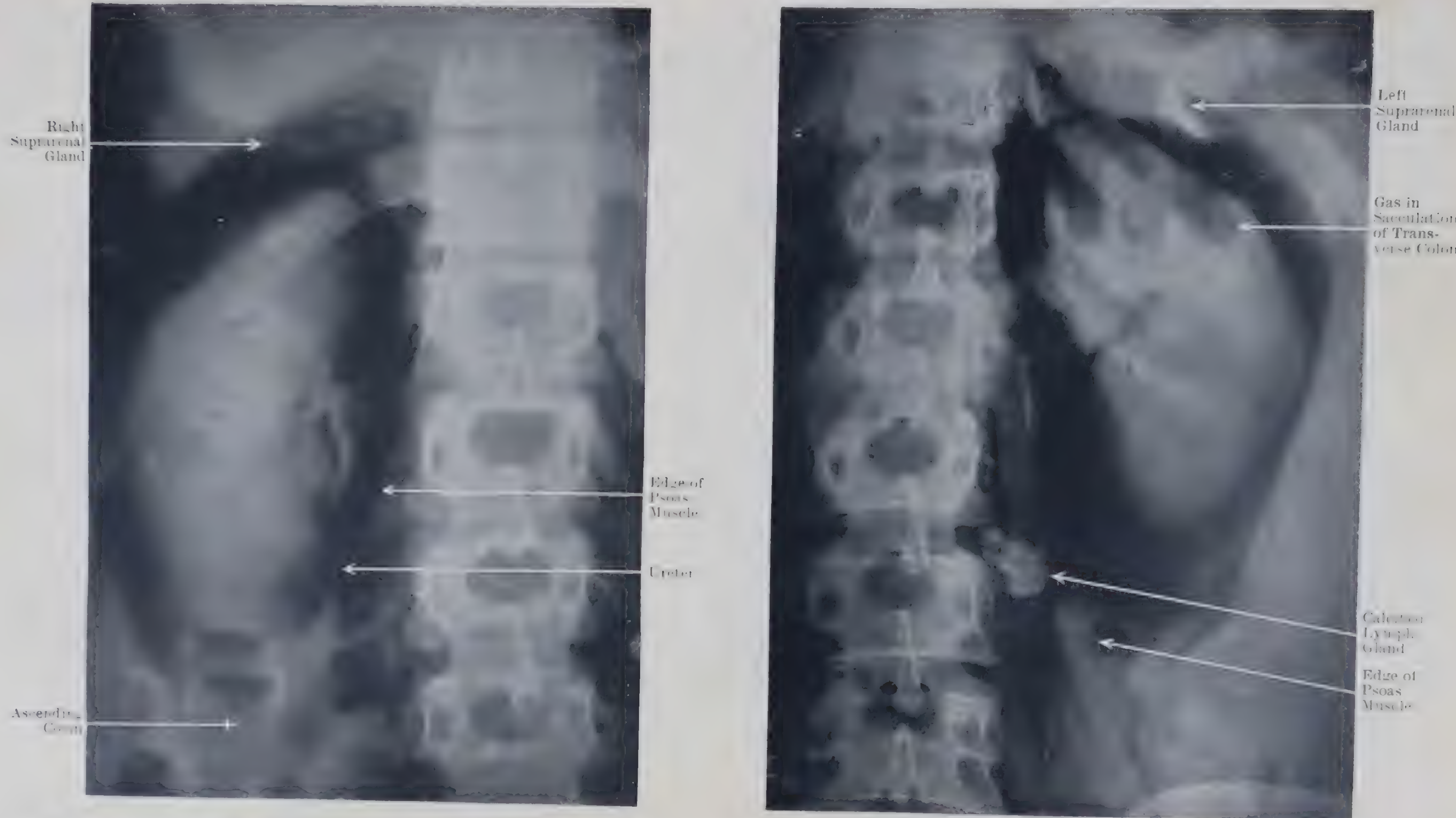

PLATE LXIX. RADIOGRAPHS OF RIGHT AND LEFT KIDNEYS, OF WOMAN AGED 28, AFTER INJECTION OF AIR INTO THE PERIRENAL FAT.

Note the separation of the suprarenal glands from the kidneys and the shadows of the psoas muscles.

[Facing p. 744

PLATE LXX.—POSTERIOR RADIOGRAPH OF URETERS, AFTER THE PASSAGE OF URETERAL CATHETERS AND THE INJECTION OF SODIUM IODIDE SOLUTION INTO THE PELVES AND CALYCES (Retrograde Pyelograph).

The resilience of the catheters has slightly displaced the lower abdominal portions of the ureters medially. Note the higher position of the left kidney and the form of the pelves and calyces. Cf. Plate LXXI, Fig. 1, Fig. 619, p. 737, Fig. 1225, p. 1509; and see pp. 739, 1556.

PLATE LXXI

FIG. 1.—POSTERIOR RADIOGRAPH OF KIDNEYS AND URETERS (DESCENDING PYELOGRAPH) OF YOUNG WOMAN AGED 17.

Note the relative density of the left kidney and compare with Plates LXIX and LXX.

FIG. 2.—RADIOGRAPH OF URINARY BLADDER OF MALE ADULT 35 MINUTES AFTER INTRAVENOUS INJECTION.

PLATE LXXI. —RADIOGRAPHS OF KIDNEYS AND URETERS AND OF URINARY BLADDER AFTER INTRAVENOUS INJECTION OF IODINE SALT (Excretion Urography).

PLATE LXXII

PLATE LXXII.—RADIOGRAPH SHOWING THE FORM OF THE CAVITIES OF THE UTERUS AND THE UTERINE TUBES AFTER INJECTION OF LIPIODOL. (Dr. J. B. King.)

Note the outlining of the Fornix of the Vagina and the escape of the injection into the peritoneal cavity in droplets. See pp. 783, 1558.

it does so, a shallow *paravesical fossa*. Posteriorly the peritoneum passes from the superior surface of the bladder upwards to be attached to the uterus at the junction of the cervix and body of that organ, and then passes forwards on the antero-inferior surface of the body of the uterus. In the female, therefore, the body of the uterus lies above the bladder and the peritoneal recess between the two organs is known as the *utero-vesical pouch*. This pouch is usually slit-like, but in some cases coils of small intestine pass into it and partly separate the bladder and uterus.

The base of the bladder in the female is attached by areolar tissue to the

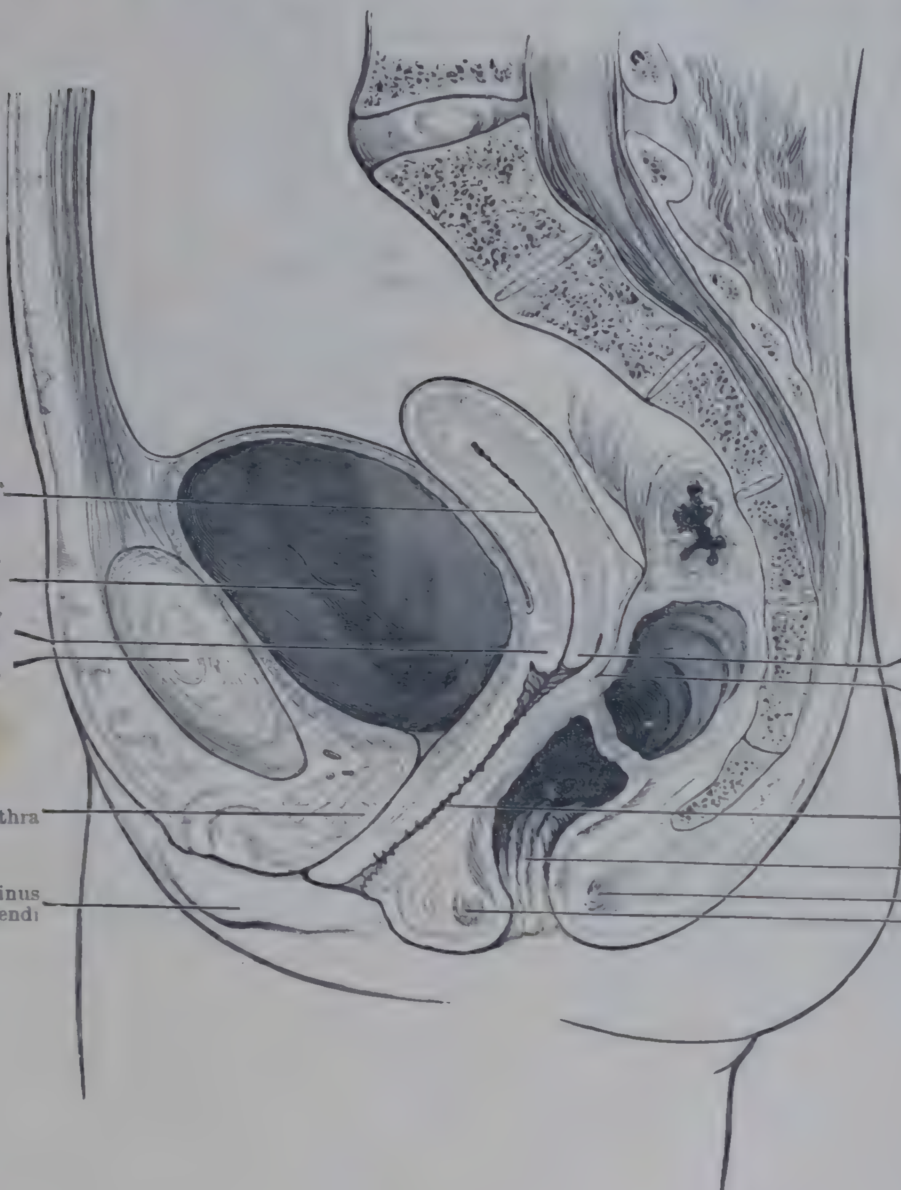

FIG. 627.—MEDIAN SECTION OF PELVIS OF ADULT FEMALE.
The cavity of the uterus is indicated diagrammatically.

anterior wall of the vagina so loosely that a line of cleavage between the two organs can be easily opened up. The upper end of the base, just as it passes into the superior surface of the organ, is separated from the front of the supravaginal part of the cervix uteri by loose areolar tissue: and laterally on each side the uterine vessels are about an inch distant (Fig. 656).

The **infero-lateral surfaces** and the **apex** have the same general relations in the female as in the male.

The **neck**, in the absence of the prostate, is continuous only with the urethra, and the fascial bands connected with it are called the pubo-vesical ligaments.

Bladder in New-Born Child and Infant.—At birth the empty bladder is spindle- or torpedo-shaped; its long axis extends from the apex to the internal urethral orifice, and is directed downwards and backwards (Fig. 628). The

lateral and posterior borders seen in the adult organ cannot be recognized at birth, nor is there any part of the bladder-wall directed backwards and downwards, as is the base of the adult organ. In the fœtus and young child the bladder occupies a much higher level than it does in the adult, and, even when empty, it extends upwards into the abdominal cavity. Its anterior surface is in contact with the back of the anterior abdominal wall. At birth the peritoneum forming the recto-vesical pouch covers the whole of the posterior surface of the bladder, and reaches as low as the upper limit of the prostate. The internal urethral orifice is placed at a high level, and sinks gradually after birth (Fig. 629). In the new-born child the opening is on a level with the upper margin of the pubic symphysis and the openings of the ureters are almost in the plane of the pelvic brim. The umbilical arteries are more intimately related to the bladder in the child than in the adult, and lie close against its sides as they pass upwards on the back of the anterior abdominal wall towards the umbilicus (Fig. 643).

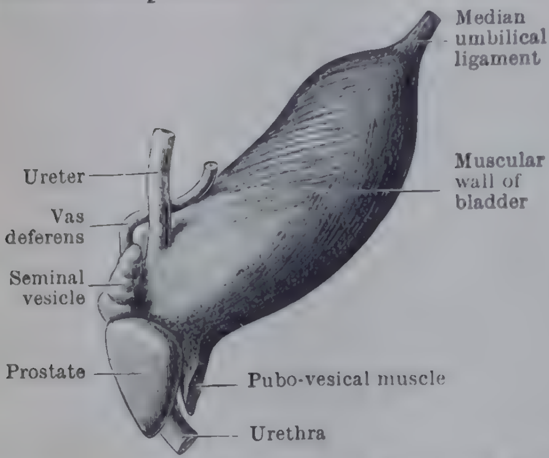

Fig. 628.—Urinary Bladder of New-Born Male Child, viewed from Right Side.
The drawing is from a specimen which had been hardened *in situ*. (Compare with Fig. 624, A.)

Interior of Bladder (Figs. 630, 631, 632, and 656).—The mucous membrane which lines the bladder is loosely connected to the muscular coat, and when the bladder is contracted the mucous lining is thrown into a number of prominent wrinkles or folds. At one place only is the mucous membrane firmly connected to the muscular coat, and the inner surface of that part of the bladder-wall is smooth and free from wrinkles. This smooth area corresponds to a triangular surface above and behind the urethral orifice, called the **trigone of the bladder**, and to the part of the bladder-wall which immediately surrounds the opening. The apex of the triangle is at the beginning of the urethra, and the base is a line drawn between the openings of the ureters. Immediately above and behind the urethral opening the bladder-wall in the male sometimes bulges slightly into the cavity owing to the presence of the median lobe of the prostate, which lies outside the mucous coat in that position. When well-marked, as it often is in old men, the bulging is termed the **uvula of the bladder**. Stretching across between the openings of the ureters there is usually a smooth **inter-ureteric ridge**, due to the presence of a transverse bundle of muscle-fibres. It may be deficient near the median plane, and it is curved so as to be convex downwards and forwards. Lateral to the openings of the ureters there is a pair of ridges, called the **ureteric folds**, produced by the terminal parts of the ureters as they traverse the bladder-wall and lie outside of the mucous coat of the bladder. In old people the region above and behind the trigone often bulges backwards and forms a shallow *retro-ureteric fossa*. A less distinct depression may sometimes be observed on each side of the trigone. Around the urethral orifice there is a number of minute radially disposed folds which, disappearing into the urethra, become continuous with the longitudinal folds of the mucous membrane of the upper part of that canal. The ureter pierces the bladder-wall very obliquely, and so the ureteral orifice has an elliptical outline. The lateral boundary of each opening is a thin, crescentic fold which, when the bladder is artificially distended in the dead subject, acts as a valve in preventing water or air from entering the ureter. In the empty bladder the urethral orifice and the openings of the two ureters lie at the angles of an approximately equilateral triangle the sides of which are about an inch in length. When the bladder is distended, the distance between the openings may be increased to two inches or more.

Position of Internal Urethral Orifice.—During the various changes in shape and size which the bladder undergoes, the region of the internal urethral orifice remains almost fixed in position. In the male the urethral orifice is immediately

above the prostate, and behind and slightly below the level of the upper margin of the pubic symphysis, from which it is distant about two to two and a half inches. It can be reached by a finger introduced into the bladder through the abdominal wall above the pubic symphysis. It is usually half an inch to one inch above the level of a plane which passes through the lower margin of the symphysis and the lower end of the sacrum, but in some cases it is slightly lower. The comparatively small variations in the level of the internal urethral orifice which do occur depend partly upon the quantity of fluid in the bladder and partly upon the amount of distension of the lower portion of the rectum. When the bladder is very much distended the orifice is at a slightly lower level than when the organ is empty; on the other hand, distension of the lower part of the rectum raises the level of the urethral orifice to some extent. In the female the internal urethral orifice is normally at a lower level than in the male (compare Figs. 620 and 627).

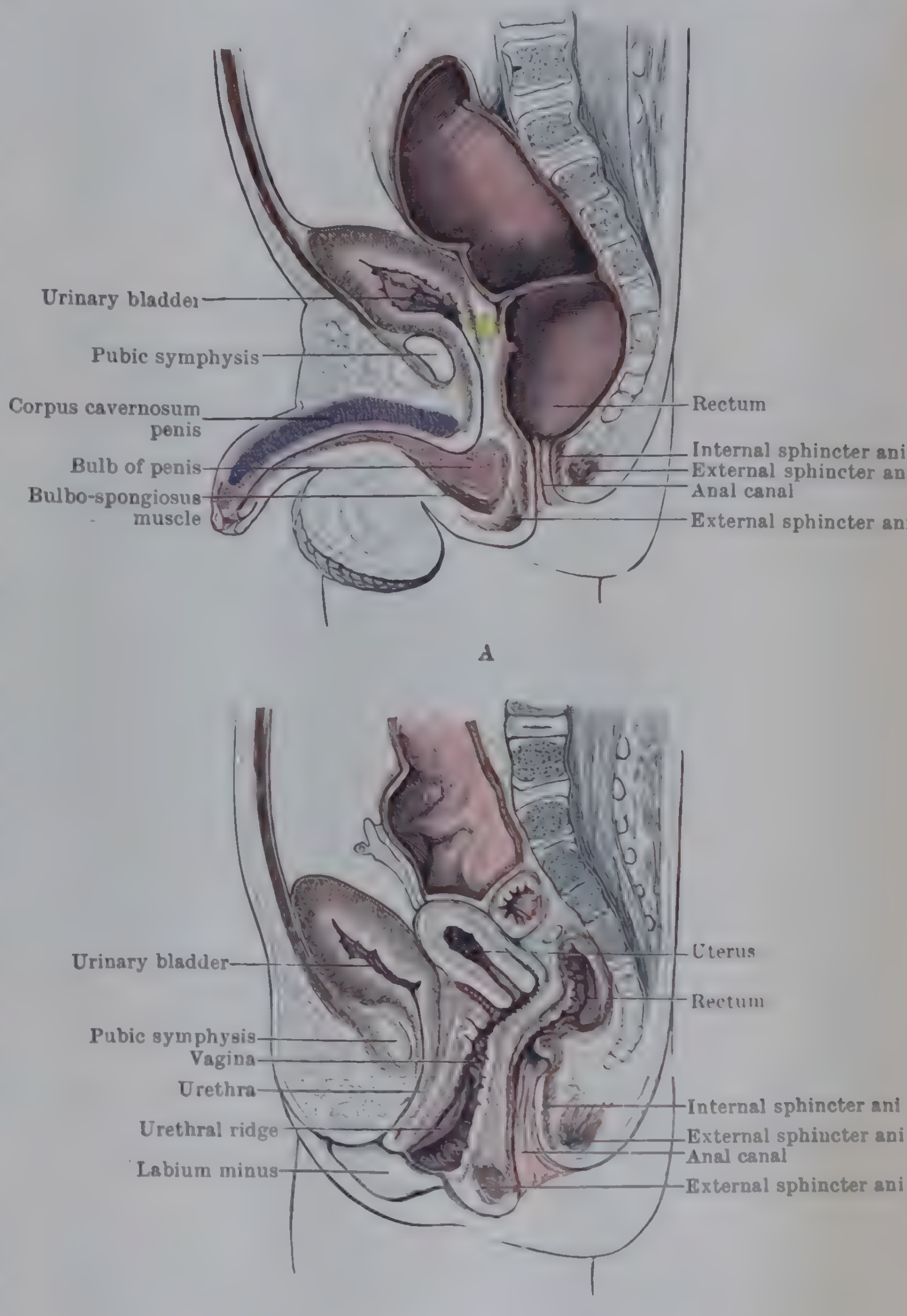

FIG. 629.—MEDIAN SECTIONS OF PELVES OF NEW-BORN CHILDREN.
A, Male; B, Female.

Capacity of Bladder.—The bladder in normal distension may contain nearly a pint; but in most cases the organ is emptied when its contents reach from six to ten ounces (Thompson, 1919). If its contents amount to three-quarters of a pint, the bladder is in contact with the back of the anterior abdominal wall for a distance of about three inches above the pubic crest and the peritoneal reflexion from its upper surface on to the abdominal wall has been raised above this level.

Structure of Bladder.—The wall of the bladder from without inwards is composed of a serous, a muscular, a submucous, and a mucous coat. The **serous coat** is the peritoneum, and covers only the upper part of the bladder (Figs. 620, 627).

A considerable amount of loose fibro-areolar tissue surrounds the **muscular coat**, and, penetrating it, divides it into numerous coarse bundles of muscle-fibres. All the muscle-fibres are of the plain variety, and the bundles which they form are arranged in three very imperfectly separated strata called external, middle, and internal. The **external stratum** is for the most part made up of fibres which are directed longitudinally, and it is best marked near the median plane on the upper and under aspects of the bladder. Farther from the median plane, on the

sides of the bladder, the fibres composing the external stratum run more obliquely, and frequently cross one another. In the male many of the fibres of the external stratum pass into the prostate in front of and behind the urethral opening, and in the female the corresponding fibres join the dense tissue which in this sex forms the upper part of the wall of the urethra. Other fibres of this stratum on each side of the median plane join the lower part of the pubic symphysis and constitute the **pubo-vesical muscle**, which follows the course of the pubo-prostatic ligaments. Lastly, some fibres of the external stratum blend posteriorly with the front of the rectum and receive the name of **recto-vesical muscle.** In both sexes many muscular fibres of the bladder are continued along the course of the ureter to form the sheath of the ureter already mentioned (p. 738). The **middle stratum** is composed of fibres which for the most part run circularly, and form the greater part of the thickness of the muscular coat. In the region of, and behind, the urethral orifice the bundles of fibres are finer and more densely arranged, and surround the opening in a plane which is directed obliquely downwards and forwards. This part

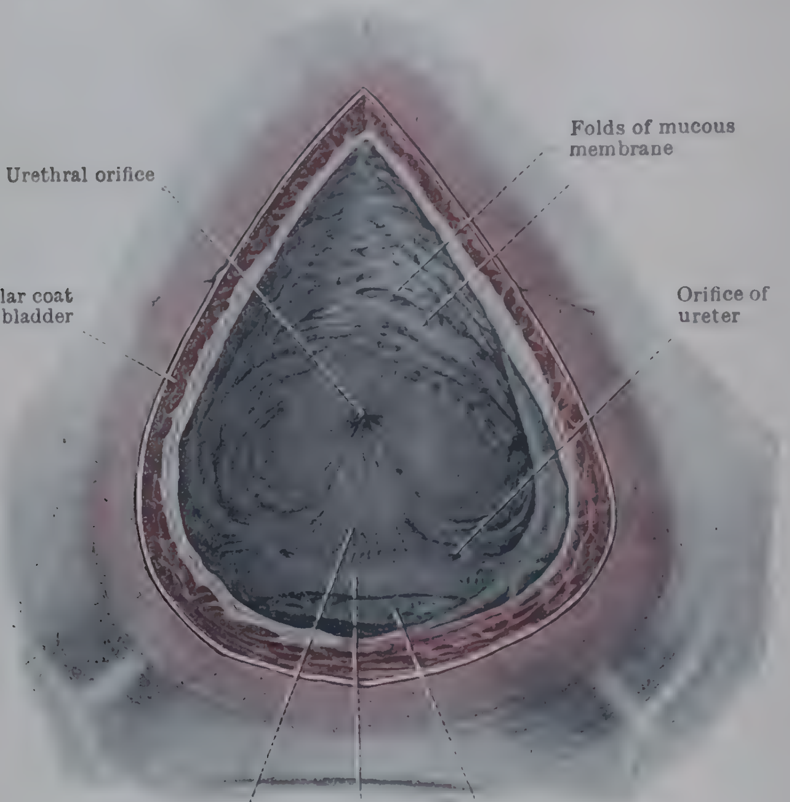

Fig. 630.—Empty and Contracted Urinary Bladder, opened by Removal of its Upper Wall.

The peritoneum is seen spreading out from the lateral and posterior borders of the organ. Compare with Fig. 625.

of the middle stratum is often spoken of as the *sphincter vesicæ.* Inferiorly the fibres of the sphincter vesicæ are continuous with the muscular tissue of the prostate in the male, and with the muscular wall of the urethra in the female. In other parts of the bladder the bundles of the middle stratum are coarser and separated by intervals filled with fibro-areolar tissue. The **internal stratum** is composed of a thin layer of muscle-fibres directed for the most part longitudinally.

The **submucous coat** is composed of areolar tissue which contains numerous fine elastic fibres.

The **mucous coat** is attached by the submucous layer to the muscular coat loosely except in the region of the trigone. There, the muscular fibres are firmly adherent to the mucous coat. Over the trigone the mucous coat is always smooth and flat; elsewhere it is thrown into folds when the bladder is empty. The mucous coat of the bladder is continuous with that of the ureters and urethra. Its epithelial covering is of the variety known as transitional epithelium; it varies much in appearance as the organ expands and contracts. The appearance of the mucous coat is described on p. 746.

When as a result of urethral obstruction the muscular coat of the bladder becomes hypertrophied, strong strands of muscular tissue become raised up and project into the cavity of the bladder. The resulting net-like arrangement of ridges resembles the trabeculæ carneæ of the ventricles of the heart.

Vessels and Nerves of Bladder.—The **arteries** on each side are the *superior* and *inferior vesical arteries.* The largest **veins** are found above the prostate and in the region where the ureter reaches the bladder. They form a dense plexus which pours its blood into tributaries of the internal iliac vein, and communicates below with the prostatic venous plexus.

The **lymph-vessels** from the bladder join the iliac groups of lymph-glands (p. 1411).

The **nerve-supply** of the bladder is derived on each side from the *vesical plexus*, the fibres of which come from two sources, namely, (1) from the *upper lumbar nerves* through the hypogastric plexus (sympathetic), and (2) from the *pelvic splanchnic nerves* (parasympathetic), which spring from the *second* and *third* or the *third* and *fourth sacral nerves*. These splanchnic nerves join the vesical plexus directly

Methods of Clinical Anatomical Examination.—The normal bladder cannot be palpated. The outlines of the normal empty bladder cannot be determined by percussion; but, as the organ fills and rises into contact with the anterior abdominal wall, its upper outline can be mapped out by percussion. The base of the female bladder can be palpated by a vaginal examination.

The interior of the bladder can be inspected by means of a cystoscope: and the outline of its cavity may be seen radiographically (Pl. LXXI, Fig. 2, p. 745) after the use of one of the opaque media employed in X-ray examination of the ureter (p. 739).

URETHRA

The **urethra** is the channel which conveys the urine from the bladder to the exterior. In the *male* its proximal part, less than one inch in length, extends from the bladder into the prostate where the ducts of the reproductive glands join the canal; a much longer distal portion serves as a common passage for the urine and the semen. The *female* urethra represents only the proximal part of the male canal. It is a short passage that leads from the bladder to the external urethral orifice—an aperture placed within the pudendal cleft immediately in front of the opening of the vagina.

Male Urethra.—The **male urethra** (Figs. 631 and 632) is a channel of about eight inches in length and leads from the bladder to the external urethral orifice at the end of the glans penis. The canal not only serves for the passage of urine; it affords an exit also for the seminal products, which enter it by the ejaculatory ducts, and for the secretion of the prostatic and bulbo-urethral glands; in addition, numerous minute **urethral mucous glands** pour their secretion into the urethra.

As it passes from the internal urethral orifice to its external opening the urethra describes an ∽-shaped course, and it is customary to divide it into three sections. The first part is within the true pelvis, and has a nearly vertical course as it traverses the prostate. Turning more forwards, the urethra passes below the pubic symphysis and pierces the fibrous layers which form the pelvic wall in that region. Leaving the pelvis, the canal enters the bulb of the penis and throughout the rest of its course it lies in the erectile tissue of the corpus spongiosum and of the glans penis. The part of the urethra which is embedded in the prostate is called the **prostatic part**; the short part which pierces the pelvic wall is called the **membranous part**; and the part surrounded by the corpus spongiosum is the **spongy part**. Of the three sections the spongy portion is much the longest, and the membranous is the shortest.

The **prostatic part** descends through the prostate from the base towards the apex, describing a slight curve which is concave forwards. It is about one inch in length, and is narrower above and below than in its middle portion, which is, indeed, the widest part of the whole urethral canal. Except while fluid is passing, the canal is contracted, and the mucous membrane of the anterior and posterior walls is in contact and thrown into a series of longitudinal folds. When distended, the middle, or widest part of the canal, may normally have a diameter of about one-third of an inch. The posterior wall, often termed the "floor", of the prostatic urethra presents a distinct median ridge called the **urethral crest** (Fig. 632). The crest projects forwards into the urethra to such an extent that the canal in transverse section presents a crescentic outline (Fig. 651). The groove on each side of the crest is known as the **prostatic sinus**, and into it the numerous ducts of the prostatic glands open by minute apertures. Some few ducts from the middle part open nearer the median plane, on the sides of the urethral crest. The highest point of the urethral crest is half-way down, and on it there is a small, slit-like opening which leads backwards and upwards for a distance of about a quarter of an inch, as a blind pouch, in the substance of the prostate. That little diverticulum is known as the **prostatic utricle**, and it represents

the fused caudal ends of the para-mesonephric ducts, from which the uterus and vagina are developed. On each side of the mouth of the utricle there is the much more minute opening of the ejaculatory duct (see p. 759). When traced upwards, the urethral crest diminishes in height and becomes indistinct, but it can often be traced as a slight median ridge as far as the uvula of the bladder. In the opposite direction the ridge becomes less marked, but it can be followed into the

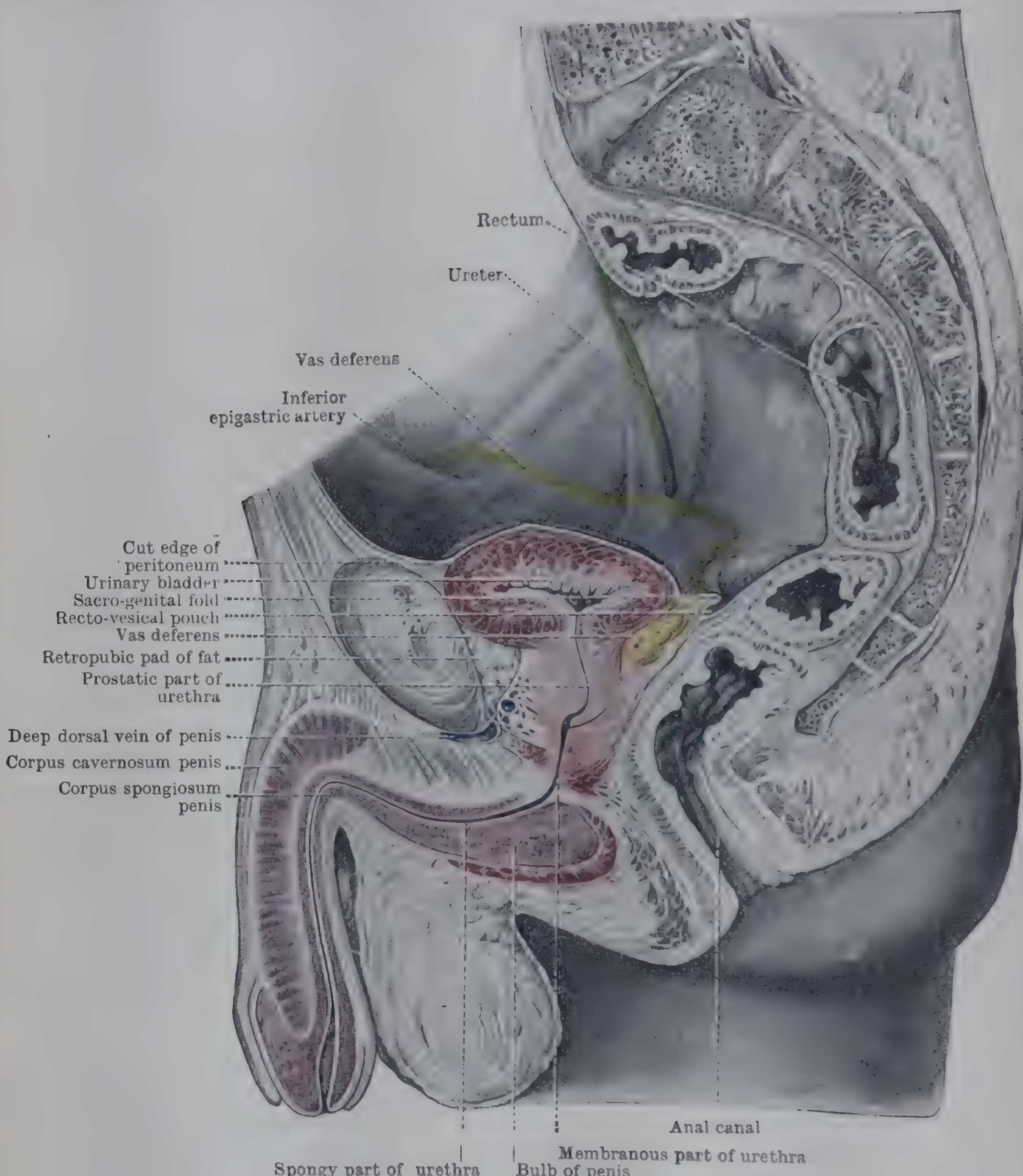

Fig. 631.—Median Section of Adult Male Pelvis.

The urinary bladder is empty and firmly contracted. The urethra is opened up in its entire length.

membranous portion of the canal, where it divides into a pair of inconspicuous elevations which gradually fade out (Fig. 632).

The curvature and, to a less degree, the length of the prostatic urethra depend upon the amount of distension of the bladder and of the rectum (compare Figs. 620 and 621).

The **membranous part** of the urethra leads downwards and forwards from the apex of the prostate to the bulb of the penis, and is the shortest of the three divisions of the canal—its length being slightly less than half an inch. It is also, with the exception of the external orifice, the least dilatable part of the urethra. It begins at the layer of fascia which lies above the sphincter urethræ muscle,

where it is continuous with the prostatic portion of the urethra. It ends about a quarter of an inch below the perineal membrane by becoming continuous with the spongy portion of the urethra. It lies about one inch behind and below the inferior pubic ligament and is surrounded by fibres of the sphincter urethræ muscle: and behind it, on each side of the median plane, lies a bulbo-urethral gland. The posterior part of the bulb of the penis projects backwards and overlaps the posterior wall of the membranous part of the urethra to a considerable extent (Fig. 650).

Besides the folds continued down from the urethral crest there are other longitudinal folds of mucous membrane seen when the canal is empty, and the lumen of the empty tube is therefore stellate in transverse section.

Although the membranous part of the urethra appears to be firmly held, it is not strongly attached to the surrounding fascia, and in the living body it is so mobile that it can be drawn upwards for a distance of about 4 cm. above the perineal membrane (Souttar, 1947). This is of some importance in the operation of "retropubic prostatectomy" (p. 1514).

It is important to note also that the lower part of the membranous portion of the urethra, where it is overlapped by the bulb, lies below the perineal membrane. It is considerably wider than the upper part, and is very thin-walled. It is the part of the canal which is most liable to rupture (Figs. 631 and 632).

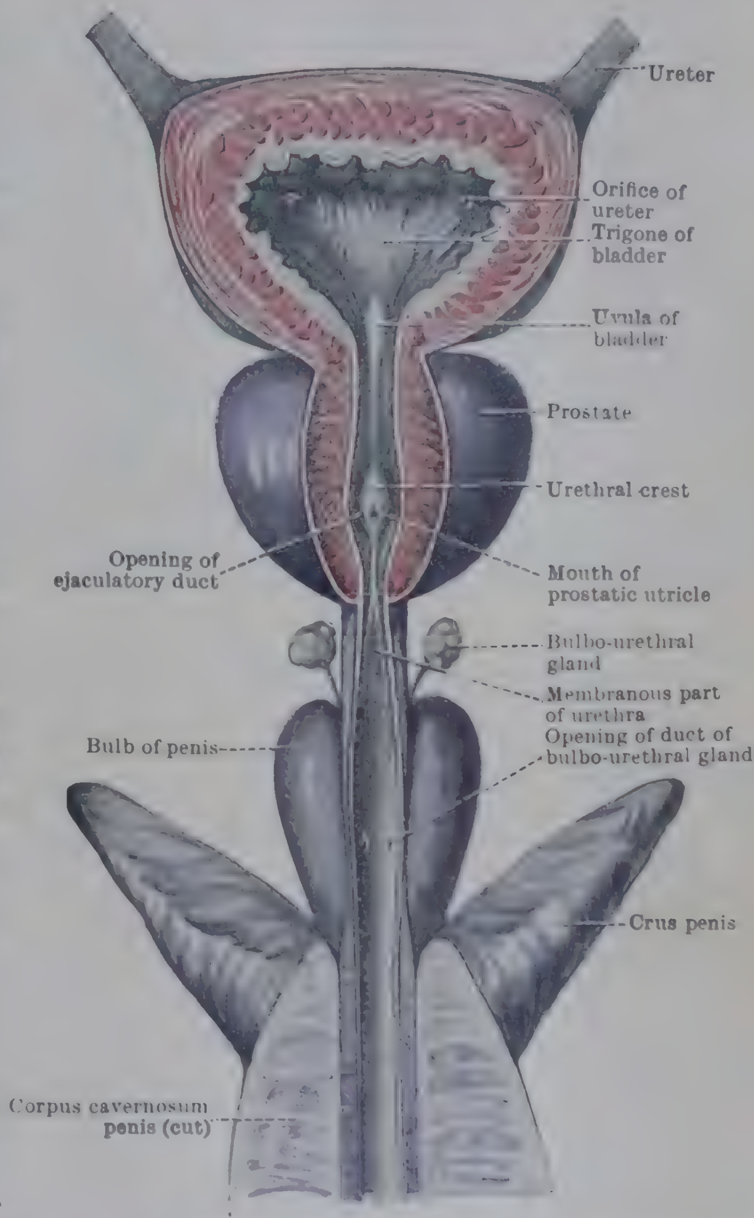

FIG. 632.—DISSECTION SHOWING TRIGONE OF BLADDER AND FLOOR OF THE URETHRA IN ITS PROSTATIC, MEMBRANOUS, AND PROXIMAL SPONGY PARTS.

The **spongy part** of the urethra is about six inches in length and is much the longest of the three divisions. It begins at a point about half an inch in front of the posterior end of the bulb of the penis, and it ends at the external urethral orifice. Its proximal or perineal portion has a fixed position and direction, while its distal part varies with the position of the penis. It traverses the corpus spongiosum, including the bulb and the glans, and is therefore entirely surrounded by erectile tissue in the whole of its length. Directed at first forwards through the bulb, it turns downwards and forwards at the point where it comes to lie in front of the lower part of the pubic symphysis (Fig. 631). The bend in the canal corresponds approximately to the place of attachment of the suspensory ligament to the dorsum of the penis. When the penis is drawn upwards towards the front of the abdomen, the direction of the terminal half of the canal is, of course, changed, and at the same time the whole spongy urethra becomes more uniformly curved.

Immediately after the urethra has pierced the perineal membrane its under-surface is overlapped by the erectile tissue of the bulb, but the upper wall remains uncovered for a distance of about a quarter of an inch (Fig. 631). The

wall of the urethra is there very thin, and the passage is more readily dilatable than in other parts. In this region the urethral wall may readily be torn if undue force is used in passing an instrument or if the handle of the instrument is depressed too soon, when an attempt is being made to pass it into the narrower, more fixed part of the canal. The urethra lies at first in the upper part of the erectile tissue, but as it passes forwards it sinks deeper and comes to occupy the middle part of the corpus spongiosum. In the glans, on the other hand, the erectile tissue lies mainly on the dorsal and lateral aspects of the urethra (Fig. 648). Like the other parts of the urethra, the spongy portion is closed except during the passage of fluid, the closure being effected by the apposition of its dorsal and ventral walls except in the glans penis, where the side-walls of the canal are in contact. Thus, the lumen of the first part of the canal, when empty, is represented in cross-section by a transverse slit (Fig. 647), and that of the terminal part by a vertical slit. The spongy part of the urethra does not present a uniform calibre throughout; it is wider in the bulb and glans than in the corpus spongiosum. In the bulb the urethra expands downwards, forming a little bulging called the **intrabulbar fossa.** The terminal dilated part is named the **fossa terminalis** and opens on the surface by the slit-like **external urethral orifice**, which is the narrowest and least dilatable point of the whole urethra.

The ducts of the bulbo-urethral glands open by very minute apertures in the inferior wall of the proximal part of the spongy part of the urethra (Fig. 632). Before opening into the canal, they lie for some distance immediately outside its mucous membrane. A number of little pit-like recesses, called the **urethral lacunæ**, also open into the spongy part of the urethra, and their openings lead for the most part obliquely into the canal in the direction of its external orifice.

A valve-like fold of the mucous membrane is sometimes found in the upper wall of the urethra in the region of the fossa terminalis. Its free edge is directed towards the external orifice, and it may engage the point of a fine instrument introduced into the urethra.

Structure.—The mucous membrane of the urethra contains numerous elastic fibres and varies in thickness in different parts of the canal. In many positions it shows distinct longitudinal folds and also minute depressions or pits—the *urethral lacunæ* already mentioned. The lining epithelium is composed of many layers of cells, and it is continuous through the internal urethral orifice with the epithelium of the bladder, which at first it closely resembles. In the region of the fossa terminalis the lining cells, which throughout the spongy portion of the canal are of a columnar type, become flat and scaly.

Numerous minute mucous glands—**urethral glands**—open into the urethra. They are most plentiful in the upper wall, but they occur in smaller numbers also in the floor and the side-walls. They are most numerous in the membranous part and in the anterior half of the spongy part.

The larger glands are deeply placed outside the mucous coat, and they communicate with the urethra by long, slender, obliquely placed, branched ducts. The smaller glands lie in the mucous coat and form flask-like depressions with very short ducts. The ducts of some of the glands open into the lacunæ; but many lacunæ have no connexion with the urethral glands.

Frequently two or more elongated ducts belonging to some of the larger glands open into the urethra quite close to its termination. They are spoken of as **para-urethral ducts**, and may be traced backwards for some distance outside the mucous membrane of the roof of the urethra. Morphologically they do not correspond to the ducts in the female which have received the same name.

The muscular wall in the upper part of the urethra consists of plain muscle-fibres directed for the most part longitudinally, but some circular fibres also are present. Throughout the greater part of the spongy urethra the muscular coat is either absent or exceedingly thin.

Around the beginning of the urethra there is an obliquely placed band of circularly arranged plain muscle-fibres which is continued downwards and forwards from below the anterior part of the trigone of the bladder. The lower and anterior fibres of this band lie in the anterior wall of the upper part of the prostatic urethra. The band is sometimes spoken of as the **sphincter vesicæ internus.** At a lower level, in front of the prostatic urethra, there is a band of striated muscular fibres which is continuous inferiorly with the inner circularly disposed part of the sphincter urethræ. Like the latter, it is probably to be regarded as a part of a primitive voluntary urogenital sphincter muscle, such as is represented also in the female subject.

Female Urethra.—The **female urethra** (Fig. 657) is a canal about an inch and a half in length which follows a slightly curved direction downwards and forwards, below and behind the lower border of the pubic symphysis. Except during the passage of urine the canal is closed by the apposition of its anterior and posterior walls. The **external urethral orifice** is placed between the labia minora, immediately in front of the opening of the vagina, about one inch below

and behind the clitoris (Fig. 663). The opening is slit-like, and is bounded by slightly marked lips. The mucous lining of the canal is raised into a number of slightly marked longitudinal folds, one of which, more distinct than the others and placed on the posterior wall of the passage, receives the name of **urethral crest.**

The upper part of the urethra is separated from the front of the vagina by a *vesico-vaginal space* filled with loose connective tissue. Lower down, however, it becomes very intimately connected with the vagina, so that, as it approaches the external urethral orifice, it appears to be embedded in the anterior vaginal wall. This is due to the fact that the lower part of the urethra is bound to the front of the vagina by the fusion of their fasciae into a single dense layer —the " post-urethral ligament " (Shaw, 1947).

Structure.—The muscular coat of the female urethra is continuous above with that of the bladder, and is composed of layers of obliquely disposed plain muscle-fibres, together with a few bundles which are longitudinally directed. In the lower part, some of the fibres do not completely surround the urethra but are attached to the anterior wall of the vagina. Within the muscular coat the wall of the urethra is very vascular, and the canal itself is lined with a pale mucous membrane which is thrown into the longitudinal folds mentioned above. The epithelium of the canal, in its upper part, is of the transitional variety, like that of the bladder; in its lower part it becomes scaly. Numerous minute **urethral glands** and pit-like **urethral lacunæ** open into the urethra. One group of these glands on each side possesses a minute common duct, known as the **para-urethral duct**, which opens into the pudendal cleft by the side of the external urethral orifice. These glands represent the prostatic glands of the male. The vascular layer which lies between the muscular coat and the mucous membrane contains elastic fibres, and in appearance resembles erectile tissue. Striated muscle-fibres are present on the outer surface of the muscular coat of the urethra. In the upper part of the canal these fibres form a complete ring-like sphincter, so that the urethra is encircled by both plain and striated fibres. Lower down, some of the striated fibres are attached to the anterior vaginal wall, and in the lower third, where they are specially developed, they pass backwards on the outer surface of the vagina to enclose that passage together with the urethra in a single loop of muscle-tissue. The lower fibres, therefore, form a urogenital sphincter associated with the **sphincter urethrae muscle.**

MALE GENITAL ORGANS

The male reproductive organs are (1) the testes together with (2) their coverings and (3) their ducts, (4) the prostate, (5) the bulbo-urethral glands, (6) the external genital organs, and (7) the male urethra.

The **testes** are the essential reproductive glands of the male, and are a pair of nearly symmetrical oval bodies situated in the scrotum. The duct of each testis is at first much twisted and contorted to form a structure known as the **epididymis**, which is applied against the back of the testis; the duct emerges from the epididymis as the **vas deferens**, which passes upwards towards the lower part of the anterior abdominal wall and pierces it obliquely to enter the abdominal cavity. There, each vas deferens is covered with the peritoneum, and, crossing the pelvic brim almost at once, enters the true pelvis. The duct now runs on the side-wall of the pelvis towards the base of the bladder, where it comes into relation with a branched tubular structure termed the **seminal vesicle.** Joined by the duct of the seminal vesicle, the vas deferens forms a short canal, called the **ejaculatory duct**, which terminates by opening into the prostatic part of the **urethra**. The **prostate** and the **bulbo-urethral glands** are accessory organs connected with the male reproductive system. The ducts of the bulbo-urethral glands and those of the prostate, like the ejaculatory ducts, open into the **urethra**, which thus serves not only as a passage for urine, but also for the generative products. The external genital organs are the **penis and scrotum**.

TESTES

The **testes** are a pair of oval, slightly flattened bodies of a whitish colour, measuring about an inch and a half in length, one inch from before backwards, and rather less in thickness. Each testis is placed within the cavity of the scrotum in such a manner that its long axis is directed upwards and slightly forwards and laterally. Usually the left gland is a little lower than the right. The testis (Fig. 635) has two slightly flattened surfaces: a *lateral surface*, which looks backwards as well as laterally, and a *medial surface*, which looks forwards as well as medially, and is usually the more flattened. The two surfaces are separated

by rounded **anterior** and **posterior borders**. The anterior border is the more convex and is free. By the posterior border the testis is suspended within the scrotum. The **epididymis** and the lowest portion of the **spermatic cord** are attached to the posterior border of the testis (Figs. 634, 635).

Epididymis.—The epididymis is a comma-shaped structure that clasps the posterior border of the testis and to some extent overlaps the posterior part of its lateral surface (Fig. 633). The upper, swollen part is called the **head of the epididymis** and overhangs the upper end of the testis, to which it is directly connected by numerous emerging ducts, by fibro-areolar tissue, and by the serous covering of the organ. The inferior and smaller end is termed the **tail of the epididymis**; it is attached by loose areolar tissue and by the serous covering to the lower part of the testis. The intervening part, or **body of the epididymis**, is applied against the posterior part of the lateral surface of the testis but is separated from it by an involution of the serous covering of the organ which forms an intervening pocket termed the **sinus of the epididymis**.

The main mass of the epididymis is composed of an irregularly twisted tube, called the **canal of the epididymis**, which forms the first part of the duct of the testis (Figs. 636, 637).

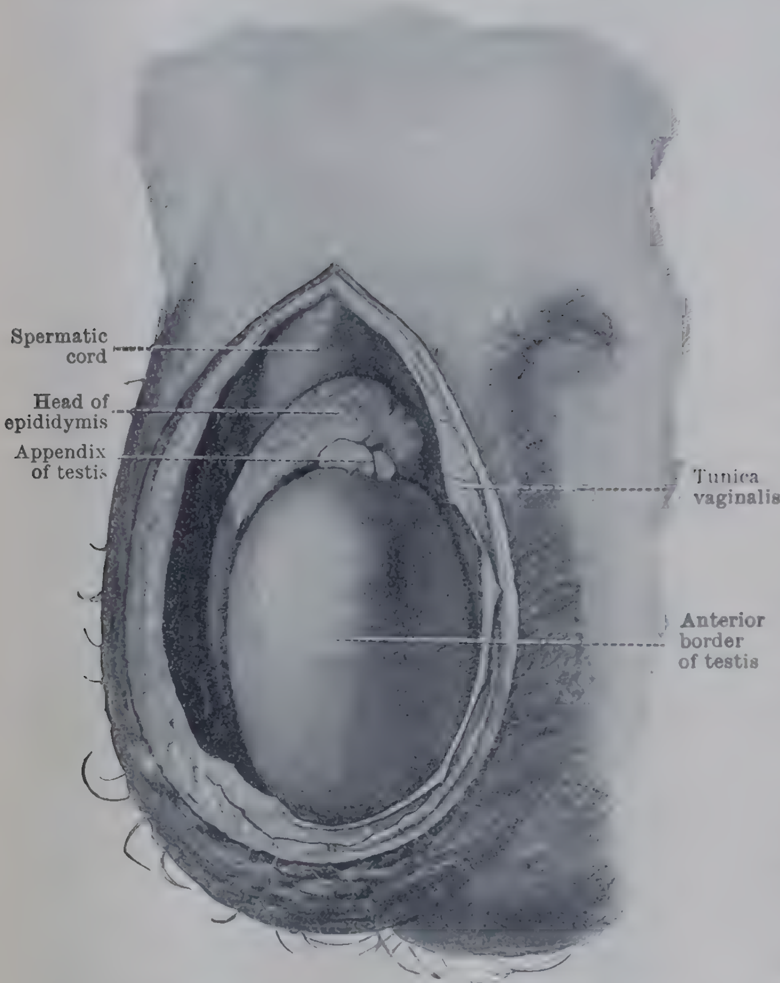

FIG. 633.—RIGHT TESTIS AND EPIDIDYMIS, EXPOSED BY REMOVAL OF ANTERIOR WALL OF SCROTUM.

Minute sessile or pedunculated bodies are often found attached to the head of the epididymis and to the upper end of the testis. They are called appendices of the epididymis and testis, and have a developmental interest. The **appendix of the testis** is a minute body which lies on the upper end of the testis and represents the free end of the para-mesonephric duct of the embryo and the fimbriated end of the uterine tube of the female; it is usually sessile. The **appendix of the epididymis** is attached to the head of the epididymis and is believed to represent a remnant of the mesonephros. Another small vestigial body called the **paradidymis**, also believed to be a remnant of the mesonephros, is sometimes found above the head of the epididymis in front of the lower part of the spermatic cord. It is best marked in young children and is seldom found in the adult.

Tunica Vaginalis.—The walls of the cavity within which the testis and epididymis are placed are lined with a serous membrane—the **tunica vaginalis**—which resembles in appearance and structure the peritoneum, from which it was originally derived. The cavity is considerably larger than the contained structures, and extends to both a higher and a lower level than the testis. The cavity tapers as it is traced upwards. The tunica vaginalis is an invaginated membrane doubled in on itself from behind, for, after lining the scrotal chamber, it is reflected forwards from the posterior wall to cover the testis, epididymis, and lower part of the spermatic cord. The inner layer is known as the visceral layer and is closely applied to the enclosed organs; the outer or parietal layer is fairly strongly attached to the wall of the scrotum; and between the two layers there is a closed

cavity that contains a little serous fluid. The visceral layer dips into the narrow interval between the body of the epididymis and the lateral surface of the testis to form a slit-like recess called the **sinus of the epididymis** (Figs. 634 and 635). In three positions the surface of the testis receives no covering from the tunica vaginalis—above, where the head of the epididymis is attached; below, where the tail is in contact; and posteriorly, where the blood-vessels and nerves enter the organ from the spermatic cord.

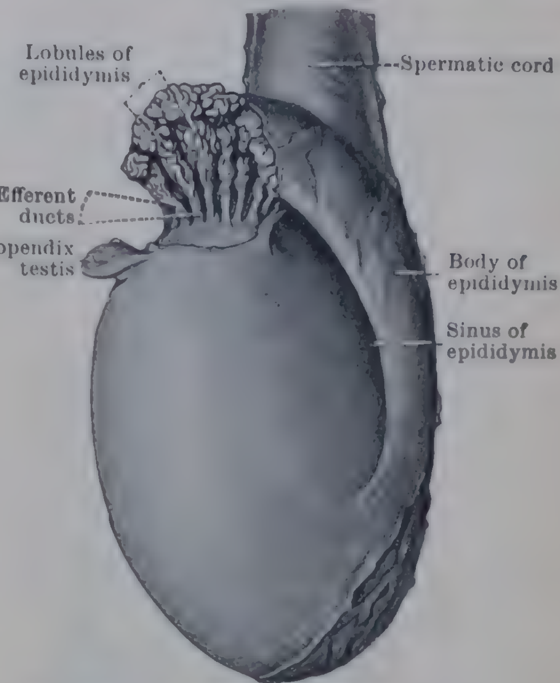

FIG. 634.—LEFT TESTIS AND EPIDIDYMIS.

Part of the tunica vaginalis has been removed in order to show the efferent ducts and the lobules of the epididymis.

Structure of Testis.—Under cover of the tunica vaginalis the testis is invested by an external coat of dense, white, inelastic fibrous tissue called the **tunica albuginea**, from the deep surface of which a number of thin fibrous **septa** dip into the gland. These septa imperfectly divide the organ into a number of wedge-shaped parts called **lobes of the testis** (Fig. 635). All the septa end posteriorly in a mass of fibrous tissue called the **mediastinum testis**, which is directly continuous with the tunica albuginea and projects forwards into the testis along its posterior border. It is traversed by an exceedingly complicated network of fine canals called the **rete testis**; the minute tubules that compose the substance proper of the testis open into the rete. The mediastinum is pierced also by the arteries, veins, and lymph-vessels of the testis; they enter the posterior border of the organ, traverse the mediastinum, and spread out on the fibrous septa. In this way a delicate network

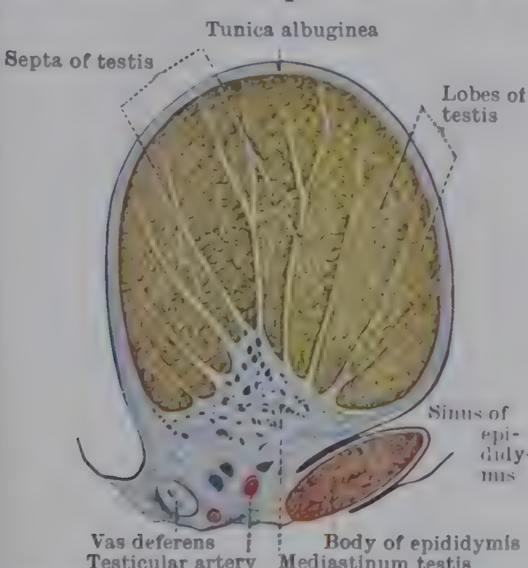

FIG. 635.—TRANSVERSE SECTION OF TESTIS AND EPIDIDYMIS.

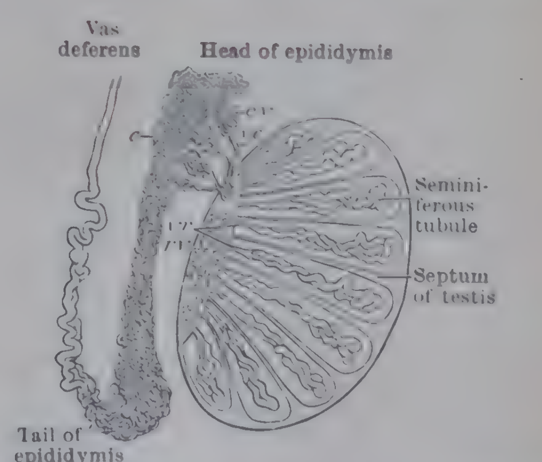

FIG. 636.—DIAGRAM TO ILLUSTRATE STRUCTURE OF TESTIS AND EPIDIDYMIS.

c. Canal of epididymis. c.v. Lobules of epididymis. r.v. Rete testis. v.e. Efferent ductules of testis. v.r. Straight seminiferous tubules.

of vessels—the *tunica vasculosa*—is formed on the deep surface of the tunica albuginea and on the sides of the septa.

The mediastinum, the septa, and the tunica albuginea form a framework enclosing a number of imperfectly isolated spaces which are filled by a substance of a light brown colour called the **parenchyma testis**. The parenchyma is composed of enormous numbers of **convoluted seminiferous tubules**. These minute tubules look like fine threads to the unaided eye, and they are but loosely held together by a small amount of areolar tissue. Usually two or four tubules are found in each lobe of the gland, and the total number in the testis has been

estimated at more than 800. The convoluted tubules pass towards the mediastinum testis and unite at acute angles to form a smaller number of slender tubes which run a straight course and are called the **straight seminiferous tubules**; and they open into the rete testis (Fig. 636). The tubules are much more twisted and convoluted near the tunica vaginalis than in the region of the mediastinum.

Microscopic sections show that the walls of the seminiferous tubules are composed of a basement membrane and of an epithelial lining formed of several layers of cells. Certain cells of the epithelium (*spermatogonia and spermatocytes*, p. 28) are, in the adult, constantly undergoing transformation into **spermatozoa**, and the appearance of the tubules in section varies much, according to age and to the greater or less activity of the epithelial cells.

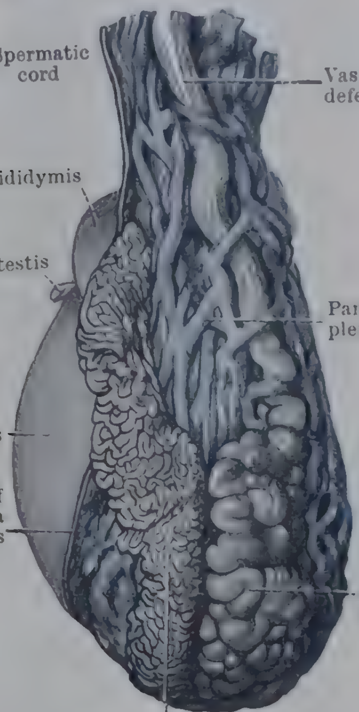

FIG. 637. — LEFT TESTIS AND EPIDIDYMIS VIEWED FROM BEHIND, SHOWING CANAL OF EPIDIDYMIS AND FIRST PART OF VAS DEFERENS.

Structure of Epididymis.—The secretion of the convoluted seminiferous tubules is carried through the straight tubules into the rete testis, and it leaves the rete, to reach the canal of the epididymis, through from fifteen to twenty minute tubules called the **efferent ductules of the testis.** These efferent ductules pierce the tunica albuginea and enter the head of the epididymis. Each ductule is at first straight, but soon becomes much convoluted, and forms a little conical mass called a **lobule of the epididymis**. Within the head of the epididymis the little twisted canals open into the single, much-convoluted tube which constitutes the chief bulk of the epididymis, and is called the **canal of the epididymis**. This canal, which is about 20 feet in length, may be said to begin in the head of the epididymis, and to end, after an extraordinarily tortuous course, at the tail by becoming the **vas deferens** (Figs. 636, 637).

In most cases one or more slender convoluted diverticula from the canal of the epididymis may be found near its lower end; they receive the name of **aberrant ductules**, and one of them which is very constantly present often measures a foot or more in length.

The canal of the epididymis and the efferent ductules of the testis are lined with a ciliated epithelium, the cilia of which maintain a constant current towards the vas deferens. The canal has a muscular coat composed of an inner stratum of circular fibres and an outer stratum of longitudinally directed fibres. The wall, at first thin, becomes much thicker as the canal approaches the vas deferens.

Vessels and Nerves of Testis.—The testis is supplied by the **testicular artery**, a branch of the aorta. It is a slender vessel which, after a long course, reaches the posterior border of the testis, where it breaks up into branches. According to Harrison & Barclay (1948), there are commonly two main branches which pass forwards in the tunica albuginea, one on each side of the organ, to ramify on its deep surface in variable patterns. From these arteries—which vary in number and arrangement—the principal terminal branches pass backwards into the substance of the testis in the tunica vasculosa of the septa and converge on the mediastinum. Only very fine branches, as a rule, pass into the testis directly through the mediastinum. For the relation of the *artery of the vas deferens* and the *cremasteric artery* to the blood-supply of the testis through anastomoses with the testicular artery, see Harrison (1949).

The **veins** issue from the posterior border of the testis and form a dense plexus, called the **pampiniform plexus**, which finally pours its blood through the testicular vein, *on the right side*, into the inferior vena cava, and, *on the left side*, into the left renal vein.

The **lymph-vessels** of the testis pass upwards in the spermatic cord and end in the lymph-glands at the sides of the aorta and inferior vena cava below the renal veins (p. 1415).

The **nerves** for the testis and epididymis accompany the artery, and are derived through the *aortic* and *renal plexuses* from the tenth thoracic segment of the spinal cord. The arteries and nerves of the testis communicate with those on the lower part of the vas deferens, namely, with the artery of the vas deferens and with nerve-bundles from the hypogastric plexus.

VAS DEFERENS AND SPERMATIC CORD

The **vas deferens** is the direct continuation of the canal of the epididymis. It begins at the lower end of the epididymis and ends, after a course of nearly 18 inches, by joining the duct of the seminal vesicle to form the ejaculatory duct, which opens into the prostatic part of the urethra; in parts of its course it is slightly convoluted, and the actual distance traversed is not more than 12 inches. It first ascends to the superficial inguinal ring; it next runs laterally in the inguinal canal to the deep ring; and then, having entered the abdomen, it bends medially and backwards to reach the true pelvis, where it ends behind the neck of the bladder.

At first it lies in the scrotum, where it ascends over the back of the testis along the medial side of the epididymis, and it is here that it is most convoluted (Fig. 637). At the upper end of the testis it falls in with the vessels and nerves of the testis and epididymis, and it is bound together with them by areolar tissue in a loose bundle called the spermatic cord.

FIG. 638.—TRANSVERSE SECTION OF SPERMATIC CORD IMMEDIATELY BELOW SUPERFICIAL INGUINAL RING.

The **spermatic cord** is therefore made up of (1) the vas deferens and its own artery, (2) the testicular artery and the pampiniform plexus of veins, (3) the lymph-vessels and nerves of the testis and epididymis, and (4) remnants of the processus vaginalis—the plexus of veins being by far the bulkiest of these constituents. The cord extends from the testis to the deep inguinal ring, and it is enclosed in three tubular sheaths or **coats**—the external spermatic fascia, the cremasteric muscle and fascia, and the internal spermatic fascia (Fig. 638). When these coats reach the scrotum they expand and take a share in the formation of the wall of the scrotum; and the cremasteric coat carries with it its blood-supply and nerve-supply—*the artery and nerve to the cremaster*.

Between the scrotum and the superficial inguinal ring, the cord lies on the deep fascia of the muscles that spring from the pubis, and it is crossed by the superficial external pudendal vessels. In this part of the course the vas is in the posterior part of the cord, and is easily distinguished from the other constituents (even in the undissected body), by its hard, firm feel when the cord is gripped between finger and thumb. When the cord enters the inguinal canal it lies on the inferior crus of the superficial ring immediately lateral to the pubic tubercle; and here it loses its external spermatic coat, which blends with the external oblique aponeurosis at the margins of the ring (Fig. 645).

During its passage through the inguinal canal, the vas lies in the lower part of the cord on the grooved, upper surfaces of the inguinal ligament and its pectineal part; the external oblique aponeurosis and the lower fleshy fibres of the internal oblique are in front; and the conjoint tendon and the transversalis fascia are behind. Half way along the canal the cord loses its cremasteric coat, for that coat is derived from the lower border of the internal oblique muscle, which arches over the cord.

Less than half an inch above the mid-inguinal point, at the lateral side of the inferior epigastric artery, the cord reaches the deep inguinal ring. Here, the cord loses its internal spermatic coat, which blends with the transversalis fascia at the margins of the ring. Here also, the cord ends, for at this point the vas deferens parts company with the vessels and nerves.

The vas deferens now curves medially across the external iliac artery behind the root of the inferior epigastric artery, and then, changing its direction, it runs for a short distance backwards, medially, and, upwards, outside the peritoneum, to a point $1\frac{1}{2}$ or 2 inches from the pubic tubercle, where it crosses the pectineal line and enters the true pelvis. In that part of its course the vas usually

lies at first in front of the external iliac vessels, and then in the floor of a little triangular fossa—the *pectineal triangle*—which lies between the external iliac

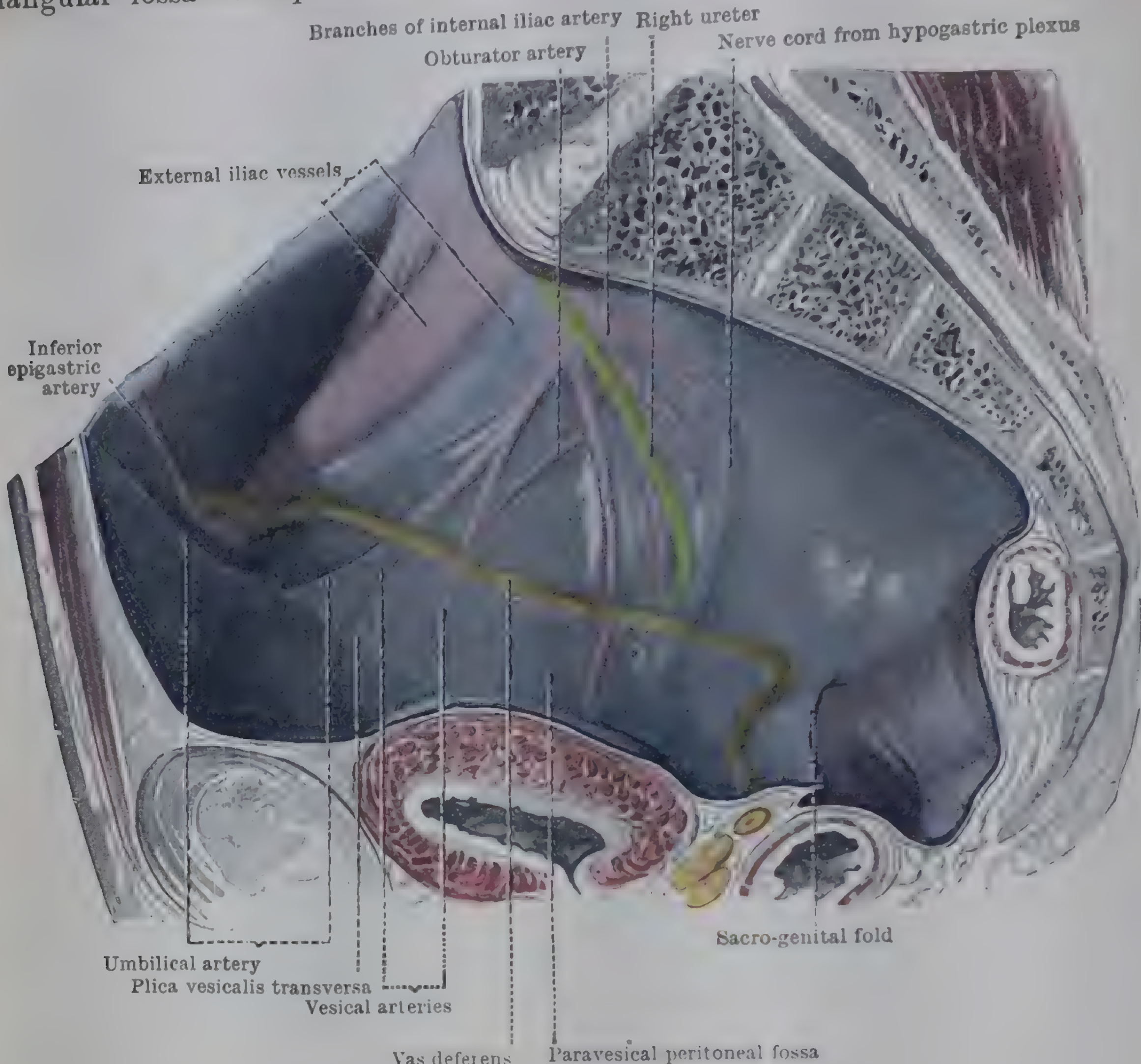

FIG. 639.—MEDIAN SECTION OF ADULT MALE PELVIS TO SHOW COURSE OF VAS DEFERENS ON SIDE-WALL OF PELVIC CAVITY.

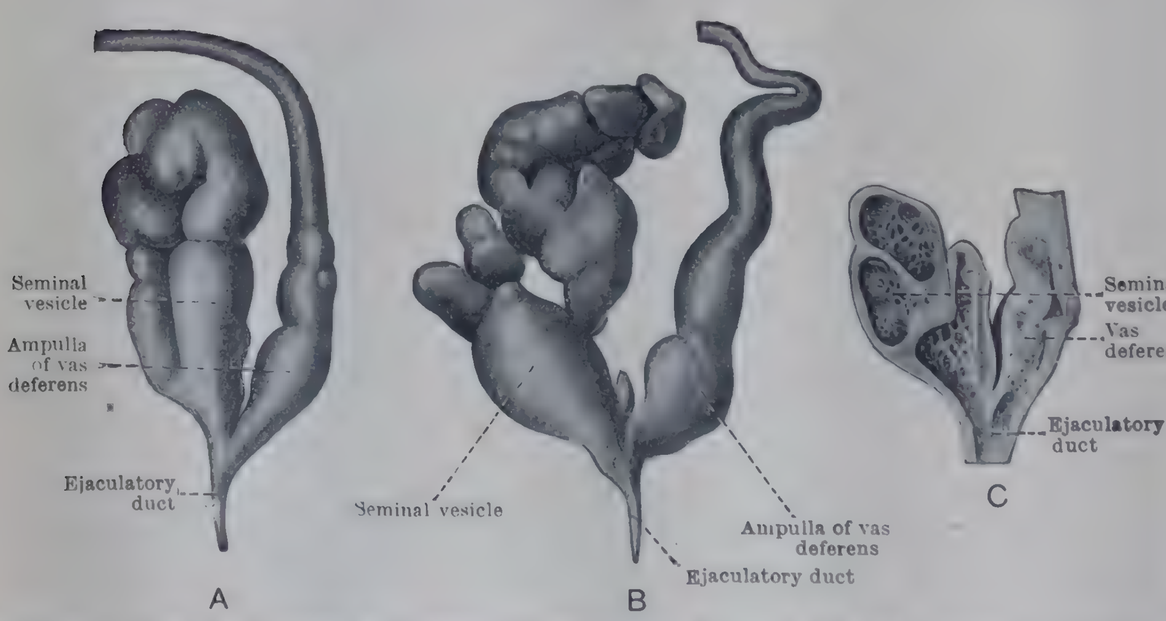

FIG. 640.—A and B. DRAWINGS OF SEMINAL VESICLE AND AMPULLA OF VAS DEFERENS TAKEN FROM DIFFERENT SUBJECTS. C. SEMINAL VESICLE AND AMPULLA OF VAS DEFERENS CUT TO SHOW THE PITTED STRUCTURE OF THEIR WALLS.

vessels and the pelvic brim (Fig. 625). On the side-wall of the pelvis the vas is continued backwards, and a little downwards and medially, in the direction of the ischial spine, and lies immediately external to the peritoneum, through which it

can usually be seen. In the pelvic part of its course the vas crosses the medial side of (1) the umbilical artery, (2) the obturator nerve and vessels, (3) the vesical **vessels**, and (4) the **ureter** (Fig. 639).

Beyond the ureter the vas deferens takes a sudden bend and passes downwards and medially outside the peritoneum of the pelvic floor. There, the vas lies a short distance behind the terminal part of the ureter and immediately in front of the sacro-genital fold of peritoneum (Figs. 625, 639). Reaching the interval between the base of the bladder in front and the rectum behind, the two vasa deferentia occupy the angle between the right and left seminal vesicles (Fig. 642). As they approach each other each vas becomes slightly tortuous, sacculated, and dilated, and assumes a general resemblance in structure to a portion of the seminal vesicle. The dilated part of the vas is termed its **ampulla**. Immediately above the base of the prostate the vas deferens becomes once more a slender tube and is joined by the duct of the corresponding seminal vesicle to form the **ejaculatory duct** (Fig. 640).

In some cases the vas deferens crosses the umbilical artery before it enters the cavity of the true pelvis; it normally does so in the fœtus (Fig. 643).

Ejaculatory Duct.—This is the very slender tube formed by the union of the vas deferens with the duct of the corresponding seminal vesicle (Fig. 640). It is less than an inch in length, and lies very close to its fellow of the opposite side as it passes downwards and forwards through the prostate behind its median lobe. The ducts open by slit-like apertures into the first part of the urethra, one on each side of the mouth of the **prostatic utricule**. They are well seen in sections through the upper part of the prostate (Fig. 651, A).

The mucous membrane of the duct is thrown into numerous complicated folds, and in connexion with it there is a number of remarkable minute diverticula which are enclosed within the muscular coat of the duct. Ancel (1920) states that the ejaculatory duct is absent on one or both sides in 18 per cent of adults and that the vas deferens and duct of the seminal vesicle then open separately either into the utricle or on the urethral crest.

SEMINAL VESICLES

The **seminal vesicles** are a pair of hollow sacculated structures placed on the base of the bladder in front of the rectum (Figs. 624, 642). Each vesicle is about two inches in length, and has its long axis directed downwards, medially, and slightly forwards. The upper end of the vesicle, which is partly covered with peritoneum, is large and rounded, and lies at a considerable distance from the median plane, behind the lower end of the ureter, and is separated from the rectum by the peritoneum of the recto-vesical pouch. Below the level of the peritoneal cavity the seminal vesicle and rectum are more intimately related. The vesicle tapers towards its lower end, which is placed not far from the median plane immediately above the prostate. In this position the vesicle becomes constricted to form a short duct which joins the lateral side of the corresponding vas deferens at an acute angle. The common duct thus formed is the **ejaculatory duct**. The medial side of each vesicle is related to the vas deferens, and the lateral side, when the bladder is empty, lies

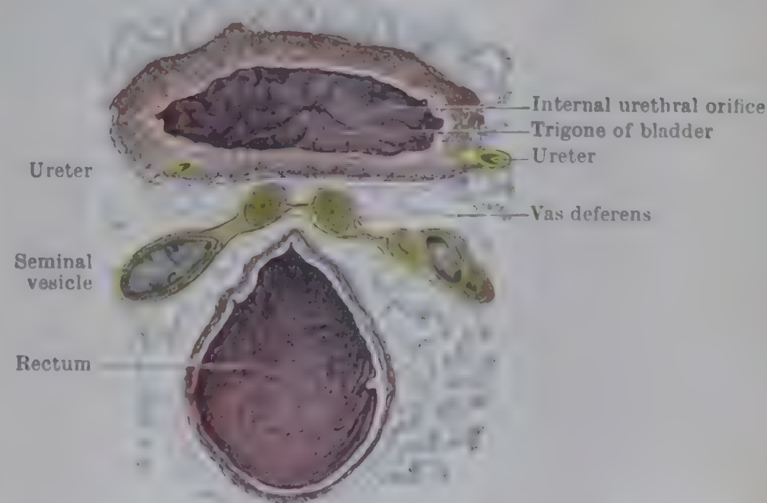

FIG. 641.—HORIZONTAL SECTION THROUGH RECTUM AND URINARY BLADDER AT THE LEVEL AT WHICH THE URETERS PIERCE THE BLADDER-WALL.

From a specimen in the Surgical Museum, Trinity College, Dublin.

close to the levator ani. The seminal vesicles are more intimately related to the wall of the bladder than to that of the rectum. Their upper ends are separated from the rectum by a portion of the recto-vesical pouch, and, lower down, the partition of plain muscle-fibres and of fascia which intervenes between the seminal vesicles and the rectum is thicker than that which separates them from the bladder.

The seminal vesicle assumes a more vertical position when the bladder is distended, and a more horizontal direction when the bladder is empty. Its upper end is sometimes curved backwards against the side of the rectum. In some cases the seminal vesicles are much smaller than usual, and may be less than one inch in length. Frequently they are asymmetrical in size and shape.

Each seminal vesicle is in reality a tube bent in a tortuous manner on itself; if the dense

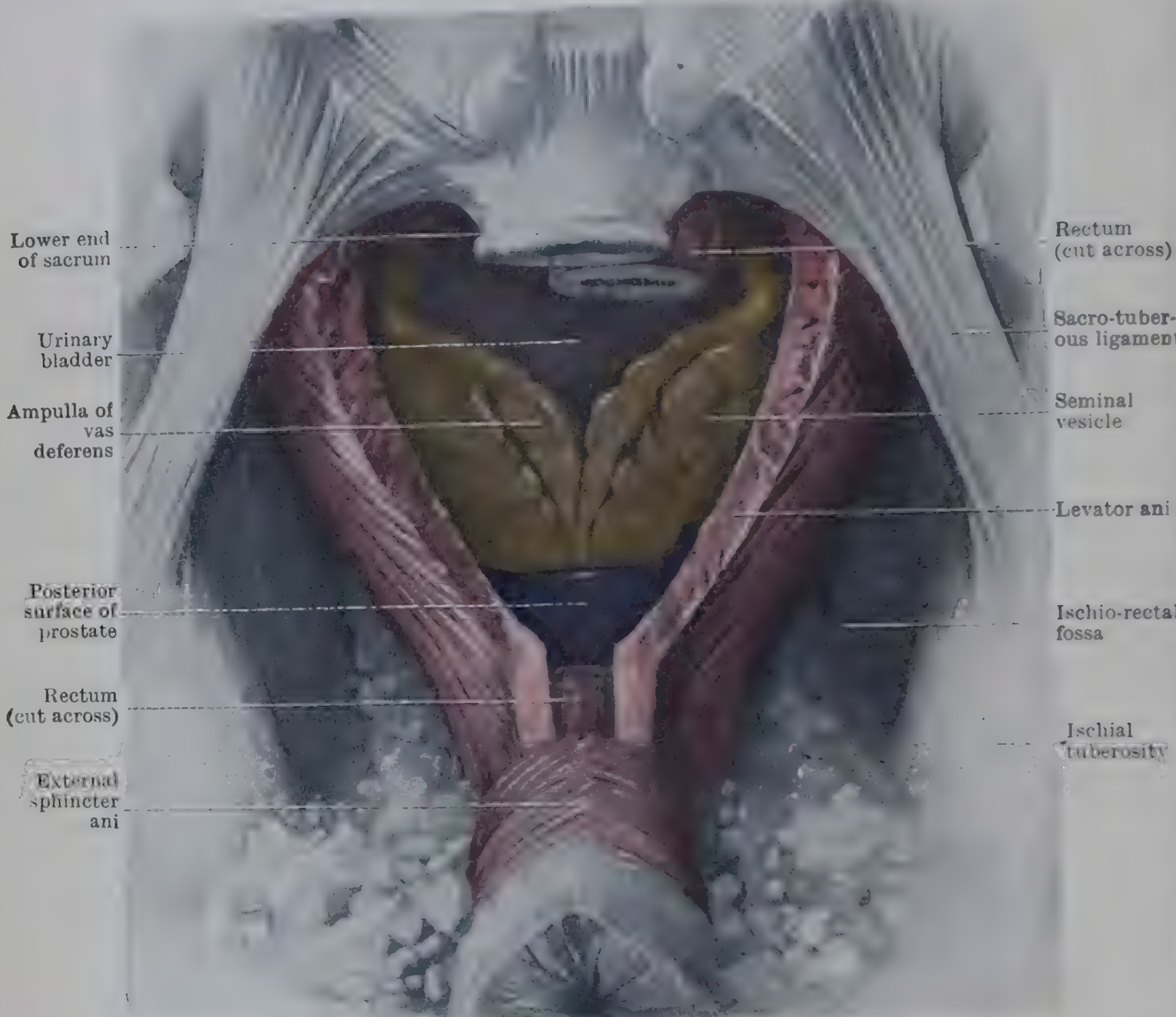

FIG. 642.—DISSECTION FROM BEHIND TO DISPLAY THE SEMINAL VESICLES, THE AMPULLÆ OF THE VASA DEFERENTIA, AND THE PROSTATE.

tissue which envelops it is taken away, the length of the tube when untwisted may be found to be as much as five inches. The tube is closed above, and a variable number of short tortuous branches arise from it at different levels. The blind end of the tube usually lies at the upper end of the vesicle, but in some cases the tubular structure is so bent upon itself that the blind terminal part lies against the side of the issuing duct. Their mode of development shows that the seminal vesicles are diverticula of the vasa deferentia, from which they originally arise as small, pouched outgrowths.

The seminal vesicles are not present in all mammals, and in those in which they do occur their relative size and form vary much. The carnivora and marsupials, for instance, have no seminal vesicles; in some other animals, *e.g.*, hedgehog, they are relatively of enormous size.

The dense tissue in which the seminal vesicles are embedded contains much plain muscle-tissue which sweeps round in the side-wall of the recto-vesical pouch. Inferiorly this tissue is attached to the capsule of the prostate. The large veins coming from the prostatic and vesical plexuses are closely related to the seminal vesicles.

Structure of Vas Deferens and Seminal Vesicle.—Except at the ampulla, the vas deferens is a thick-walled tube with relatively a very small lumen. The hard cord-like sensation which it conveys to the touch is due to the thickness and denseness of its wall. The wall of the vas is composed of three layers—an outer **adventitious coat** of fibrous tissue, a middle **muscular coat**, and an inner **mucous coat**. The thickness of the wall is due to the great

development of its coat of plain muscle, which is arranged in three layers: an outer and an inner of longitudinal fibres, and a middle layer—by far the thickest—of circular fibres. The mucous membrane of the vas exhibits a number of slight longitudinal folds and is covered with a ciliated epithelium. The ampulla has a much thinner wall, and, as the surface of its mucous membrane has a number of ridges separating depressed areas, the lining of this part of the tube presents a honeycomb appearance. The wall of the seminal vesicle resembles that of the ampulla in being thin, and in having a mucous lining with uneven, honeycomb-like ridges and depressions (Fig. 640, C). In it the same coats are to be recognized as in the vas deferens but the muscular layer is much thinner, and the strata composing it are less regularly arranged.

Vessels and Nerves of Vas Deferens and Seminal Vesicle.—The vas receives its main **artery** from the superior or the inferior vesical artery. This *artery to the vas* accompanies it as far as the testis, where it ends by anastomosing with branches of the testicular artery. The seminal vesicle is supplied by twigs from the *inferior vesical artery*. The **nerves** come from the hypogastric plexus. In lower animals the nerves for the seminal vesicles are derived from the nerve-roots of the second, third, and fourth lumbar nerves.

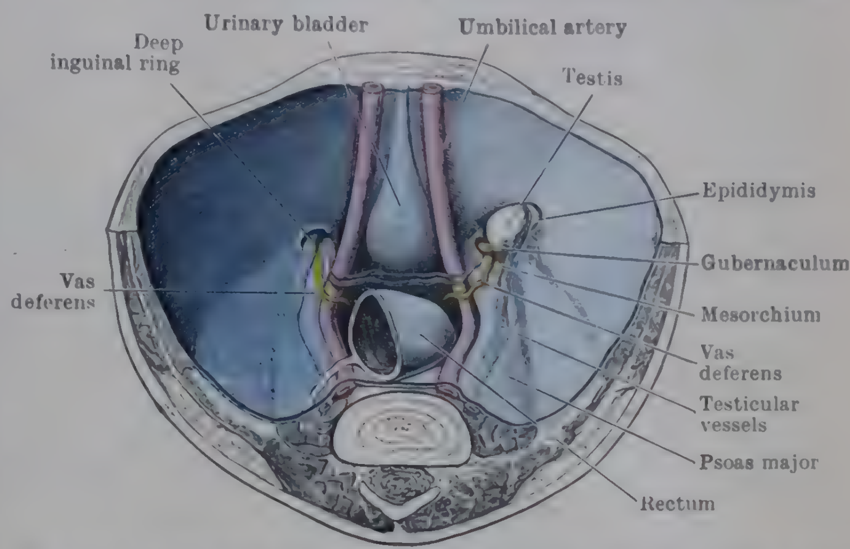

Fig. 643.—View from Above of Cavity of Pelvis and Lower Part of Abdomen in Male Fœtus about the Seventh Month.

On the left side, which represents a slightly more advanced condition than the right, the testis has entered the inguinal canal; on the right side the testis is still within the abdominal cavity.

Descent of Testis

The cause of the peculiar course pursued by the vas deferens in the adult, and the manner in which it is related to the anterior abdominal wall, are made clear by a study of the arrangement of the parts in the fœtus (Kirk, 1936; Wyndham, 1943). Until nearly the end of intra-uterine life the testes are in the abdominal cavity. The testis at first lay on the posterior abdominal wall at the level of the upper lumbar vertebræ. To its lower pole a ridge of tissue called the **gubernaculum testis** (John Hunter, 1786) was attached and this ridge extended down to the inguinal region. Both testis and gubernaculum were behind the primitive peritoneum but they pushed it forwards; the gubernaculum thus formed a ridge covered with peritoneum, and the testis—almost completely surrounded by peritoneum—was attached to the posterior abdominal wall by a peritoneal fold called the **mesorchium**. Meanwhile a blind tube of peritoneum called the **processus vaginalis** grew down through the layers of the developing abdominal wall in the inguinal region, and as it did so it pushed attenuated parts of these layers before it. These layers become the coats of the spermatic cord. As the processus vaginalis grew down, the gubernaculum grew down behind it, forming a peritoneum-covered ridge similar to that in the abdominal cavity, and then, by tension of the gubernaculum, the testis, still protruding forwards into a peritoneal invagination, slid down the posterior abdominal wall and the back of the processus vaginalis. By the third month of fœtal life the testis lies in the iliac fossa, and by the seventh it is near the deep inguinal ring (Figs. 643, 644).

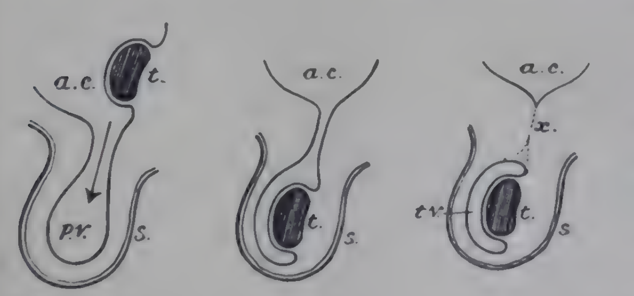

Fig. 644.—Diagram to illustrate Descent of the Testis and Origin of Tunica Vaginalis.

a.c. Abdominal cavity. *p.v.* Processus vaginalis. *t.* Testis. *s.* Scrotum. *t.v.* Tunica vaginalis. *x.* Vestige of processus vaginalis.

Often a small fibrous band may be found in the adult passing through the inguinal canal and joining the peritoneum superiorly in the region of the deep inguinal ring. Sometimes the band is connected below with the tunica vaginalis, but more often it cannot be traced so far downwards. When present it represents the obliterated portion of

the processus vaginalis, and is therefore known as the **vestige of the processus vaginalis.**

The processus vaginalis occasionally persists after birth as a channel freely open to the abdominal cavity above; or the passage, becoming closed at intervals, may give rise to one or more cysts within the coats of the spermatic cord.

It sometimes happens that the descent of the testis is arrested, and then it either remains on the posterior abdominal wall or protruding forwards into a persisting upper part of the processus vaginalis in the inguinal canal. The term "cryptorchism" is applied to such cases of undescended testis; and the organ is then usually functionless. On the other hand, the testis may be *ectopic* through irregular descent into the perineum or even into the upper part of the thigh.

As the testis enters the inguinal canal the gubernaculum atrophies, but at birth a short part of the gubernaculum may still be found passing downwards towards the lower part of the scrotum and lying below the level of the tunica vaginalis. It is considered by some anatomists that the movement downwards of the testis may be partly due to a pull caused by the shrinking of the gubernaculum as it atrophies. In its descent the testis takes with it its duct and vessels and nerves, and they form the *spermatic cord.*

In some mammals, such as the elephant, the testes remain permanently within the abdominal cavity; while in others, such as the rabbit and the hedgehog, the peritoneal pouches remain widely open throughout life, and the testes are periodically withdrawn into the abdomen. There is some evidence that the descent of the mammalian testes is related to the fact that temperature in the scrotum is lower than in the abdomen (Crew, 1922); but intra-abdominal pressure may also be a factor (Keith, 1948). (See also Wells, 1943.)

SCROTUM

The **scrotum** varies much in appearance in different subjects, and even in the same person at different times. As the result of cold or of exercise, the wall of the scrotum becomes contracted and firm, and its skin becomes wrinkled; at other times the wall may be relaxed and flaccid, the scrotum then assuming the appearance of a pendulous bag. The left side of the scrotum reaches a lower level than the right, in correspondence with the lower level of the left testis. The skin of the scrotum is of a darker colour than the general skin of the body and is covered sparsely with hair; it is marked in the median plane by a ridge called the **raphe scroti**, which is continued backwards towards the anus and forwards on to the urethral surface of the penis. The difference in the appearance of the scrotum at different times is due to the degree of contraction or relaxation of a layer of plain muscular fibres, constituting the **dartos**, situated in the superficial fascia. When that muscular layer is contracted, the scrotum becomes smaller, and the skin is thrown into folds or wrinkles; when it is relaxed, the scrotum is flaccid and pendulous, and the skin becomes more smooth and even. The layer of fascia which contains the muscle-fibres can be shown to be continuous superiorly with the superficial fascia of the penis, and with the deep layer of the superficial fascia of the abdomen, and to be attached laterally to the sides of the pubic arch. The muscle-fibres are arranged in a thick layer of interlacing bundles, and many of the deeper fibres are continued into the **septum of the scrotum**, which divides the scrotum into a pair of chambers, one for each testis. The wall of each chamber is formed by the corresponding tunica vaginalis, internal spermatic fascia, cremasteric muscle and fascia and external spermatic fascia, while the skin, the superficial fascia, and the dartos muscle form coverings which are common to the whole scrotum, and they enclose both chambers. The layer of tissue immediately internal to the dartos is made up of exceedingly loose and easily stretched areolar tissue, and in it, as throughout in the superficial fascia of the scrotum, there is an entire absence of fat.

The scrotum in the fœtus has no cavity, but, like the labia majora in the female, it is composed entirely of vascular and fatty areolar tissue.

Vessels and Nerves of Scrotum.—On each side the **arteries** are *scrotal branches* from the internal pudendal artery, which reach it from behind, and from the external pudendal arteries, which reach its upper and anterior part.

The **nerves** of the scrotum are derived on each side from the posterior scrotal branches of the pudendal nerve, from the perineal branch of the posterior cutaneous nerve of the thigh, and from the ilio-inguinal nerve. The branches from the pudendal and posterior cutaneous nerves reach the scrotum from behind, while the ilio-inguinal supplies its upper and anterior part.

PENIS

The **penis** (Figs. 620, 650) is composed chiefly of erectile tissue, and is traversed by the urethra. The surface nearest the urethra is called the **urethral surface**; the opposite and more extensive aspect is the **dorsum penis**. The erectile tissue is for the most part disposed in three longitudinal columns, which in the body of the organ are closely united, while at the root of the penis they separate from one another and become attached to the perineal membrane and the sides of the pubic arch. Two of the columns of erectile tissue are placed alongside the median plane; they form the dorsum and sides of the penis, and are called the **corpora cavernosa penis**. The third column is situated in the median plane near the urethral surface, and is called the **corpus spongiosum penis**. The corpus spongiosum is the part of the penis

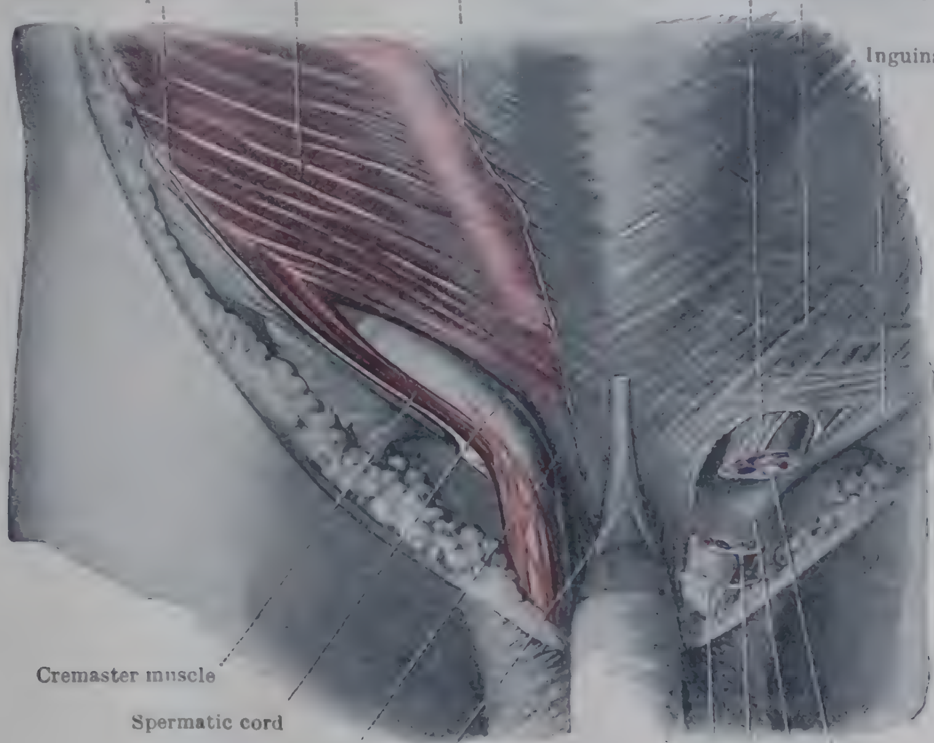

FIG. 645.—DISSECTION TO SHOW THE SPERMATIC CORD AS IT ISSUES FROM THE SUPERFICIAL INGUINAL RING. On the right side the external oblique muscle has been removed.

traversed by the urethra, and it is considerably smaller than the corpora cavernosa, which form the chief bulk of the organ (Figs. 646, 647).

In the **body of the penis** each corpus cavernosum presents a rounded surface, except where it is flattened by contact with its fellow of the opposite side. They are separated on the dorsal surface by a shallow groove, and on the urethral aspect by a deeper and wider furrow in which the corpus spongiosum lies (Fig. 646). Towards the distal end of the penis the corpus spongiosum expands, and, spreading towards the dorsal surface, forms a kind of conical cap—the **glans penis**—which covers over the blunt terminations of the corpora cavernosa (Fig. 648). The prominent margin of the glans, called the **corona glandis**, projects backwards and laterally beyond the ends of the corpora cavernosa. The glans is traversed by the terminal part of the urethra, which ends near the summit of the glans in a slit-like opening—the **external urethral orifice**. The united corpora cavernosa end in a blunt conical extremity, the apex of which is received into a hollow in the base of the glans. The skin of the body of the penis is thin, delicate, and freely movable, and, except near the pubis, is free from hairs; on the urethral aspect the skin is marked by a median raphe, continuous with the raphe of the scrotum. Traced towards the base of the glans, the skin forms

a free fold—the **prepuce** or foreskin—which overlaps the glans to a variable extent. From the deep surface of the prepuce the skin is reflected on to the terminal part of the penis along a line a little proximal to the corona glandis, and is continued over the entire glans to the external urethral orifice (Fig. 631). A small median fold—the **frenulum of the prepuce**—passes to the deep surface of the prepuce from a point immediately below the external urethral orifice. The skin of the glans is firmly attached to the underlying erectile tissue, and here, as well as on the deep surface of the prepuce, it has some resemblance to mucous membrane.

The secretion known as the **smegma præputii**, which tends to collect beneath the prepuce, has its source in the desquamated and broken-down epithelial cells derived from the surface of the glans and prepuce. A long, narrow prepuce, which cannot be retracted from the glans and may be adherent to it, may have to be removed by the operation of *circumcision.*

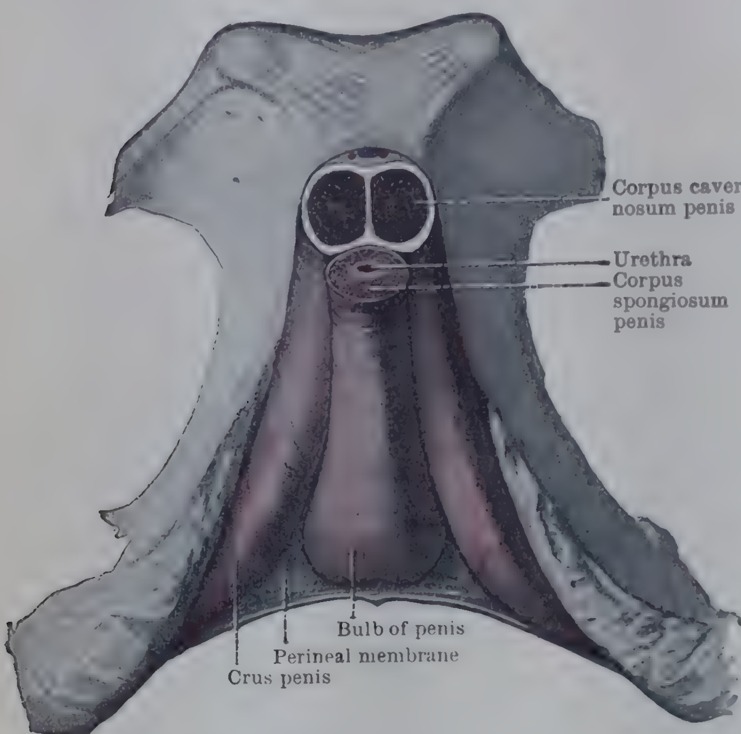

Fig. 646.—Root of Penis.
The body of the penis is seen in section.

At the **root of the penis** its three corpora separate from one another (Fig. 646). The corpora cavernosa, diverging sidewards, at first become slightly swollen, and then, gradually tapering, gain a firm, fibrous attachment to the periosteum on the medial surface of the sides of the pubic arch. These diverging parts of the corpora cavernosa are called the **crura penis** and each is covered by the corresponding ischio-cavernosus muscle. The corpus spongiosum, lying between the crura, becomes enlarged, and forms a globular mass which receives the name of the **bulb of the penis**. The bulb varies much in size in different subjects, and is attached to the under surface of the perineal membrane. The posterior part and under surface of the bulb usually show a median notch—an indication that the bulb is originally composed of two symmetrical portions which during development have become fused in the median plane. A slightly marked fibrous median septum indicates, at a deeper level, the plane along which fusion took place. The urethra, having pierced the perineal membrane, enters the bulb obliquely a short distance in front of its posterior end (Fig. 631). The superficial surface of the bulb is covered by the bulbo-spongiosus muscles.

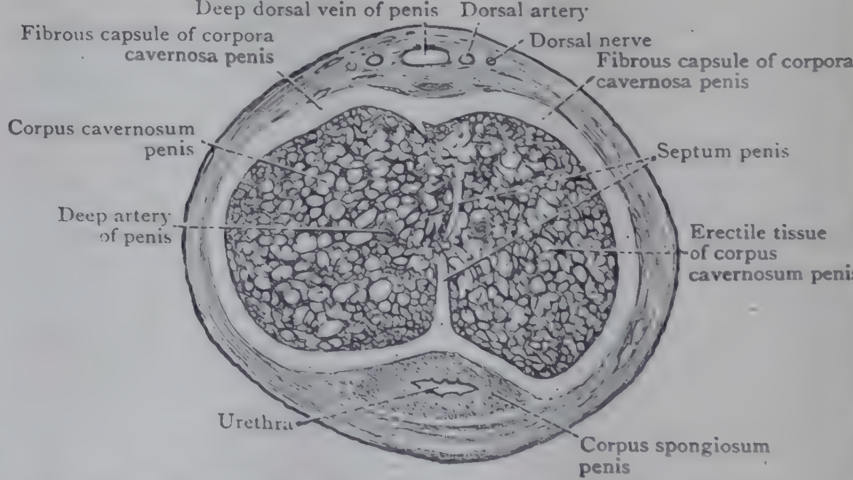

Fig. 647.—Transverse Section through Anterior Part of Body of Penis to show its Structure.

A triangular band of strong fibrous tissue, called the **suspensory ligament of the penis**, is attached to the front of the pubic symphysis and extends to the fascial sheath of the penis, with which it becomes continuous (Fig. 645).

Structure of Penis.—Each corpus cavernosum penis is enclosed in a dense, white fibrous coat which fuses with the corresponding coat of the opposite side to form the median **septum of the penis.** The septum is very incomplete, especially near the end of the penis, where it is interrupted by a number of nearly parallel slits (Figs. 647 and 648). Through these slits the erectile tissue of the two corpora cavernosa is continuous.

The fibrous coat contains some elastic fibres, and it is divided into an outer layer of longitudinal fibres and an inner layer of circular fibres, some of which latter are continued into the septum. Numerous fibrous strands proceed from the deep surface of the fibrous coat, and, stretching across the interior of the corpus cavernosum, form a fine sponge-like framework whose interspaces communicate freely with one another and are filled with blood. These spaces lead directly into the veins of the penis, and, like the veins, have a lining of flat endothelial cells. The size of the penis varies with the amount of blood in the erectile tissue. The structure of the corpus spongiosum resembles that of the corpora cavernosa, but the fibrous coat is much thinner and more elastic, and the spongework is finer (Fig. 647).

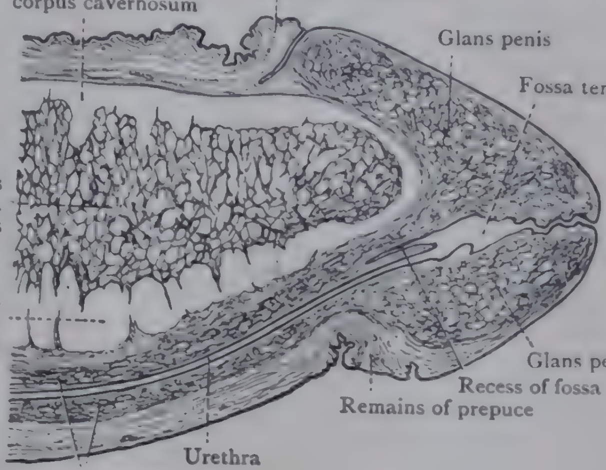

Fig. 648.—Median Section through Terminal Part of (circumcised) Penis to show its Structure.

The glans penis also is composed of erectile tissue which communicates by a rich venous plexus with the corpus spongiosum. No strongly marked fibrous coat is present, and the erectile tissue is bounded by the skin, which is exceedingly thin and firmly adherent. The urethra in this part of the penis is dilated and is compressed sideways into a slit-like passage called the *fossa terminalis*; the fossa is surrounded by a mass of fibro-elastic tissue which forms a kind of double median septum within the glans. This septum is continued backwards to join the fibrous coat of the conical end of the corpora cavernosa, and ventrally it gives attachment to the frenulum of the prepuce. It divides the erectile tissue of the glans imperfectly into right and left portions, which, however, freely communicate dorsally. From the septum, trabeculæ pass out in all directions into the tissue of the glans.

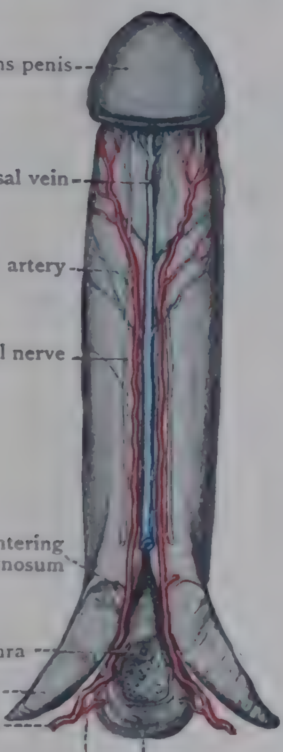

Fig. 649.—Dorsal Surface of Penis, showing the main Blood-Vessels and Nerves.

A fascial sheath, containing numerous elastic tissue fibres, forms a loose common envelope for the corpora cavernosa and the corpus spongiosum. It is termed the *fascia penis*, and reaches as far as the base of the glans, where it becomes fixed to the floor of the groove limited by the corona of the glans. In its proximal part the sheath gives insertion to many of the fibres of the bulbo-spongiosus and ischio-cavernosus muscles.

Superficial to the fascia penis there is a layer of extremely lax areolar tissue, and more superficial still is a prolongation of the dartos tunic of the scrotum, covered by the delicate skin of the penis. Numerous sebaceous glands are present in the skin, especially on the urethral surface of the penis.

In some mammals, such as the walrus, dog, bear, and baboon, a bone called the **os penis** is developed in the septum between the corpora cavernosa penis.

Vessels and Nerves of Penis.—The **arteries** are derived from the internal pudendal artery. The erectile tissue of the corpora cavernosa is supplied chiefly by the *deep arteries of the penis*, and that of the corpus spongiosum by the *arteries to the bulbs.* Branches of the *dorsal arteries* of the penis pierce the fibrous coat of the corpora cavernosa and furnish additional twigs to the erectile tissue. The glans receives its chief blood-supply from branches of the dorsal arteries. The small branches of the arteries run in the trabeculæ of the erectile tissue; and the capillaries, into which they lead, open directly into the cavernous venous spaces. As they lie in the finer trabeculæ the smaller branches often present a peculiar twisted appearance, and the name **helicine arteries** is therefore applied to them.

The **veins** with which the cavernous spaces communicate carry the blood, for the most part,

either directly into the *prostatic plexus*, or into the *deep dorsal vein* and so to that plexus. The deep dorsal vein of the penis begins in tributaries from the glans and prepuce, ascends in the groove between the corpora cavernosa, and passes beneath the inferior pubic ligament to join the prostatic plexus. On each side of it lies a dorsal artery, and, still farther from the median plane, a dorsal nerve (Figs. 647, 649).

The **lymph-vessels** of the penis are arranged in a deep and superficial series, and they end in the medial group of the *superficial inguinal lymph-glands*.

The **nerve-supply** of the penis is derived from the pudendal nerve (2nd, 3rd, and 4th sacral nerves), and from the pelvic sympathetic plexuses. The branches of the pudendal are the *dorsal nerve of the penis*, and branches from the *perineal nerves*. They supply the cutaneous structures of the penis, while the filaments from the *pelvic plexuses*, which reach the penis through the prostatic nerve-plexus, end in the erectile tissue.

PROSTATE

The **prostate** is a partly glandular, partly muscular organ of a dark brown-red colour which surrounds the beginning of the urethra in the male. It lies within the pelvis behind the pubic symphysis and is enclosed by a dense fascial sheath. Through the various connexions of this sheath the prostate is firmly fixed within the pelvic cavity. The ejaculatory ducts traverse the upper part of the prostate in their course to join the urethra. The size of the prostate varies considerably, but usually its greatest transverse diameter is $1\frac{1}{2}$ inches, its antero-posterior diameter $\frac{3}{4}$ of an inch, and its vertical diameter $1\frac{1}{4}$ inches. Superficially the prostate is separated from the bladder by deep, wide lateral grooves and by a narrow posterior groove (Figs. 624, 650).

The prostate has an apex which is directed downwards, a base looking upwards, a posterior surface, and a pair of lateral surfaces. The *base* is directed upwards against the inferior aspect of the bladder in the neighbourhood of its urethral opening. The greater part of the base is structurally continuous with the bladder wall; only a narrow portion remains free on each side and forms the lower limit of the deep groove which marks the separation of the bladder and prostate (Fig. 624). The *lateral surfaces* of the prostate are convex and prominent, especially in their posterior and upper portions, and rest against the fascia covering the levatores ani muscles. They are directed for the most part laterally, downwards, and slightly forwards, and meet together in front in a rounded anterior border, sometimes called the "anterior surface" of the prostate (Fig. 651). The *posterior surface*, is flat and triangular, and is directed backwards and very slightly downwards against the anterior wall of the rectum, through which it may be felt in the living subject. The apex points downwards and is in relation to the fascial covering of the sphincter urethræ muscle. From the apex, the anterior border passes upwards in the median plane behind the pubic symphysis and retropubic pad of fat; and it is interrupted in its lowest part by the passage of the urethra.

When its fascial sheath is stripped off, the prostate has a more rounded outline, and the surfaces just described are not so clearly defined. The anterior border may now appear to be a surface rather than a border, and the antero-posterior diameter is considerably reduced.

The urethra enters the prostate at a point near the middle of its base, and leaves it at a point on its anterior border immediately above and in front of the apex.

The ejaculatory ducts enter a slit immediately in front of the posterior border of the base and run downwards and forwards to open into the prostatic portion of the urethra at the margins of the mouth of the prostatic utricle.

The wedge-shaped portion of the prostate which separates these ducts from the urethra is called the *median lobe* (Fig. 651). It projects upwards against the bladder, and is continuous with the bladder-wall immediately behind the urethral orifice. When hypertrophied, as it often is in old men, the median lobe of the prostate may cause a considerable elevation in the cavity of the bladder, which is of surgical interest, and to which the term **uvula of the bladder** is applied. The remaining part of the prostate is described as a pair of large *lateral lobes*, which are, however, not marked off from one another superficially.

In front of the prostate, between it and the pubis, there is a close venous network called the *prostatic plexus*, with which the deep dorsal vein of the penis communicates. That plexus is continued backwards, round the sides of the

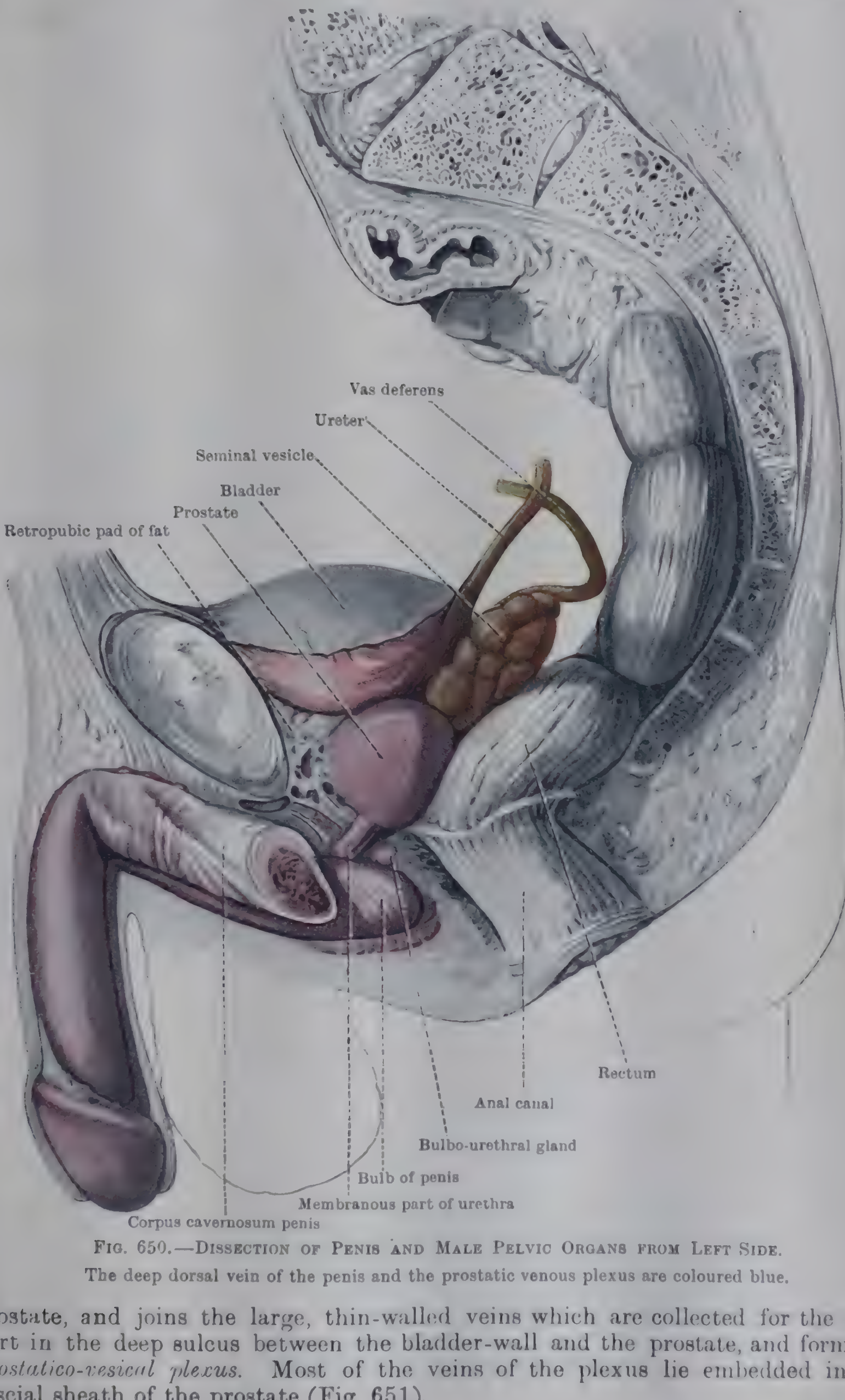

FIG. 650.—DISSECTION OF PENIS AND MALE PELVIC ORGANS FROM LEFT SIDE.
The deep dorsal vein of the penis and the prostatic venous plexus are coloured blue.

prostate, and joins the large, thin-walled veins which are collected for the most part in the deep sulcus between the bladder-wall and the prostate, and form the *prostatico-vesical plexus*. Most of the veins of the plexus lie embedded in the fascial sheath of the prostate (Fig. 651).

Fascial Sheath of Prostate.—This sheath is a dense fibrous portion of the pelvic fascia, and closely invests the prostate. Inferiorly the sheath becomes continuous with the fascia on the sphincter urethræ muscle and, through it, gains attachment to the sides of the pubic arch. In

front and at the sides, it is fused with the pubo-prostatic ligaments, by which it is connected with the pubic bones and the fascia on the levatores ani. Between the two medial pubo-prostatic ligaments there is a shallow depression, the floor of which is formed by a thin layer of fascia which connects the anterior part of the sheath of the prostate with the back of the pubic symphysis. The medial (or anterior) edges of the levatores ani muscles are immediately below the pubo-prostatic ligaments, and, when followed backwards, they are seen to embrace the lower part of the prostate.

Posteriorly the upward prolongation of the sheath is continuous with the fascial layers which enclose the ampullæ of the vasa deferentia and the seminal vesicles, and it is adherent to the peritoneum of the recto-vesical pouch. In this position it is spoken of as the *recto-vesical septum*.

Structure of Prostate.—Inside the fascial sheath the superficial part of the prostate is largely composed of matted interlacing bundles of plain muscle-fibres and fibrous tissue which form the capsule of the organ. The **capsule** is not sharply defined, for from its deep surface fibrous and muscular strands pass inwards, converging towards the posterior wall of the urethra, to become continuous with the mass of plain muscular tissue which surrounds this canal. These radially arranged strands divide the prostate into a number of incompletely defined

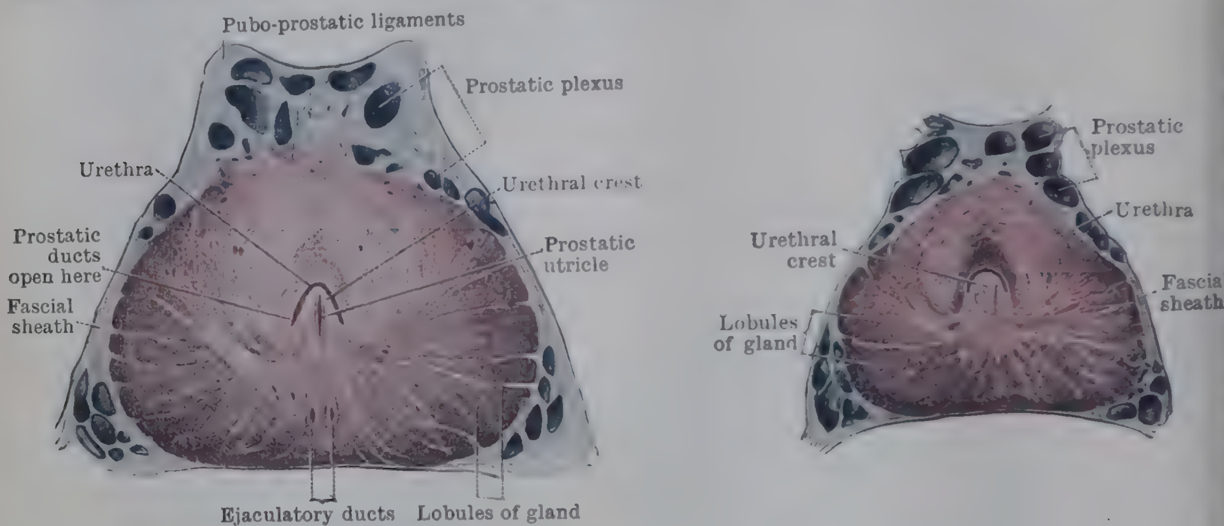

FIG. 651, A and B.—HORIZONTAL SECTIONS THROUGH PROSTATE.
Section A is at a higher level than B.

lobules, of which there are about fifty. The yellowish-coloured glandular tissue of the lobules is composed of minute, slightly branched tubules, the walls of which in certain places show numerous saccular dilatations. In the upper portion of the prostate the tubules are more convoluted, slightly dilated and shorter than in the lower part. The glandular tubules lead into the minute **prostatic ducts**—in number twenty or thirty—which open for the most part into a pair of grooves called the **prostatic sinuses**, which run along the sides of a median elevation —the **urethral crest**—in the posterior wall of the urethra.

The bulk of the glandular tissue is situated at the sides of the urethra and behind it. In front of its upper part there is a mass of plain muscular fibres which is continued upwards and backwards on its sides to form a part of the sphincter vesicæ. At a lower level striated muscular tissue, which is continuous with the deep part of the sphincter urethræ, occupies a position in front of the urethra.

The muscular tissue of the prostate is to be regarded as the thickened muscular layer of the wall of the urethra broken up and invaded by the prostatic glands, which arise and are developed from the lining layer of the canal during fœtal life.

Small at birth, the prostate enlarges rapidly at puberty. After the fourth decade the glandular tissue may atrophy, and the organ becomes more fibrous and diminishes in size. In many individuals, however, the glandular tissue persists and the prostate progressively enlarges (Swyer, 1944). Not infrequently calcareous concretions are found in it.

Vessels and Nerves of Prostate.—The **arteries** are branches of the middle rectal and inferior vesical arteries. The **veins** are wide and thin-walled; they form the prostatic plexus, which communicates with the vesical plexus and is drained into the internal iliac veins. In old men the veins of the prostate usually become much enlarged. The **lymph-vessels** (p. 1412) are associated with those of the seminal vesicle and the neck of the bladder. The **nerves** of the prostate are derived from the pelvic sympathetic plexuses.

BULBO-URETHRAL GLANDS

The **bulbo-urethral glands** are a pair of small bodies placed behind the membranous part of the urethra among the fibres of the sphincter urethræ. In old age they are often difficult to find without microscopical examination; in

young adults they are each about the size of a pea and are of a yellowish-brown colour. Placed deep to the perineal membrane, the glands lie below the level of the apex of the prostate and above that of the bulb of the penis (Figs. 632 and 650). Each gland is made up of a number of closely applied lobules, and is of the compound racemose type. The ductules of the gland unite to form a single **duct** which enters the bulb of the penis, and, after a relatively long course (about an inch), ends by opening into the spongy portion of the urethra by a minute aperture. The secreting acini are lined with columnar epithelium.

The glands receive their arterial supply from the arteries to the bulb.

Methods of Clinical Anatomical Examination.—The testis, epididymis, and lower end of the spermatic cord can be easily palpated in the living subject; and the back of the prostate and lower ends of the seminal vesicles and vasa deferentia can be palpated by a rectal examination.

FEMALE GENITAL ORGANS

The female genital organs are: (1) the ovaries, (2) the uterine tubes, (3) the uterus, (4) the vagina, (5) the external genital organs, (6) the greater vestibular glands, and (7) the mammary glands.

The reproductive glands in the female (Fig. 652) are a pair of **ovaries** placed one on each side in the cavity of the pelvis. In connexion with each ovary there is an elongated tube—the **uterine tube** or **oviduct**—which leads to the uterus and opens into its cavity. There is no direct continuity between the ovary and the uterine tube, such as exists between the other glands of the body and their ducts, but the ova, when shed from the ovary, pass into the pelvic opening of the tube and are conducted by it to the uterine cavity. The **uterus** is a hollow muscular organ which occupies a nearly median position in the true pelvis. It is joined by the uterine tubes above, and it communicates with the vagina below. The ovum, having passed through the tube, reaches the cavity of the uterus, and in it, if fertilization has taken place, the ovum undergoes its development into the embryo and fœtus. The **vagina** is the passage which leads from the uterus to the exterior, and has its external opening behind that of the urethra, within the **pudendal cleft**. In relation to the cleft there are a number of structures, included under the term *external genital organs,* which represent in the female the various parts of the penis and scrotum in the male. They are the **labia majora** and the **mons pubis**, the **labia minora**, the **clitoris**, and the **bulbs of the vestibule**. The **greater vestibular glands**, placed one on each side of the lower part of the vagina, are accessory organs of the female reproductive system.

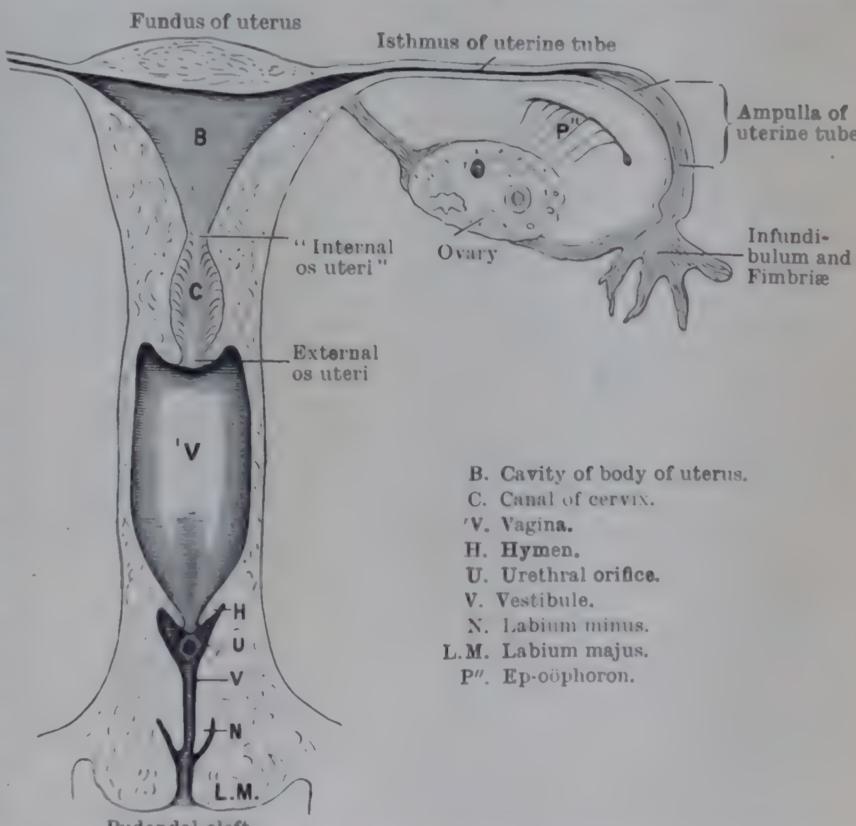

FIG. 652.—DIAGRAM OF FEMALE GENITAL ORGANS. (Symington.)

OVARIES

The **ovaries** are a pair of solid bodies, flattened from side to side, each about the size and shape of a large almond. Their length is usually between 1 inch and $1\frac{1}{2}$ inches, and the thickness from side to side about $\frac{1}{3}$ of an inch. In the adult the ovary is placed against the side-wall of the pelvic cavity, and is connected by a peritoneal fold with the broad ligament of the uterus. The position occupied by the ovary within the pelvic cavity is fairly constant, although the broad ligaments do not hold the organ firmly fixed in any definite place.

The ovary has two *ends*—upper and lower. The upper end is the larger and more rounded; it is termed the **tubal end**, as it is most intimately connected

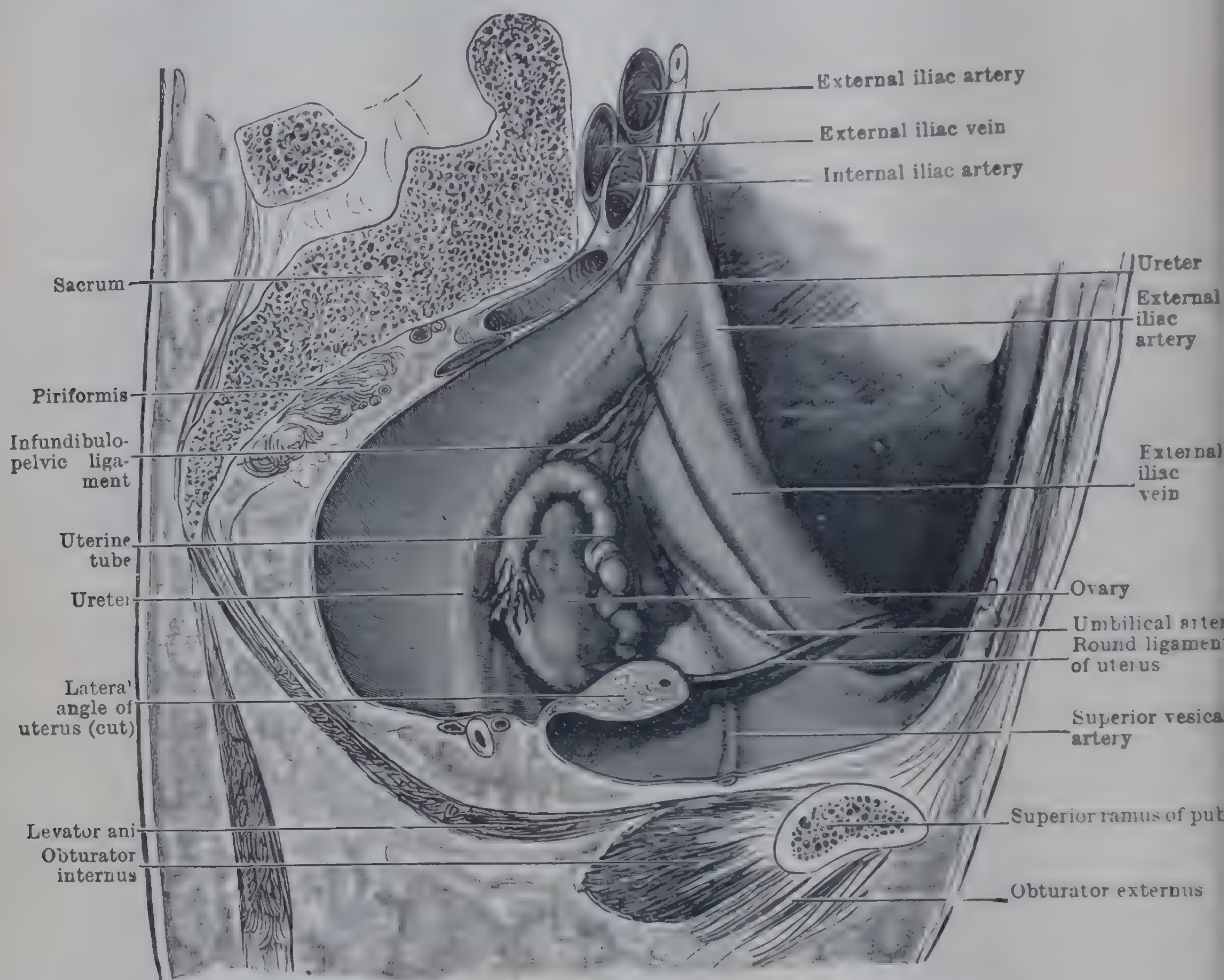

FIG. 653.—SIDE-WALL OF FEMALE PELVIS, SHOWING POSITION OF THE OVARY AND ITS RELATION TO THE UTERINE TUBE.

The pelvis was cut parallel to the median plane, but at some distance from it.

with the uterine tube. The lower end is more pointed; it is called the **uterine end**, since it is connected with the uterus by a fibrous cord termed the **ligament of the ovary**. The *surfaces* of the ovary are called **medial** and **lateral**, and the *borders* separating them are the anterior or **mesovarian border** and the posterior or **free border**. The free border is convex; the mesovarian border is straighter and narrower, and it is connected by two very short peritoneal layers, called the **mesovarium**, with the upper or posterior layer of the broad ligament of the uterus. The vessels and nerves enter the ovary at the mesovarian border, which is therefore termed its **hilum**.

Position and Relations of Ovary (Figs. 653, 656-658).—When the ovary is in its typical position its long axis is vertical. Its lateral surface lies against the wall of the true pelvis, and its medial surface looks into the pelvic cavity. The peritoneum of the pelvic wall, where the ovary lies against it, is depressed to form a shallow fossa between the ureter and the umbilical artery. Outside the peritoneum forming the floor of this fossa are the obturator nerve and vessels. The tubal end of

the ovary lies a little below the level of the external iliac vessels, and its uterine end is immediately above the peritoneum of the pelvic floor. The mesovarian border is immediately behind the line of the umbilical artery, and the free border is immediately in front of the ureter (Fig. 653). The medial surface of the ovary is largely covered by the uterine tube, which, passing upwards on it near its mesovarian border, arches over the tubal end and then turns downwards in relation to the free border and posterior part of the medial surface.

The description given corresponds to the typical position of the organ in women who have not borne children. When the uterus is much inclined towards the right side of the body the left ovary has its long axis directed obliquely downwards and medially, the right gland remaining vertical.

Connexions of Ovary.—When the ovary is in position a small peritoneal fold passes upwards from its tubal end and becomes lost in the peritoneum over the external iliac vessels and the psoas major muscle (Fig. 653). It is called the **infundibulo-pelvic ligament** and is continuous below with the mesovarium and, in front of it, with the broad ligament of the uterus. It contains between

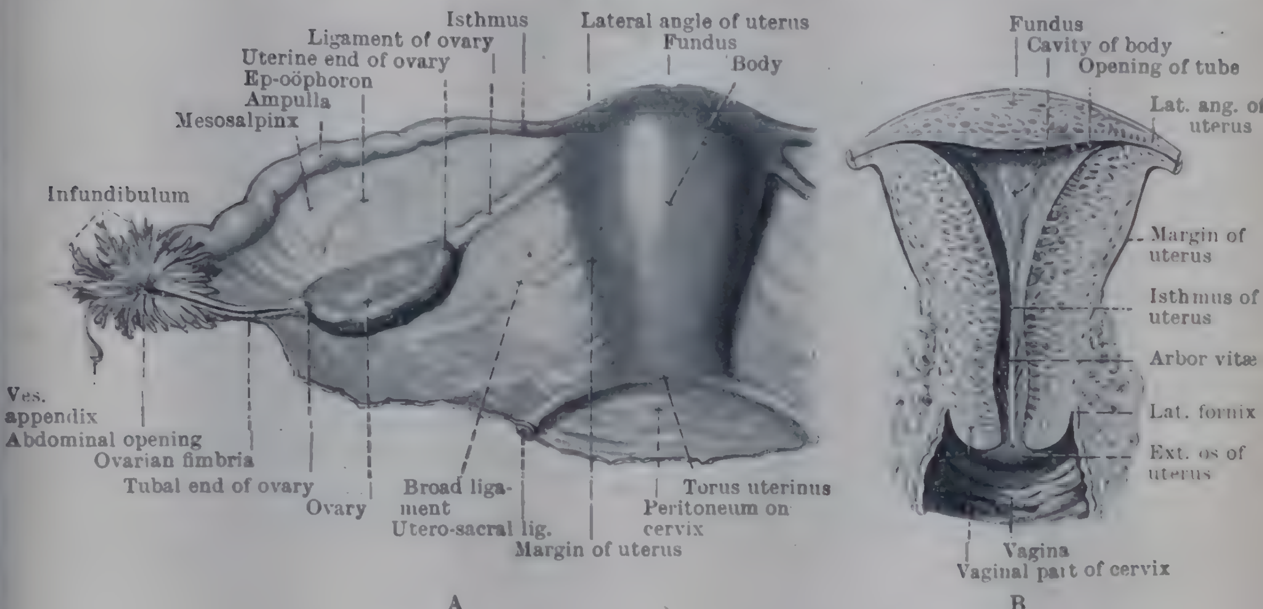

Fig. 654.—A. Intestinal Surface of Uterus and Broad Ligament.
The broad ligament has been spread out.
B. Diagrammatic Representation of Uterine Cavity.
The dense mass at the side of the cervix uteri represents the lateral cervical ligament.

its two layers the ovarian vessels and nerves as they pass down into the pelvis to enter the mesovarium and thus reach the hilum of the ovary. Anteriorly the ovary is connected with the broad ligament by a very short mesentery, or **mesovarium**, along the whole length of its mesovarian border. The uterine end of the ovary is connected with the lateral angle of the uterus by a round cord called the **ligament of the ovary**; this band lies in the free border of the medial part of the mesovarium, and is attached to the lateral angle of the uterus behind the point of entrance of the uterine tube. It is composed chiefly of plain muscle-fibres continuous with those of the uterus. The tubal end of the ovary is directly connected with the **ovarian fimbria**—one of the largest of the fimbriæ of the uterine tube (Fig. 654).

Descent of Ovary.—Like the testes, the ovaries at first lie in the abdominal cavity and only later attain a position in the pelvis. At birth the ovary lies partly in the abdomen and partly in the pelvis; soon, however, it takes up a position entirely within the true pelvis. As in the male, a **gubernaculum** is present in the early stages of development and is connected inferiorly with the tissues that become the labium majus; but in the female the gubernacula become attached to the para-mesonephric ducts, from which the uterus is developed. Consequently, the gubernaculum becomes the round ligament of the uterus in front and the ligament of the ovary behind; and it pulls the ovary down only as far as the pelvis: it is a rare abnormality for the ovary, instead of entering the pelvis, to take a course similar to that of the testis, and pass through the inguinal canal into the labium majus.

Structure of Ovary.—The ovary is, for the most part, composed of a fibro-areolar tissue, called the **stroma of the ovary**, richly supplied by blood-vessels and nerves. The stroma contains

very numerous spindle-shaped cells, white fibres, and some elastic tissue. The surface of the ovary is covered with an epithelium composed of columnar or cubical cells, and continuous with the flat-celled epithelium of the peritoneum which forms the mesovarium. The ovarian epithelium is a persistent portion of the "germinal" epithelium which covers the genital ridges of the embryo and from which the cells of the ovarian follicles are derived. The position in which it becomes continuous with the peritoneum can usually be distinguished as a fine white line near the hilum of the ovary. Shining through the epithelium of the fresh ovary (except in old age) a variable number of small vesicles can usually be seen—the **vesicular ovarian follicles**—in which the egg-cells or oöcytes are contained. The number of follicles visible, and also the size which each follicle reaches before it ruptures and sheds its contents, are by no means constant. When a follicle ruptures and discharges the oocyte, its walls at first collapse, but later the cavity becomes filled with extravasated blood and cellular tissue of a yellowish colour. The resulting structure, called a **corpus luteum**, slowly degenerates unless impregnation has taken place, and then it develops and becomes larger during pregnancy. As it atrophies, the cells of the corpus luteum disappear, and the structure, losing its yellow colour, receives the name of **corpus albicans**. After a time the corpus albicans completely disappears. Owing to the periodic rupture of the ovarian follicles, the surface of the ovary, which is at first smooth and even, becomes in old age dimpled and puckered. For details of these changes and an account of the hormones produced by the ovary, see Selye (1947).

A section through the ovary, especially in the young child, presents in its superficial

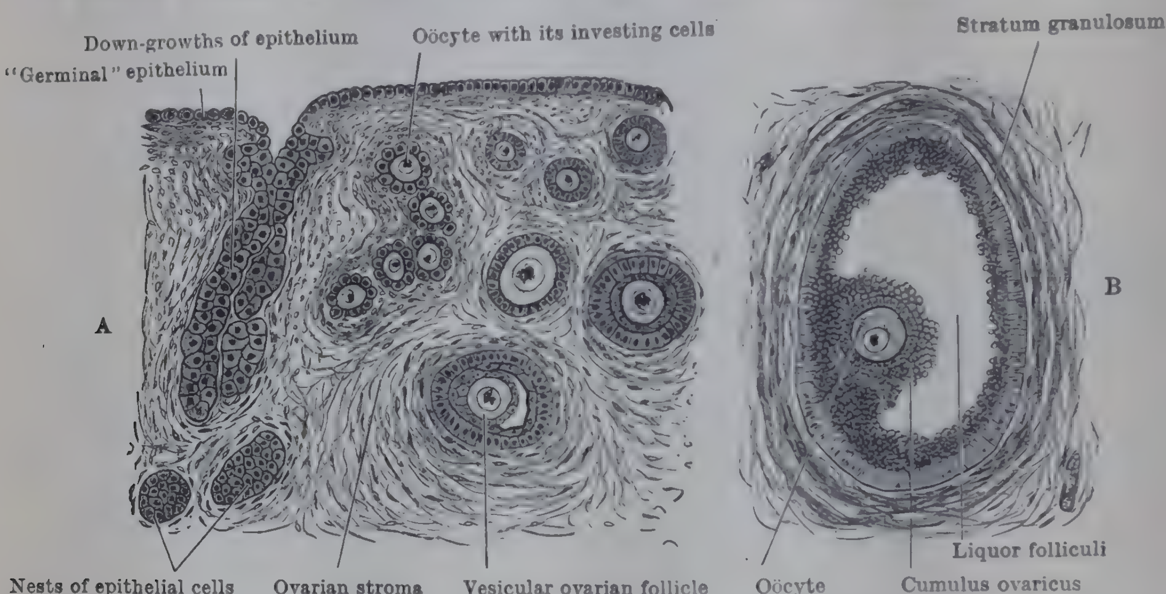

Fig. 655.—A. Diagrammatic Representation of the Manner in which Vesicular Follicles arise during Development of Ovary.

B. Diagram illustrating Structure of a Ripe or Vesicular Ovarian Follicle.

part a granular appearance which is due to the presence of large numbers of small follicles, or collections of epithelial cells, embedded in the fibro-areolar tissue near the surface of the ovary. The larger follicles lie deeper in the stroma, but when they become fully developed they pass towards the surface, where the ripe follicles may be seen bulging slightly and ready to burst. In the deepest part of the ovary the blood-vessels are most numerous, and there also some plain muscle-fibres are found.

The cells that compose the ovarian follicles are derived in part from the "germinal" epithelium which covers the developing ovary in the embryo. The epithelium, at first simple, grows down into the underlying tissue in the form of branching tube-like processes, or "egg-tubes". This takes place during fœtal development, and the branching, cellular processes, so formed, become broken up within the stroma into little nests or clumps of cells, each of which becomes a follicle. But in the human embryo the earliest formed nests of epithelial cells arise *in situ* and only at a later stage become connected with the "egg-tubes", derived from the ovarian epithelium. From the beginning, some cells of the "egg-tubes" are larger than the others; these are the oöcytes, while the cells round them become the investing cells of the follicle. The investing cells, at first flattened, form a single layer around each oocyte. Later, becoming columnar, as the follicle increases in size and sinks more deeply into the stroma, these cells divide in such a manner that the oöcyte becomes surrounded by a double layer of cells. Fluid—**liquor folliculi**—accumulates between the two cellular layers, except at one place, where the inner cells surrounding the ovum remain attached to the outer layer or **stratum granulosum**. To the inner cellular mass which encloses the oocyte the term **cumulus ovaricus** is applied (Fig. 655). The ripe follicle contains a relatively large amount of fluid, and the surrounding stroma becomes differentiated to form a capsule or **theca folliculi**. The capsule is composed of an *inner coat*, which is vascular in character, and an *outer coat*, which is more fibrous in structure. In the young child there are numerous small follicles in the superficial parts of the ovary, and the question whether any new ova are produced in the human ovary after birth has been much debated (p. 24).

Vessels and Nerves of Ovary.—The **ovarian arteries**, which correspond to the testicular arteries of the male, are a pair of long, slender vessels which spring from the front of the aorta below the level of origin of the renal vessels. Each gains the true pelvis in the infundibulo-pelvic ligament, and it enters the ovary at its mesovarian border. Close to the ovary the ovarian artery anastomoses with branches of the **uterine artery**. The blood is returned by a series of communicating **veins**, similar to the *pampiniform plexus* in the male.

The **lymph-vessels** of the ovary run with those from the upper part of the uterus to end in the lymph-glands beside the aorta and inferior vena cava (p. 1416).

The **nerves** of the ovary are derived chiefly from a plexus which accompanies the ovarian artery and is continuous above with the renal plexus. Other fibres are derived from the lower part of the aortic plexus and join the plexus on the ovarian artery. The afferent impulses from the ovary reach the central nervous system through the fibres of the posterior root of the tenth thoracic nerve.

UTERINE TUBES

The **uterine tubes** are a pair of ducts which convey the oöcytes, discharged from the follicles of the ovaries, to the cavity of the uterus (Fig. 654 and Pl. LXXII, p. 745). Each tube is about four inches in length, and opens at one end into the peritoneal cavity near the ovary, and at the other end by a smaller opening into the lateral part of the uterine cavity. The tube is enclosed in a fold of peritoneum called the **mesosalpinx**, which is a portion of the broad ligament of the uterus.

The **pelvic opening** of the tube is only about 2 mm. in diameter when its walls are relaxed, and much narrower when the muscular coat of the tube is contracted. It is placed at the bottom of a funnel-like expansion of the tube called the **infundibulum**, the margins of which are produced into a number of irregular processes, called **fimbriæ**, many of which are branched or fringed. The surface of the fimbriæ which looks into the cavity of the infundibulum is covered with a mucous membrane continuous with that of the tube, while the outer surface is clothed with peritoneum. The mucous surfaces of the larger fimbriæ present ridges and grooves which are continued into the folds and furrows of the mucous coat of the tube. One of the fimbriæ, usually much larger than the rest, is connected either directly or indirectly with the tubal end of the ovary, and to it the name **ovarian fimbria** is applied. The part of the tube continuous with the infundibulum is called the **ampulla**. It is the widest and longest portion of the tube, and is usually slightly tortuous and of varying diameter, being slightly constricted in some places and dilated in others. The ampulla ends in the narrower, thicker-walled, and much shorter **isthmus** of the tube, which joins the lateral angle of the uterus. The **uterine part** of the tube is embedded in the uterine wall, which it traverses to reach the cavity of the uterus (Fig. 654). The **uterine opening** is smaller than the pelvic opening, being about 1 mm. in diameter. The lumen of the canal gradually increases in width as it is traced from the uterus towards the ovary.

Course of Uterine Tube.—From the uterus, the uterine tube is directed at first horizontally towards the uterine end of the ovary, and then upwards in relation to the medial side of the mesovarian border, until it reaches the tubal end. It next arches backwards and then descends along the free border of the ovary, resting against its medial surface (Figs. 653, 656). The looped portion of the tube often covers almost the entire medial surface of the ovary. The fimbriated end is applied against the free border and lower part of the medial surface of the ovary, and from it the ovarian fimbria passes upwards to gain attachment to the tubal end. The fimbriated end of the uterine tube lies in the abdominal cavity until the ovary in its descent has entered the true pelvis.

Structure of Uterine Tubes.—The wall of each tube is composed of a number of concentric layers. First a **serous coat** of peritoneum, under which there is a thin **subserous coat** of loose areolar tissue containing many vessels and nerves. Internal to the subserous coat there is the **muscular coat** composed of two strata of plain muscle-fibres—a more superficial, thin stratum of longitudinally arranged fibres, and a deeper, thicker layer, the fibres of which are circularly disposed. Inside the circular muscular coat is a **submucous layer**, and then the lining membrane or **mucous coat**. In the part of the tube near the uterus the muscular layer is thicker than towards the other end, and in the isthmus it forms the chief part of the wall. The mucous membrane, on the contrary, is thickest towards the fimbriated end, and there it forms the chief part of the wall. The stratum of circular muscle-fibres is especially well developed near

the uterus. The mucous membrane is thrown into numerous longitudinal folds, which in the ampulla are exceedingly complex, the larger folds bearing on their surface numerous smaller ones. In transverse sections of that part of the tube, examined under the microscope, the folds of the mucous membrane look like large branching processes which project into the lumen of the tube and almost completely fill it. The mucous membrane is covered with a ciliated epithelium, the cilia of which tend to drive the fluid contents of the tube towards the uterus.

Vessels and Nerves of Uterine Tube.—The chief **artery** of the uterine tube is a tubal branch of the *uterine artery*, but it receives small branches of the *ovarian artery* also. The **veins** of the tube pour their blood partly into the *uterine* and partly into the *ovarian* veins. The **lymph-vessels** run with those of the ovary and the upper part of the uterus to the lymph-glands beside the aorta. The **nerves** are derived from the plexus that supplies the ovary, and also from the plexus in connexion with the uterus. The afferent fibres are believed to belong to the eleventh and twelfth thoracic and the first lumbar nerves.

EP-OÖPHORON AND PAR-OÖPHORON

The ep-oöphoron and the par-oöphoron are two vestigial structures found between the layers of the broad ligament.

The **ep-oöphoron** (Fig. 652) lies in the mesosalpinx between the uterine tube and the ovary. In the adult it consists of a number of small rudimentary blind tubules lined with epithelium. One of the tubules—the **duct of the ep-oöphoron**—lies close to the uterine tube and runs nearly parallel with it. It is joined by a number of **tubules** which enter it at right angles from the neighbourhood of the ovary. The duct is a persistent portion of the mesonephric duct, and represents the canal of the epididymis; the tubules are derived from the mesonephros and represent the efferent ducts of the testis (and probably also the ductuli aberrantes of the canal of the epididymis).

One or more small pedunculated cystic structures, called **vesicular appendices**, are often seen near the infundibulum of the uterine tube. They are supposed to represent portions of the cephalic end of the mesonephric duct.

The **par-oöphoron** is a collection of very minute tubules that lie in the mesosalpinx nearer the uterus than the ep-oöphoron. They represent the paradidymis in the male, and are derived from the part of the mesonephros which lies nearer the caudal end of the embryo. Though sometimes visible in the child at birth, the par-oöphoron in the adult can be recognized only by microscopic examination.

UTERUS

The **uterus** or womb (Figs. 656 and 658) is a hollow, thick-walled muscular organ that projects upwards and forwards above the bladder from the upper part of the vagina (Figs. 659 and 661).

Shape and Parts.—The upper two-thirds of the uterus, known as the **body**, is pear-shaped with the blunt end upwards, and the whole is slightly flattened from before backwards; the lower third, called the **cervix**, is cylindrical and tapers slightly at its extreme lower end, which projects through the anterior vaginal wall into the upper part of the cavity of the vagina, and thereby the cervix is divided into a *vaginal* and a *supravaginal part*. A slight constriction marks the junction of the body with the cervix.

In the centre of the extremity of the vaginal part of the cervix is a small opening—the **external os**—by which the cavity of the uterus communicates with that of the vagina. This part of the cervix is slightly flattened from before backwards, and the external os of a uterus which has not been pregnant has therefore the appearance of a short transverse slit bounded above and below by thick lips; in women who have borne children the slit is larger and has an irregular outline. The lower lip is thicker and more rounded than the upper, and both lips are usually in contact with the posterior wall of the vagina.

The uterine tubes enter the organ at its upper and lateral angles, where it attains its maximum breadth; and the rounded part above a line joining the points of entrance of the two tubes is known as the **fundus**. The uterus, therefore, is described as possessing an anterior or *vesical surface* and a posterior or *intestinal surface*, and these two surfaces are separated by right and left *lateral borders*. Both surfaces are convex, but the intestinal is much the more rounded. The length of the body is about two inches; its maximum breadth also is two inches;

and its thickness or depth is an inch. The cervix is an inch long and about an inch in diameter. During pregnancy the whole organ is greatly enlarged.

Position and Attachments.—The non-pregnant uterus lies completely within the cavity of the pelvis. It rarely lies exactly in the median plane, but is usually inclined slightly to one or other side, more frequently to the right. The lower end of the cervix is very firmly fixed to the wall of the vagina where it pierces that organ, being in fact structurally continuous with it. From this point the cervix projects upwards and forwards. From the upper end of the cervix, the body also projects upwards and forwards, but its direction is slightly more forwards than that of the cervix so that the cervix and body form a wide angle open downwards and forwards. In its usual position, therefore, the uterus is said

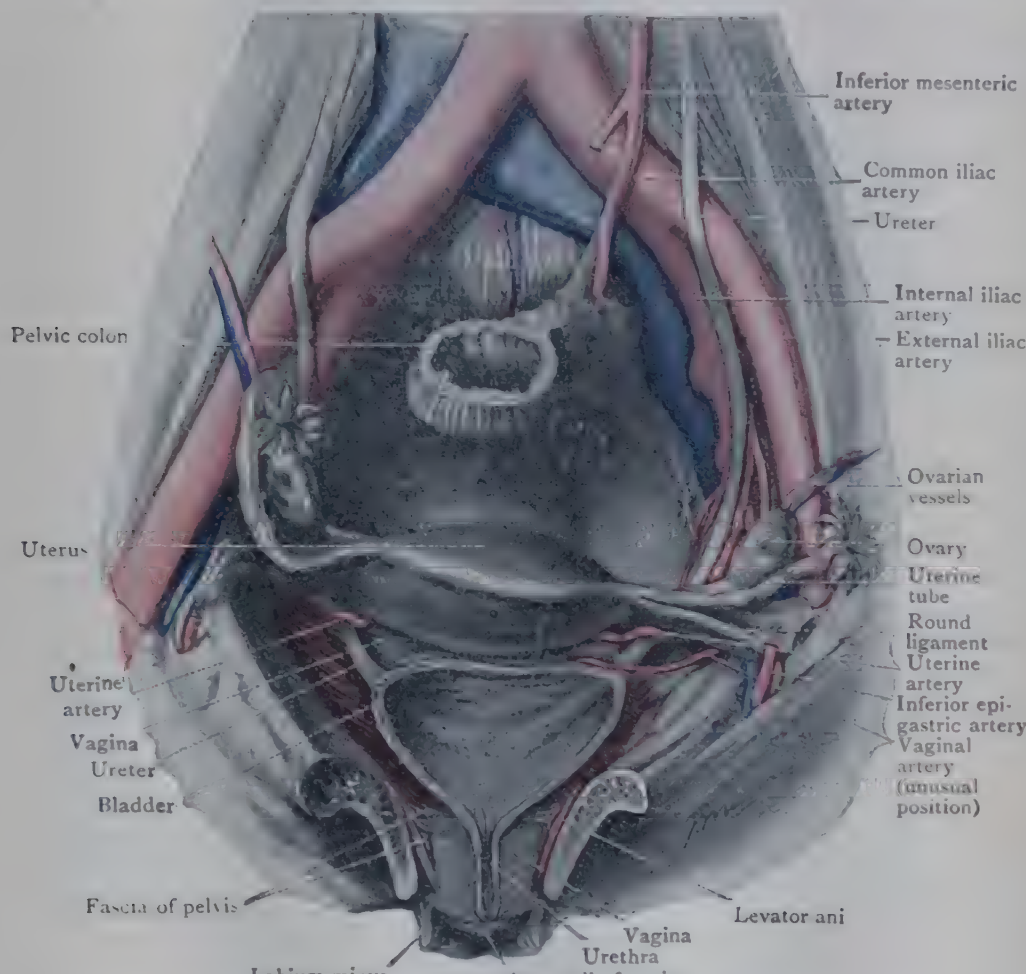

FIG. 656.—DISSECTION OF PELVIS OF MULTIPAROUS FEMALE, SHOWING SOME OF THE RELATIONS OF THE INTERNAL GENITAL ORGANS.

to be **anteverted** and **anteflexed**, for the whole organ projects forwards and upwards from the upper end of the vagina, and it is bent forwards at the junction of the cervix with the body. Although anteversion and anteflexion of the uterus are regarded as the normal condition, it should be realized that in many women the uterus is retroflexed or retroverted without producing any symptoms.

The peritoneum which covers the upper surface of the urinary bladder is reflected from the posterior edge of that organ upwards on to the uterus at the junction of the cervix with the body and then passes upwards and forwards, covering the anterior or vesical surface of the body. Thus, a rather deep **utero-vesical pouch** is formed (Fig. 659). From the vesical surface of the uterus the peritoneum passes over the fundus and then downwards and backwards, covering the intestinal surface of the body and supravaginal part of the cervix; it then passes on to the upper part of the back of the vagina and is reflected from it upwards and backwards on the anterior wall of the rectum (Figs. 657, 662). The peritoneal pouch between the back of the uterus and the front of the rectum is known as the **recto-uterine** or **recto-vaginal pouch**, the bottom of which is about three inches or rather less above the level of the anus. The two layers of peritoneum which

cover the vesical and intestinal surfaces of the uterus come together at its lateral margins and are then carried laterally as extensive peritoneal folds to the side-walls of the pelvis. These folds are known as the **broad ligaments of the uterus** (Figs. 654, 656), and they enclose between their two layers various important structures associated with the uterus.

The two layers of each broad ligament are continuous with each other at a free edge which is directed forwards and upwards; and they enclose some loose areolar tissue and a little plain muscle. To the contained tissue the name *parametrium* is given. In the upper part of the broad ligament the parametrium is small in quantity and the two layers of the ligament are close together, but

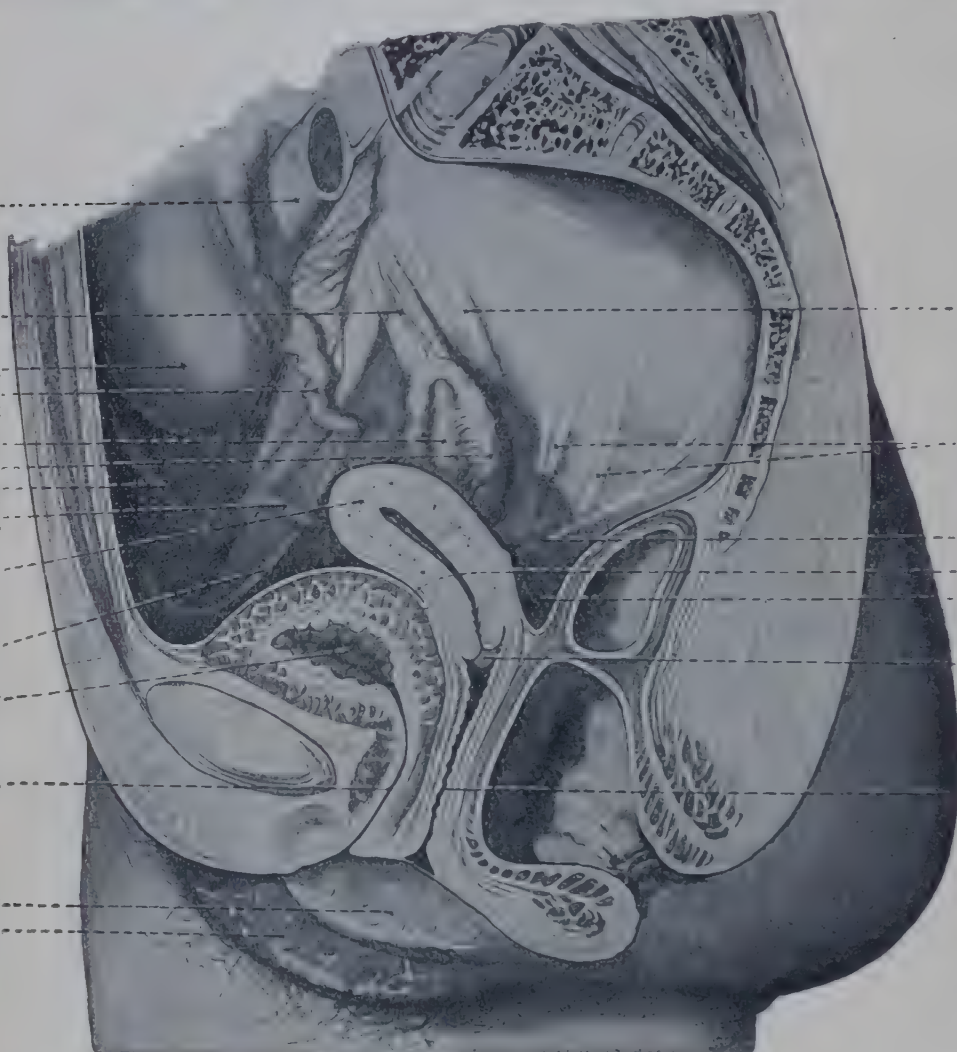

FIG. 657.—MEDIAN SECTION OF FEMALE PELVIS.

towards its root the parametrium increases considerably in amount and the two peritoneal layers diverge from each other. The anterior layer passes forwards into the floor of the paravesical fossa; the posterior layer forms a prominent, shelf-like **recto-uterine fold**, corresponding to the *sacro-genital fold* in the male, which curves backwards from the cervix uteri to the posterior wall of the pelvis a little lateral to the rectum. The two recto-uterine folds sometimes meet across the back of the cervix, forming a ridge known as the *torus uterinus.*

Enclosed in the broad ligament along its free edge is the *uterine tube*; and just below the entrance of the tube into the uterine wall two other structures also are attached to the uterus, namely, the *round ligament of the uterus* in front and the *ligament of the ovary* behind (Fig. 658). These three structures are all enclosed in the broad ligament, and while they are very close together at their attachments to the uterus, they diverge widely as they approach the pelvic wall. It thus happens that the attachment of the broad ligament to the uterus is almost a straight line but its attachment to the pelvic wall is drawn out into a sort of tripod (Figs. 658 and 659). The inferior part of the ligament passes laterally

from the side of the cervix to the side of the pelvis, and as the whole uterus slopes from above downwards and backwards the lower part of the broad ligament slopes in the same general direction. The anterior part of the ligament is drawn out by the round ligament of the uterus, which is a narrow flat band of fibrous tissue containing some plain muscle at its uterine end. It passes from the lateral angle of the uterus laterally, forwards, and very slightly upwards to the deep inguinal ring, crossing the umbilical artery and external iliac vessels, and, after hooking round the lateral side of the inferior epigastric artery and traversing the inguinal canal, it ends in the skin and subcutaneous tissue of the labium majus. In some cases a minute diverticulum of the peritoneal cavity accompanies the round ligament through the inguinal canal; it is the **vestige of the processus vaginalis**, which is formed in the fœtus in both sexes. The round ligament draws the anterior part of the broad ligament forwards and very slightly upwards.

The part of the broad ligament that is drawn out to enclose the uterine tube is known as the **mesosalpinx**. Laterally the mesosalpinx is continuous with the *infundibulo-pelvic ligament*, which crosses the external iliac vessels about an inch below their upper end, and this part of the broad ligament is therefore drawn upwards and slightly backwards (Fig. 658). The lateral part of the mesosalpinx is more free than the medial part, and this permits the lateral part of the uterine tube to curve down along the posterior border of the ovary and almost enclose that organ in a fold of the mesosalpinx itself, thus forming a peritoneal compartment known as the *bursa ovarica*. The mesosalpinx contains the ep-oöphoron and paroöphoron and terminal branches of the uterine artery.

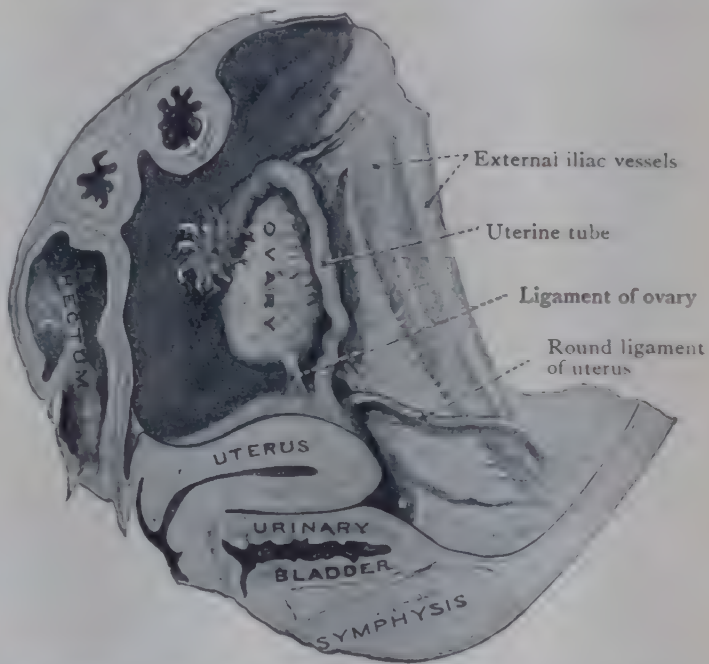

FIG. 658.—LEFT WALL OF FEMALE PELVIS TO SHOW TRIPOD ATTACHMENT OF LATERAL END OF BROAD LIGAMENT.
The ovary is much scarred owing to the shedding of ova.

The part of the broad ligament that is drawn out to enclose the ligament of the ovary is really the medial continuation of the mesovarium (Fig. 654 A), and, as the mesovarium is continuous laterally with the infundibulo-pelvic ligament also, the complete fold follows the same general direction as the mesosalpinx. It at first passes laterally as a narrow horizontal shelf which projects backwards and contains the ligament of the ovary in its free edge, but when it nears the ovary it becomes deeper and turns vertically upwards. In this part of its course it is called the **mesovarium** and becomes continuous above with the infundibulo-pelvic ligament. The *ligament of the ovary* is a round fibrous band, about an inch long, containing a considerable amount of plain muscle, and it is attached laterally to the lower pole of the ovary.

At the root of the broad ligament, where the two layers of peritoneum diverge to pass into the pelvic floor, a considerable amount of fibrous tissue and plain muscle occurs. This mass is the upper end of the fascial condensation which passes from the side of the vagina and the base of the urinary bladder to the fascia on the levator ani muscles. Its upper and more bulky part is attached medially to the side of the supravaginal part of the cervix and to the side of the upper third of the vagina, while laterally it fans out. Its posterior part passes backwards in the recto-uterine fold of peritoneum and gains an attachment to the front of the sacrum; this part is known as the *utero-sacral ligament*. The anterior part, passing directly sidewards to blend with the fascia on the levator ani muscle, is called the *lateral cervical ligament* (Mackenrodt, 1895). It has a

shallow anterior and a deep posterior surface, and in sagittal section it is shaped like an inverted letter U or J. On its upper rounded surface lie the ureter and uterine artery (Power, 1944). As already mentioned, it is really a condensation of fascia around the internal iliac artery and its branches.

The *ureter* passes from behind forwards and medially below the root of the broad ligament about three-quarters of an inch from the side of the cervix uteri; in this position it is crossed from lateral to medial side by the *uterine artery*, which first lies lateral to the ureter on the pelvic wall and then runs down in front of it to enter the root of the broad ligament and cross over it just at the level of the upper end of the cervix (Fig. 659). The uterine artery then turns upwards in the broad ligament and ascends beside the uterus. Near the upper

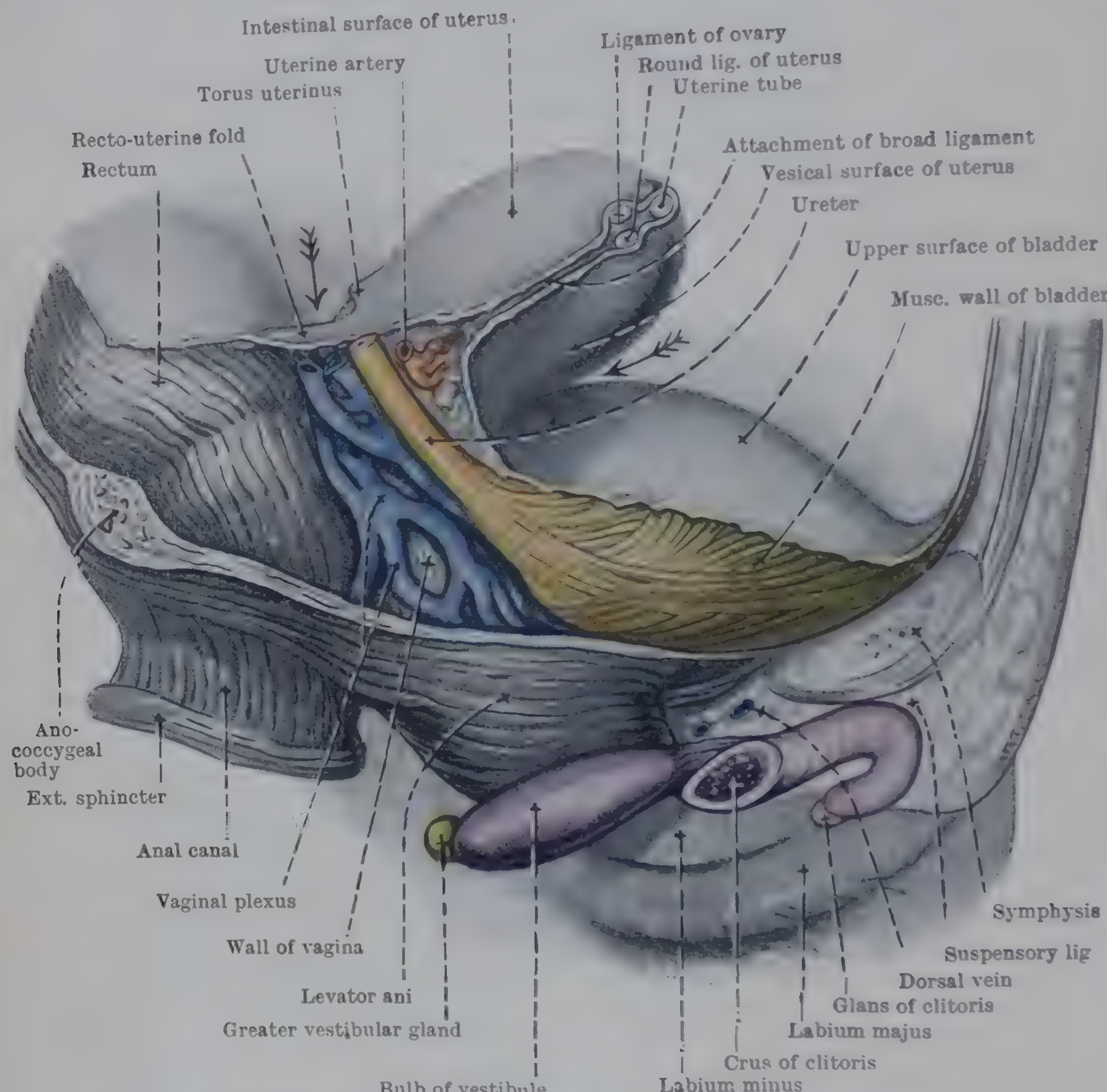

FIG. 659.—MODEL OF DISSECTION OF FEMALE PELVIC ORGANS.
The arrows point to the utero-vesical and recto-vaginal pouches.

end of the uterus the artery turns laterally into the mesosalpinx, where it lies about half an inch below the uterine tube. It ends by anastomosing with branches of the ovarian artery in the infundibulo-pelvic ligament. In addition to the structures described above, the broad ligaments contain some lymph-vessels and branches of the pelvic autonomic plexus.

Relations of Uterus.—*Anteriorly* the body of the uterus is separated from the bladder by the utero-vesical pouch of peritoneum; the front of the supravaginal part of the cervix is separated from the bladder by loose areolar tissue. *Posteriorly* the body and supravaginal part of the cervix are separated by a layer of peritoneum from the pelvic colon or coils of small intestine. *Laterally*, on each side, there is the broad ligament of the uterus with its contained structures. Of particular importance is the close relationship of the ureter and uterine artery to each other and to the side of the cervix. The uterus rises and falls as the urinary

bladder fills and empties. The vaginal part of the cervix pierces the anterior wall of the vagina and projects into its cavity, where it is clothed with mucous membrane. It tapers towards its lower end and is then abruptly truncated so that its lower extremity is blunt.

Cavity of Uterus.—In comparison with the size of the organ, the cavity of the uterus is small, owing to the great thickness of the uterine wall. The **cavity of the body** of the uterus, when viewed from the side, is a mere chink (Fig. 657); but when viewed from the front it is triangular with the base upwards (Fig. 654 B), and the sides of the triangle are convex inwards. The two lateral angles of the triangle mark the entrance of the two uterine tubes; at the median angle the cavity of the body becomes continuous with that of the cervix. The cavity of the cervix is called the **canal of the cervix**, and it extends from the internal os to the external os, where it opens into the vagina. It is a spindle-shaped passage, being narrower at its ends than in its middle part; and sections show also that its antero-posterior diameter is shorter than its transverse. In the body of the uterus the walls of the cavity are smooth and even, but in the cervix the mucous membrane forms a remarkable series of folds called the **arbor vitæ**. They consist of an anterior and a posterior longitudinal fold or ridge from which a large number of secondary folds or rugæ branch off obliquely upwards and laterally (Figs. 652 and 654).

Fig. 660.—Section of Uterus immediately before Onset of Menstruation.
The isthmus is distinguished from the body by relative lack of pre-menstrual vascular congestion.

Isthmus of Uterus.—In order to define an upper limit of the cervix it has been customary to describe an "internal os uteri" at its junction with the body (Fig. 652); but such a constricted opening between them does not in fact appear to exist in the non-pregnant uterus. The constriction in reality involves the lowest part of the cavity of the body, about 1 cm. in length, and this tubular portion is commonly known to obstetricians as the "isthmus" of the uterus (Fig. 654 B). Moreover, the separate identity of this part of the uterus has a functional basis, and the structure of its mucous coat is less complex than in the main part of the body (Frankl, 1933). Not only is it much less affected by the periodic changes of the menstrual cycle (Fig. 660), but in the last months of pregnancy it becomes more distinct and during labour is transformed into the "lower uterine segment" of the obstetricians. There is some evidence that the upper part of the cervix is incorporated into the lower uterine segment during labour; and, on the whole, it seems well to abandon the term "internal os" as redundant and to employ in its place the recognized expression **isthmus of the uterus**.

Supports of Uterus.—The uterine supports are mainly the bony pelvis and the pelvic floor, for although the uterus itself does not rest directly on these structures, yet it is supported by such organs as the rectum and urinary bladder, which do rest directly on them. The strength of the pelvic floor is therefore essential to the support of the uterus, and the strength of the floor is dependent on an intact *perineal body* (p. 466). This fibro-muscular mass is liable to injury and laceration during parturition; and it is of such importance in obstetrical practice that some obstetricians refer to it simply as "the perineum". The ligaments of the uterus function mainly by maintaining the uterus in a correct position of anteflexion and anteversion. The round ligaments keep the fundus forwards, while the utero-sacral keep the cervix back. The ligaments support the uterus against a sudden and temporary stress, but they are unable to resist sustained stress if the pelvic floor has given way. (See Smout and Jacoby, 1948.)

Structure of Uterus.—The uterine wall is composed of three chief layers—the serous, the muscular, and the mucous coats.

The **serous coat**, or *perimetrium*, is the peritoneal covering. Over the fundus and body it is very firmly adherent to the deeper layers, and cannot be easily peeled off without tearing either it or the underlying muscular tissue. Near the lateral borders of the uterus the peritoneum is less firmly attached, and over the back of the cervix it may readily be stripped off without injury to the underlying structures.

The **muscular coat** is composed of plain fibres, and forms the chief part of the uterine wall. Inferiorly the muscular coat of the uterus becomes continuous with that of the vagina. The more superficial layer of the muscular coat sends prolongations into the recto-uterine folds, into the round and broad ligaments of the uterus, and into the ovarian ligaments. Other fibres join the walls of the uterine tubes. The main branches of the blood-vessels and nerves of the uterus lie among the muscle-fibres. In the deeper layers of the muscular coat a considerable amount of fibrous tissue and some elastic fibres are to be found. At the isthmus the muscular fibres decrease and the fibrous tissue increases, and the muscular coat of the cervix contains more fibrous and elastic tissue than that of the body; hence its greater firmness and rigidity.

The deeper and thicker part of the muscular tissue of the uterus is considered by some anatomists to represent a lamina muscularis mucosæ, and is therefore described as part of the mucous coat. The deep and superficial portions of the muscular coat are, however, quite continuous, and there is no representative of a submucous vascular layer of tissue such as separates the muscular coat from the lamina muscularis mucosæ in the alimentary canal.

The **mucous coat** in the body of the uterus is smooth and soft and covered with columnar ciliated epithelium. Simple tubular glands, also lined with a ciliated epithelium, are present in the mucous membrane, and their deeper parts penetrate into the muscular coat. In the isthmus the glands are fewer, less deep, stain less intensely and are less affected by the menstrual cycle (Fig. 660). In the cervix the mucous coat is firmer and more fibrous than in the body, and its surface is not smooth but presents a number of peculiarly disposed ridges which have been mentioned already. Like the mucous membrane of the body of the uterus, that of the cervix is covered with a ciliated epithelium which passes into squamous epithelium just inside the external os of the uterus. In addition to unbranched tubular glands, numerous slightly branched glands are found in the cervix uteri. Both kinds of glands are lined with ciliated epithelium. In many cases little clear retention cysts are to be seen in the cervical mucous membrane. They arise as a result of obstruction at the mouths of the glands.

Differences in Uterus at Different Ages.—At birth the cervix uteri is relatively large, and its cavity is not distinctly marked off from that of the body by an internal os. At that time also the arbor vitæ extends throughout the whole length of the uterus. The organ grows slowly until just before puberty, when its growth is rapid for a time. As the body increases in size the mucous membrane becomes smooth and the arbor vitæ becomes restricted to the cervix. In women who have borne children the cavity remains permanently a little wider and larger than in those who have never been pregnant. In old age the uterine wall becomes harder and has a paler colour than in the young subject.

Variations.—In rare cases the uterus may be divided by a septum into two distinct cavities, or its lateral angles may be produced into straight or curved processes, called "horns". The latter abnormality recalls the appearance of the bicornuate uterus of some animals. Both the above conditions arise from an arrest in the fusion of the two separate tubes—the para-mesonephric ducts—which normally unite in the embryo to form the uterus.

Periodic Changes in Uterine Wall.—At each menstrual period a remarkable series of changes occurs which results in a periodic shedding of the superficial parts of the uterine mucous membrane. For a few days before menstruation begins, the mucous membrane gradually thickens and becomes more vascular, while at the same time its surface becomes uneven. Soon the superficial parts of the mucous membrane disintegrate and hæmorrhage takes place from the small superficial blood-vessels. In that way a hæmorrhagic discharge is caused, and the superficial parts of the uterine mucous membrane are shed at each period. When menstruation is over the mucous membrane is rapidly regenerated (see also p. 80, and consult Marshall, 1950; Selye, 1947).

Pregnant Uterus.—The pregnant uterus increases rapidly in size and weight, so that from being a pelvic organ 3 inches in length and about 1½ ounces in weight, it rises into the abdomen and becomes by the eighth month of pregnancy about 7 or 8 inches in length and sometimes as much as 2 lb. in weight. In shape the uterus is then oval or rounded, with a thick wall composed chiefly of muscle-fibres arranged in distinct layers. The fundus is very round and prominent. During labour the lower uterine segment (p. 779) is formed mainly by the isthmus, but the upper part of the cervix also is incorporated into it. The round ligaments are longer, and the layers of the medial part of the broad ligaments become separated by the growth of the uterus between them. The blood-vessels, especially the arteries, are very large and tortuous. The changes which occur in the mucous membrane of the pregnant uterus are described on p. 80 *et seq.* For changes in the pelvic floor during parturition, see Power (1946).

Involution of Uterus.—Immediately after delivery the uterus contracts, but it is still many times the size of the normal resting organ. It weighs about 2¼ lb. or 1000 gms. and lies against the anterior abdominal wall almost as high as the umbilicus. The peritoneum on its surface is thrown into wrinkles, and owing to the slackness of the ligaments the whole organ is extremely mobile. The cervix is lengthened and is flaccid, with thin walls and a widely open os. Sometimes on the second day after delivery the uterus rises above the umbilicus, apparently owing to the organ regaining elasticity, but from then onwards it rapidly shrinks. By the end of the first week it has diminished in weight to about 1 lb. or 500 gms., the wrinkles in its

peritoneal covering have disappeared and the cervix has shortened and become firmer. The ligaments of the uterus shorten as the uterus shrinks, and the pelvic floor also regains tone, so that the organ is less mobile. By the end of the second week it weighs 11 ozs. or 350 gms. and by the end of the eighth week it should be reduced to its resting size and should weigh 2 ozs. (60 gms.) or less. This process of gradual reduction of the uterus to its normal size is known as *involution*.

Vessels and Nerves of Uterus.—The uterus receives its **arterial supply** mainly from the *uterine arteries*, which are branches of the internal iliac arteries, and also from the *ovarian* branches of the aorta. The vessels derived from these two sources communicate freely with one another. Each uterine artery, reaching the side of the uterus, divides into a large branch which passes forwards to supply the body and fundus, and a much smaller branch which passes downwards to supply the cervix. The vessels distributed to the body and fundus have an exceedingly tortuous course. The branches of the uterine artery, having entered the muscular coat, break up within its deeper layers into smaller twigs which supply the muscular tissue and the mucous coat. The small uterine branch from the ovarian artery reaches the uterus in the region of the lateral angle. During pregnancy the arteries become enormously enlarged.

Numerous thin-walled **veins** form a plexus at the side of the cervix and pour their blood into the tributaries of the internal iliac vein.

The **lymph-vessels** from the fundus of the uterus join those from the ovary and end in *aortic lymph-glands*. One or two run along the round ligament to the *superficial inguinal lymph-glands*. The lymph-vessels from the cervix run to the sacral glands and all the iliac groups; those from the body end chiefly in the external iliac glands (p. 1412).

The **nerves** of the uterus are derived chiefly from a plexus—*utero-vaginal*—placed in the neighbourhood of the cervix uteri. Superiorly this plexus is continuous with the pelvic sympathetic plexuses, but it receives parasympathetic fibres also from the second and third or the third and fourth sacral nerves through the pelvic splanchnics.

Clinical observations indicate that afferent impulses reach the central nervous system from the uterus through the posterior roots of the tenth, eleventh, and twelfth thoracic nerves and the first lumbar nerves (Whitehouse and Featherstone, 1923).

VAGINA

The **vagina** (Figs. 657 and 661) is a passage about 3 inches in length, open at its lower end, and communicating above with the cavity of the uterus. The passage is directed downwards and forwards, describing a slight curve which is convex backwards. When the urinary bladder is empty, the axis of the vagina makes with the axis of the uterus an angle of slightly more than 90 degrees, but this angle increases as the bladder fills and raises the fundus of the uterus. Its anterior and posterior walls are in contact except at its upper end, where the cervix is inserted; and that is its widest part also. In transverse section the lower part is usually an H-shaped cleft, the middle part a simple transverse slit, while the lumen of the upper portion is more open. The cervix uteri enters the vagina through the upper portion of its anterior wall (Fig. 657). As more of the posterior part of the cervix than of the anterior part projects into the vagina, the recess between the vaginal wall and the cervix is deeper behind than in front or laterally. The term **anterior fornix** is applied to the recess in front, **posterior fornix** to the recess behind, and **lateral fornix** to the recess on each side. The *anterior wall* of the vagina is about 3 inches in length; the *posterior wall* is a little longer—about 3½ inches. At its lower end the vagina opens into the pudendal cleft between the labia minora. The opening is partly closed in the virgin by a thin, crescentic or annular fold, called the **hymen**, torn fragments of which persist around the opening, as the **carunculæ hymenales**, after the fold itself has been ruptured.

Relations of Vagina.—The vagina is related *anteriorly* from above downwards to the cervix uteri, the base of the bladder and ends of the ureters, from which it is separated by areolar tissue, and the urethra, to which it is intimately connected. Its upper end usually deviates a little to one side, with consequent asymmetrical relation to the ureters (p. 738). *Posteriorly* it is related from above downwards to the recto-vaginal peritoneal pouch for half an inch or more, then to the ampulla of the rectum, from which it is separated by a thin layer of very loose areolar tissue, and then to the perineal body. *Laterally* it is related on each side to the root of the broad ligament and the ureter crossed by the uterine vessels; lower down it is related to the levator ani muscle, a plexus of

veins intervening; and lower still it is related to the greater vestibular gland and to the bulb of the vestibule covered by the bulbo-spongiosus muscle. As the perineal membrane approaches the median plane, it turns downwards on each side of the vagina deep to the bulb of the vestibule and fuses below with the root of the labium minus.

Structure of Vagina.—The vaginal wall has a **muscular coat** composed of plain muscle-fibres, most of which are longitudinally disposed. Towards the lower end there are circular bundles of striated muscle-fibres, some of which are continuous with those which form a part of the

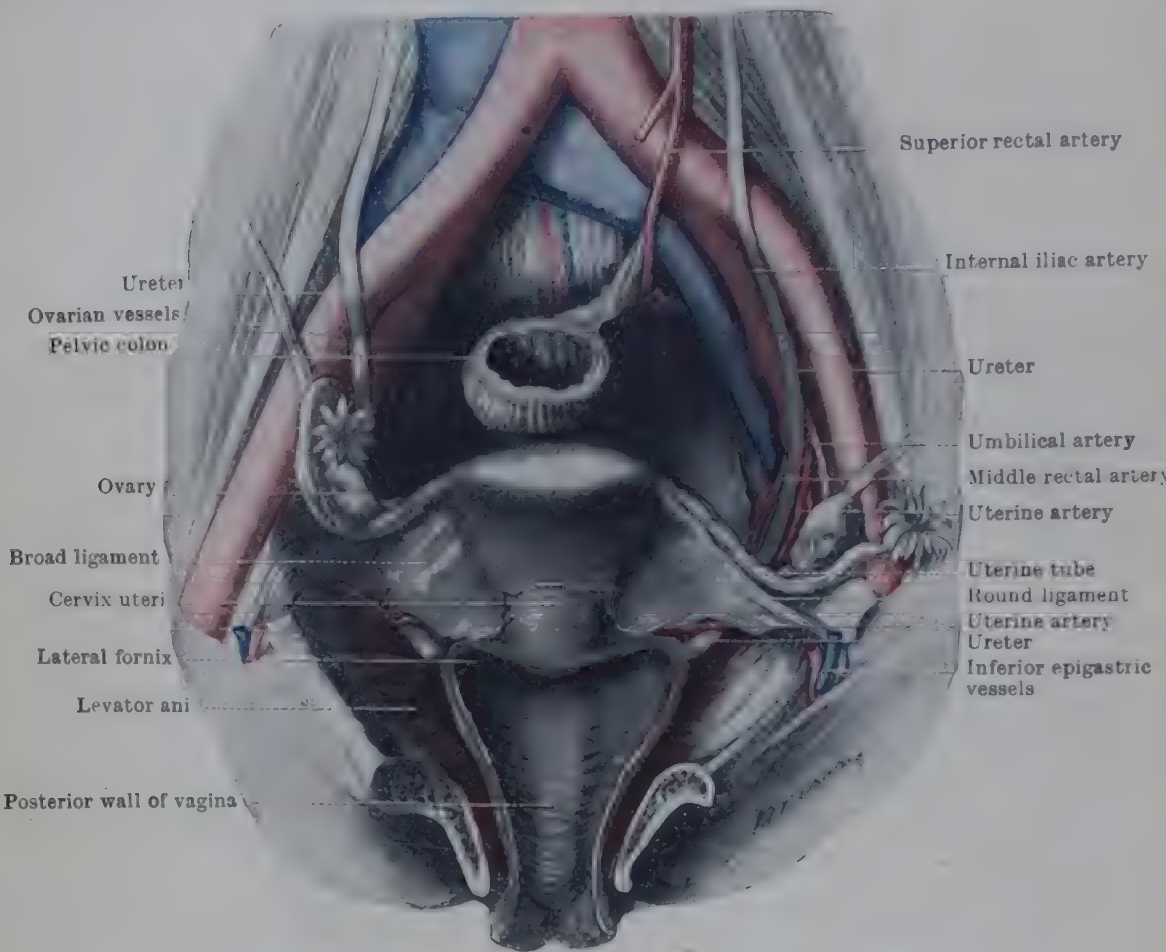

FIG. 661.—UTERUS AND VAGINA DISPLAYED BY FURTHER DISSECTION OF PELVIS OF MULTIPAROUS FEMALE SHOWN IN FIG. 656.

urethral wall. The **mucous coat** is thick and is corrugated by a number of transverse ridges or elevations known as **vaginal rugæ**; and it is covered with stratified squamous epithelium. In addition to the transverse rugæ, a slightly marked longitudinal ridge is to be seen on the anterior wall and another on the posterior wall. These receive the name **columns of rugæ**, and, like the transverse rugæ, they are seen best in young subjects and in the lower part of the vagina. The urethra lies in close relationship to the anterior column in its lower part, and hence that portion of the column is called the **urethral ridge**. Between the muscular and mucous coats there is a thin layer of vascular tissue which resembles erectile tissue; and in the mucous coat there are small nodules of lymphoid tissue.

The vaginal wall is surrounded by a layer of loose, vascular areolar tissue which contains numerous large communicating veins.

Vessels and Nerves of Vagina.—The **arteries** on each side are the *vaginal artery*, the vaginal branch of the *uterine artery*, the vaginal branches of the *middle rectal artery*, and branches of the *internal pudendal artery*. The **veins** form a plexus around the vaginal wall, and drain their blood into the tributaries of the *internal iliac veins*.

The **lymph-vessels** from the upper part of the vagina join the *external* and *internal iliac glands*, and those from the lower part end in the *superficial inguinal glands* (p. 1412).

The **nerves** of the vagina are derived from the *utero-vaginal plexus* and from the *vesical plexus*. Parasympathetic fibres are derived from the *third* and *fourth sacral nerves*.

Methods of Clinical Anatomical Examination.—The interior of the vagina and the vaginal part of the cervix can be inspected through a vaginal speculum. By a bimanual examination—two fingers of one hand in the vagina and the other hand on the anterior abdominal wall above the pubic crests—the fundus of the uterus can be felt when the fingers in the vagina press the cervix forwards and upwards. Normal uterine tubes

nnot be felt, but if thickened or inflamed they can often be palpated in a bimanual .amination.

The external os of the uterus is usually at the level of the spines of the ischium, which can be felt from the vagina; if the os is below this level, the uterus is prolapsed. The vaginal part of the cervix and the external os can be felt by a finger in the rectum. The

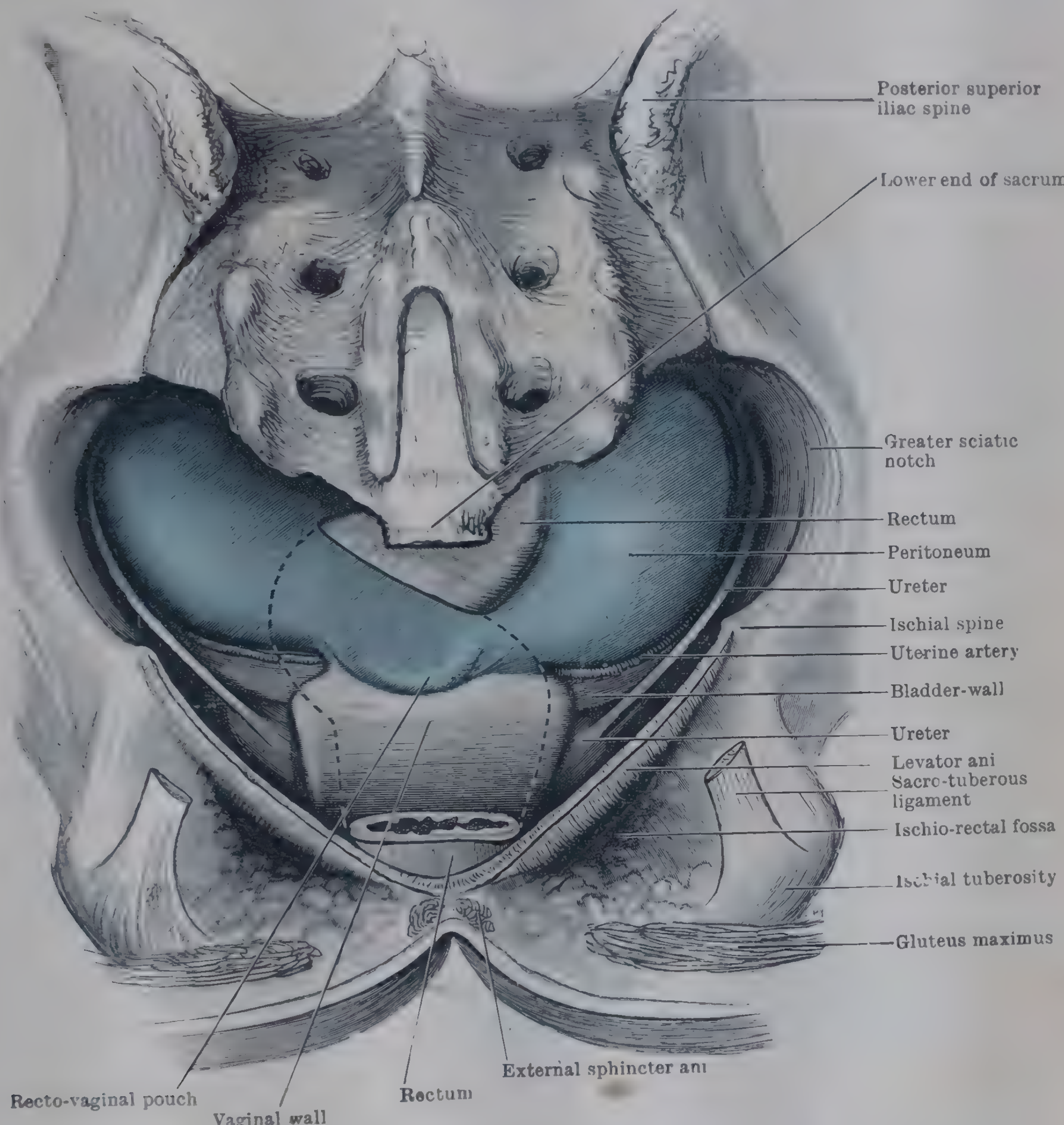

Fig. 662.—Vagina, Base of Bladder, and Recto-Vaginal Pouch from Behind.

The coccyx and the sacro-tuberous and sacro-spinous ligaments have been removed. The levatores ani h: been separated and drawn laterally. A considerable portion of the rectum has been removed, but position is indicated by the dotted lines. The recto-vaginal pouch is probably not quite so deep usual. The triangular interval between the ureter and uterine artery was filled by a mass of fibr muscular tissue.

pregnant uterus can be palpated as soon as it has risen above the pelvic cavity and lies against the anterior abdominal wall.

Radiographic Examination.—Materials opaque to X-rays can be injected into the uterus and thence into the uterine tubes, so that the shape of the uterine and tubal cavities and the position of the organs may be shown (Pl. LXXII, p. 745).

A fœtus in a pregnant uterus can be demonstrated by X-rays after the fourth month of pregnancy.

FEMALE EXTERNAL GENITAL ORGANS

The collective term **pudendum muliebre** or **vulva** is applied to the female external genital organs, *i.e.*, to the mons pubis and the labia majora and the structures which lie between the labia (Fig. 663).

Labia Majora.—The labia majora represent the scrotum in the male, and they form the largest part of the female external genital organs. They are the boundaries of the **pudendal cleft**, into which the urethra and vagina open. Each labium is a prominent, rounded fold of skin, narrow behind where it approaches the anus, but increasing in size as it passes forwards and upwards to end in a median elevation—the **mons pubis**. The mons pubis lies over the pubic symphysis, and, like the labia majora, it is composed chiefly of fatty and areolar tissue, and is covered with hair. The skin of the lateral, convex surface of each labium majus contains numerous sebaceous glands and resembles that of the scrotum in the male, but the medial surface is flatter and smooth and has a more delicate cutaneous covering. In some cases the posterior ends of the labia majora are connected across the middle line, in front of the anus, by a slight transverse fold — the **posterior commissure.**

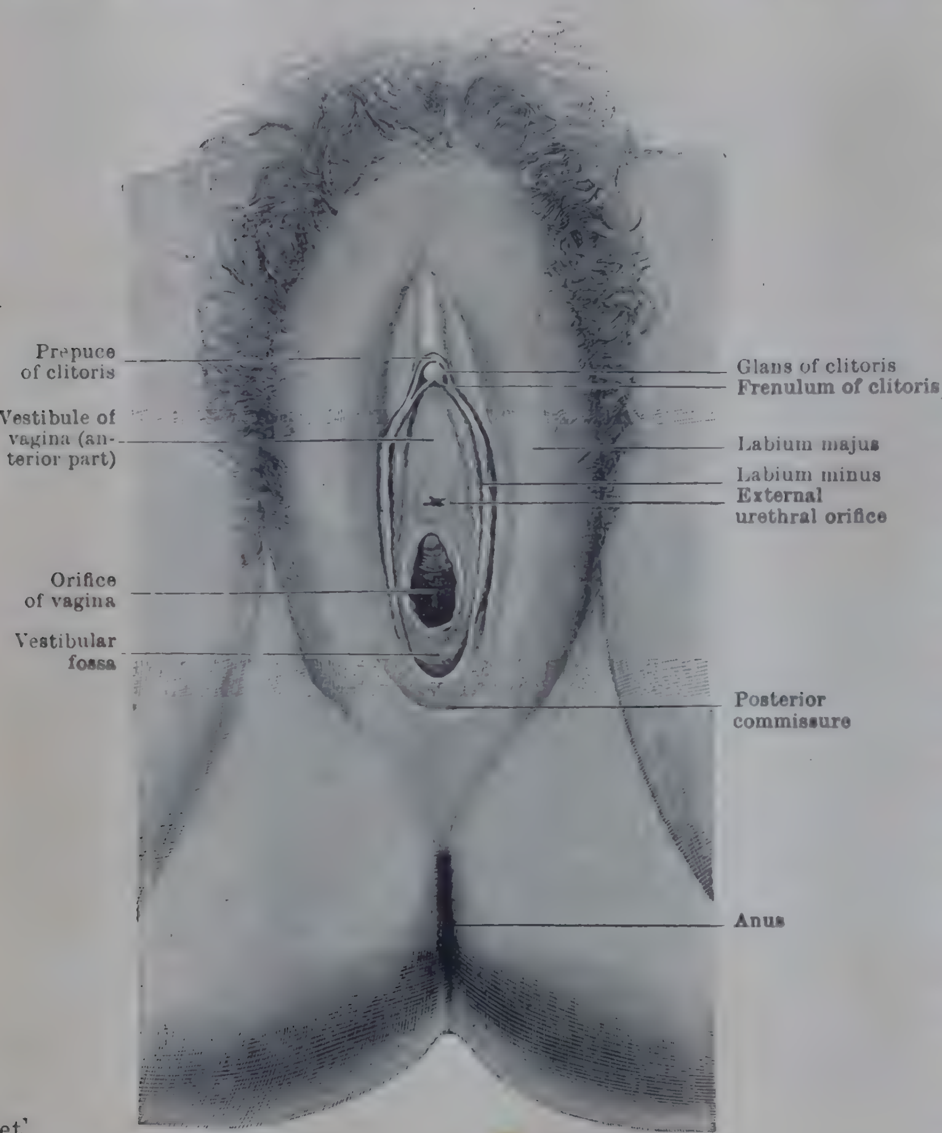

FIG. 663.—FEMALE EXTERNAL GENITAL ORGANS.
The frenulum labiorum is seen stretching across behind the vestibular fossa.

Usually the mons and the labia majora are the only visible parts of the external genital organs, since the labia are in contact with each other and completely conceal the structures within the pudendal cleft.

The round ligament of the uterus ends in the skin and fibro-fatty tissue of the labium majus. The superficial layer of the subcutaneous tissue resembles that of the scrotum, but contains no muscular fibres.

The **nerve-supply** corresponds with that of the scrotum—the anterior part of each labium being supplied by branches of the ilio-inguinal nerve, and the posterior part by branches from the pudendal nerve and by the perineal branch of the posterior cutaneous nerve of the thigh. The **blood-vessels** are derived from the external pudendal branches of the femoral and from the labial branches of the internal pudendal vessels.

Labia Minora.—The labia minora are a pair of much smaller and narrower longitudinal folds of skin usually completely hidden in the cleft between the labia majora. Their posterior parts diminish in size and end by gradually joining the medial surfaces of the labia majora. In the young subject a slightly raised transverse fold is usually seen connecting the posterior ends of the labia minora; to this fold the term **frenulum labiorum** is applied. Traced forwards, each labium minus divides into two portions—a lateral and a medial. The lateral portions of

the two labia unite over the glans clitoridis and form for it a fold or covering called the **prepuce of the clitoris**. The medial portions, uniting at an acute angle, join the glans and form the **frenulum of the clitoris**. The skin of the labia minora resembles that on the medial surface of the labia majora, being smooth, moist, and pink in colour. The medial surfaces of the labia minora are in contact with each other, and their lateral surfaces with the labia majora. The labia minora and the frenulum are devoid of fat.

The openings of the urethra and vagina are in the median plane, between the labia minora, which must be separated to bring them into view.

Vestibule of Vagina.—The vestibule is the name applied to the space between the labia minora. In its floor are the openings of the urethra, the vagina, and the ducts of the greater vestibular glands.

The **vestibular fossa** is the part of the vestibule behind the vaginal opening and in front of the frenulum labiorum.

The **external urethral orifice** is immediately in front of that of the vagina, and is about one inch behind the glans clitoridis. The opening has the appearance of a vertical slit or of an inverted V-shaped cleft whose margins are prominent and in contact with each other. Sometimes on each side of the urethral orifice there may be seen the minute opening of the para-urethral duct (see p. 753).

The **orifice of the vagina** varies in appearance with the condition of the **hymen**. When the hymen is intact the opening is small, and is seen only when that membrane is put on the stretch. When the hymen has been ruptured the opening is much larger, and round its margins are often seen small projections—**carunculæ hymenales**—which are fragments of the hymen.

The **hymen** is a thin membranous fold which partially closes the lower end of the vagina, and is perforated usually in front of its middle point. The position of the opening gives the fold, when stretched, a crescentic appearance. The opening in the hymen is sometimes cleanly cut, sometimes fringed. The membrane is not stretched tightly across the lower end of the vagina, but is so ample that it projects downwards into the pudendal cleft. The opening is thus a median slit whose margins are normally in contact.

On each side of the vaginal opening, in the angle between the labium minus and the under surface of the carunculæ hymenales, is the opening of the duct of the **greater vestibular gland**. It is usually just large enough to be visible to the unaided eye.

Numerous minute mucous glands — the **lesser vestibular glands**—open into the vestibule between the urethral and vaginal orifices.

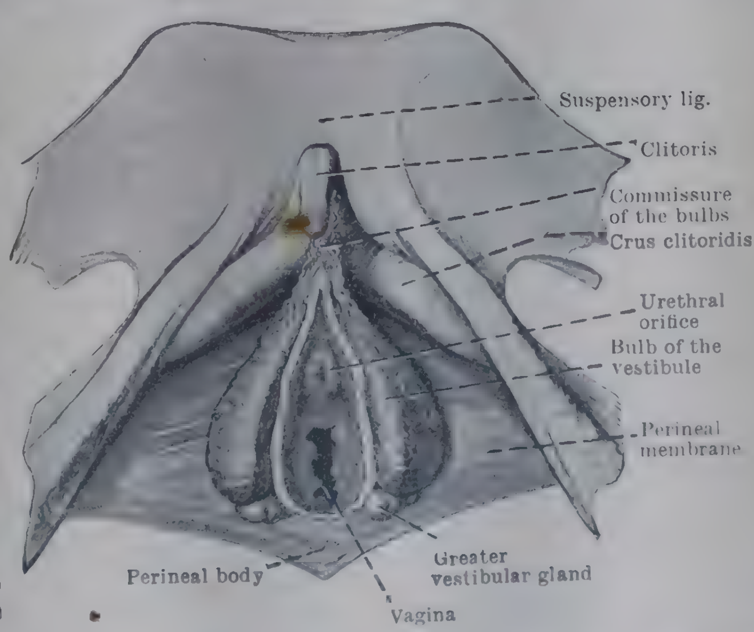

Fig. 664.—Dissection of Female Perineum to show Clitoris, Bulb of the Vestibule, and the Greater Vestibular Glands.

Clitoris.—The clitoris is the morphological equivalent of the penis, and it has a body, a pair of crura, and a minute glans on the summit of the body. Unlike the penis, the clitoris is not traversed by the urethra.

The **body** is composed for the most part of erectile tissue resembling that of the penis. It is about an inch in length, and is bent upon itself, forming an angle open downwards. It tapers towards its distal end, which is covered by the glans. It is enclosed in a dense fibrous coat and is divided by an incomplete **septum** into a pair of cylindrical **corpora cavernosa clitoridis**, which diverge from

each other at the root of the clitoris to form the **crura clitoridis**. A fibrous *suspensory ligament* passes from the body of the clitoris to the pubic symphysis (Fig. 664).

The **glans clitoridis** is a small mass of erectile tissue fitted over the pointed end of the body, and, like the glans penis, it is covered with a very sensitive epithelium. The **prepuce**, which hoods over the glans, and the **frenulum clitoridis**, which is attached to it inferiorly, are continuous with the labia minora (Fig. 663).

The **crura clitoridis** diverge from the body posteriorly, and are attached to the sides of the pubic arch. Each is continuous with one of the corpora cavernosa, and has a firm fibrous sheath, which is covered by the corresponding ischio-cavernosus. In structure the crura and body of the clitoris resemble the corpora cavernosa penis, while the glans more closely resembles the bulbs of the vestibule, with which it is connected by a slender band of erectile tissue (Fig. 664).

In the seal and some other animals a bone—the *os clitoridis*, which represents the os penis of the male—is developed in the septum of the clitoris.

The **arterial supply** of each crus is the deep branch from the internal pudendal. The glans is supplied by the dorsal arteries of the clitoris.

The **nerve-supply** of the clitoris is derived partly from the pelvic sympathetic plexuses and partly from the dorsal nerves of the clitoris, which are branches of the pudendal nerves.

FIG. 665.—DIAGRAMS TO ILLUSTRATE MANNER IN WHICH URETER, VAS DEFERENS, AND URINARY BLADDER ARISE IN THE EMBRYO.

The structures developed from the cloaca are indicated in blue, those from the mesonephric duct in red, and the ectoderm in black.

The manner in which the rectum and bladder become separated and acquire openings into the ectodermal cloacal fossa is shown in II and III.

A. Allantois.
B. Bladder.
C. Cloaca.
CM. Ectoderm of cloacal fossa.
K. Pelvis of ureter.
R. Rectum.
Ur. Urogenital canal.
U. Ureter.
VD. Vas deferens.
VS. Seminal vesicle.
WD. Mesonephric duct.

Bulbs of Vestibule.—These are a pair of masses of erectile tissue which correspond developmentally to the two halves of the bulb of the penis, but are almost completely separated from each other by the vagina and the urethra—being only slightly connected in front by a narrow median part called the **commissure**. Each bulb is thick posteriorly, and more pointed in front, where it joins the commissure. It rests against the lateral wall of the vagina and the lower surface of the perineal membrane. Superficially it is covered by the bulbo-spongiosus muscle. The commissure lies in front of the opening of the urethra, and is connected by a slender band of erectile tissue with the glans clitoridis. The bulb is for the most part composed of minute convoluted blood-vessels held together by a very small amount of areolar tissue; they frequently anastomose with one another, and with the vessels of the commissure and the glans clitoridis.

The **blood-supply** of the bulb is derived from a special branch of the internal pudendal.

GREATER VESTIBULAR GLANDS

The **greater vestibular glands** are placed one on each side of the lower part of the vagina, below the perineal membrane and concealed by the posterior parts of the bulbs of the vestibule. Each is about the size and shape of a small bean; and it has a long slender duct which pierces the perineal membrane and opens into the vestibule in the angle between the labium minus and the hymen (Figs. 659, 664).

DEVELOPMENT OF UROGENITAL ORGANS

General Account.—In tracing the developmental history of the urogenital passages it is convenient to begin with an embryo about 2·5 mm. in length. At that time a longitudinal duct on the lateral side of the mesodermal somites begins to develop on each side of the body. With the exception of the pronephros, the anterior portion of the cloaca and the proximal part of the allantois, that duct, which has received the name of *mesonephric duct* (Wolffian duct), is the earliest formed structure from which, or in connexion with which, the parts of the adult urogenital system arise.

The mesonephric duct serves as the canal for the primitive excretory organs—the pronephros and the mesonephros of the embryo. With the atrophy of these organs the duct suffers modification; yet adults of each sex possess structures which have their embryonic origin from it. In the male the **canal of the epididymis**, the **vas deferens**, and the **ejaculatory duct** are directly developed from the mesonephric duct; in the female the **duct of the ep-oöphoron** and the **vesicular appendices** are vestigial structures having a like origin. The **ureter** and its **pelvis** and the collecting tubules of the kidney arise in both sexes as an outgrowth from the mesonephric duct. In the male the **seminal vesicle** is developed as a diverticulum from it.

The primitive excretory organs—the **pronephros** and the **mesonephros**—develop in connexion with the anterior part of the mesonephric duct, and they correspond respectively to the functional kidneys of some primitive vertebrates (pronephros) and of the fishes and amphibia (mesonephros). In the human embryo the pronephros is functionless and soon becomes vestigial, and it is replaced by the far more important mesonephros. With the development of the permanent kidney or **metanephros** the mesonephros atrophies; yet some of its tubules persist in the adult. The **efferent ductules** of the testis, the **ductuli aberrantes** and the **paradidymis** in the male, and the tubules of the **ep-oöphoron** and of the **par-oöphoron** in the female, are structures which owe their origin to the tubules of the mesonephros.

After the formation of the mesonephric ducts another pair of longitudinally disposed canals are developed, called the **para-mesonephric ducts** (Müllerian ducts). Each duct begins as a solid outgrowth of cells from the wall of the body-cavity in the region of the mesonephros, but it soon acquires a lumen which opens at its cephalic end into the body-cavity. The ducts then grow slowly in a caudal direction and at their caudal ends they unite with each other in the median plane. From them are formed in the female the **uterine tubes**, the **uterus**, and the **vagina**; and in the male the **appendices of the testis** and the **prostatic utricle**.

The mesonephric and the united para-mesonephric ducts open at their caudal ends into the ventral or urogenital part of the **cloaca**, which in the course of development becomes transformed into the **urinary bladder** and the **urogenital canal** of the embryo (Fig. 665). The developing ureter at first arises as a diverticulum from the mesonephric duct at a short distance from the point where that duct joins the cloaca. Soon, however, the ureters acquire independent openings into the cloaca, and these openings become gradually shifted farther from each other and from those of the mesonephric ducts. The ureters come to open into the anterior portion of the cloaca, which lies nearer to the head of the embryo than the part with which the mesonephric ducts are connected. The cephalic portion of the anterior subdivision of the cloaca which receives the ureters becomes the urinary bladder and the upper part of the urethra. The caudal part, lying below the level of the entrance of the mesonephric ducts, is called the *urogenital canal* and is represented in the adult male by the lower part of the prostatic urethra and the whole of the membranous portion; in the female by the lower part of the urethra and the part of the pudendal cleft which immediately surrounds the openings of the urethra and vagina (Figs. 674, 675). The united para-mesonephric ducts open into the caudal part of the cloaca or urogenital canal between the mesonephric ducts. In the male the position of the opening, which is represented in the adult by the orifice of the prostatic utricle, remains almost unchanged. In the female, on the other hand, a shortening of the urogenital canal causes the opening, which in that sex is represented by the vaginal orifice, to appear on the surface of the body in the pudendal cleft.

After the complete separation of the cloaca into anterior or urogenital and posterior or rectal divisions, the rectum establishes a communication with the exterior in the floor of the shallow depression known as the ectodermal **cloacal fossa**. At a little later time the urogenital canal also joins the cloacal fossa at a point in front of the opening of the rectum. The ectodermal cloacal fossa lies in front of the vestigial tail, and extends forwards as far as a tubercle known as the **cloacal tubercle**, which later gives rise to the **genital eminence** and a pair of elevations called the **labio-scrotal folds**. The genital eminence becomes converted into the **clitoris** or **penis** according to the sex. The labio-scrotal folds, extending backwards on each side, form the **labia majora** of the female, and, fusing posteriorly, give rise to the **scrotum** in the male. In the female the lower part of the urogenital canal opens out to form a part of the floor of the pudendal cleft of the adult, and the shortening of the canal leads to the urethra and the vagina having independent openings into the cleft the margins of the cleft becoming elongated to form the **labia minora**. In the male the slit-like opening of the urogenital canal is prolonged forwards by an active growth at the base of the genital eminence, and, its margins uniting, it gives rise to the penile portion of the **urethra**.

Mesonephric Duct and Embryonic Excretory Organ

The **mesonephric duct** arises in the mesoderm of the intermediate cell-mass (p. 51), about the fifteenth day, as a solid cord of cells, and occupies a position immediately lateral to the mesodermal somites and medial to the body-cavity. During the fourth week this cellular cord acquires a lumen (Fig. 666), and about the end of the same week the duct in its growth reaches the cloaca. As soon as the cloaca has become divided into dorsal and ventral parts, the mesonephric duct ends in the cephalic part of the ventral division, which becomes the bladder and urogenital canal (Figs. 667, 668).

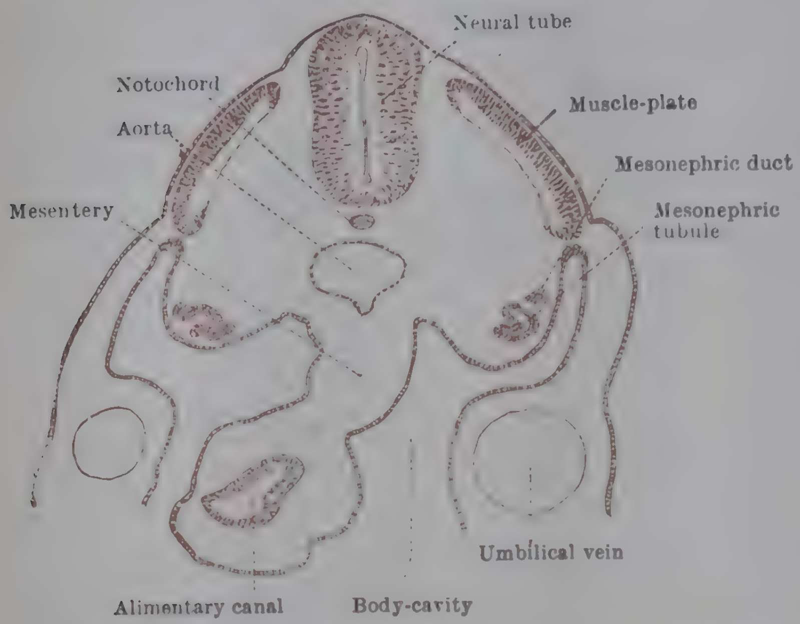

Fig. 666.—Transverse Section of 5 mm. Human Embryo.

The **mesonephros** is developed in the mesoderm of the intermediate cell-mass immediately adjoining the mesonephric duct, and it consists of a number of minute transversely arranged tubules, each of which opens by one end into the mesonephric duct, while its other end is blind. The transverse tubules, like the canal into which they open, are at first solid cellular structures, and only later acquire a lumen. Increasing rapidly in length and number, the tubules become twisted and tortuous, and the blind end of each dilates to form a capsule invaginated upon itself and containing a bunch of capillary blood-vessels similar to the *glomeruli* of the adult kidney. It would appear that primitively one tubule is developed in the portion of the intermediate cell-mass (nephrotome) which corresponds to each mesodermal somite, but, in higher vertebrates at all events, such a correspondence between the number of somites and the number of tubules cannot be demonstrated. In the tailward part of the mesonephros the tubules are very numerous—more numerous than the segments in that region. The tubules

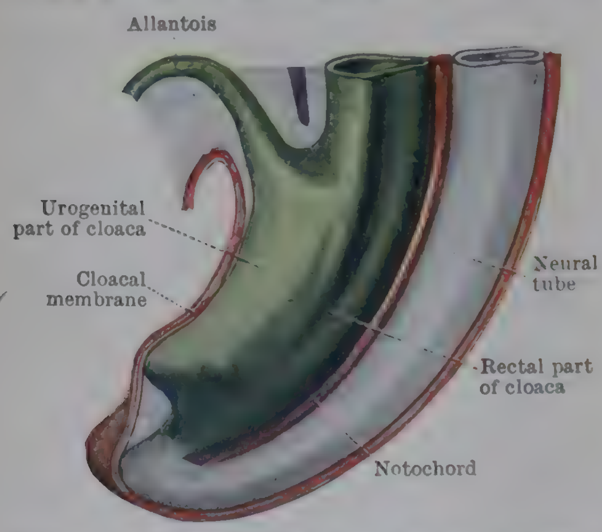

Fig. 667.—Tail-End of 3 mm. Human Embryo, before the time at which the Mesonephric Ducts reach the Cloaca. (Keibel, 1896.)

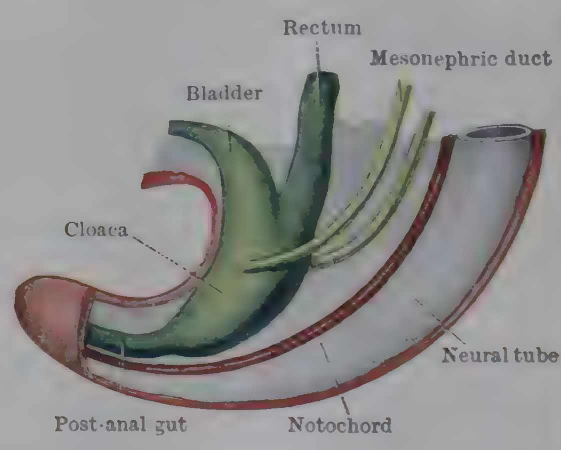

Fig. 668.—Tail-End of 4·2 mm. Human Embryo. The mesonephric ducts open into the anterior part of the cloaca. (Keibel, 1896.)

of the mesonephros arise in all segments from the sixth cervical to the third lumbar. The tubules in the headward part atrophy and disappear at a very early time, even while others are being formed towards the caudal end of the embryo. When at its greatest development (fifth to eighth week) the mesonephros is a relatively large glandular mass composed of tubules which resemble in a general way those of the adult kidney. At that time it bulges into the dorsal part of the body-cavity, and extends from the region of the liver to the caudal end of the cavity. Along its lateral surface lies the mesonephric duct (Fig. 669).

As the permanent kidney or metanephros is developed, the mesonephros atrophies; a portion of it, however, is retained *in the male*, and forms the excretory apparatus of the testis. The mesonephric duct becomes the canal of the epididymis and the vas deferens of the adult (see p. 793). *In the female*, when the permanent kidney is formed, the mesonephros and its

duct undergo atrophy to a greater extent than in the male, and they are represented only by the vestigial structures in the broad ligament of the uterus (see pp. 774 and 793).

In anamniate vertebrates—fishes and amphibia—the mesonephros persists as the excretory organ of the adult.

Pronephros.—The mesonephric duct originally served as the duct of the still earlier excretory organ—the **pronephros**. In the human embryo the pronephros arises earlier than the mesonephros, when the embryo possesses only ten segments, and its tubules are represented by coiled, solid cords of cells. The pronephros is found in the headward segments of the embryo only, and it atrophies at a very early time in development.

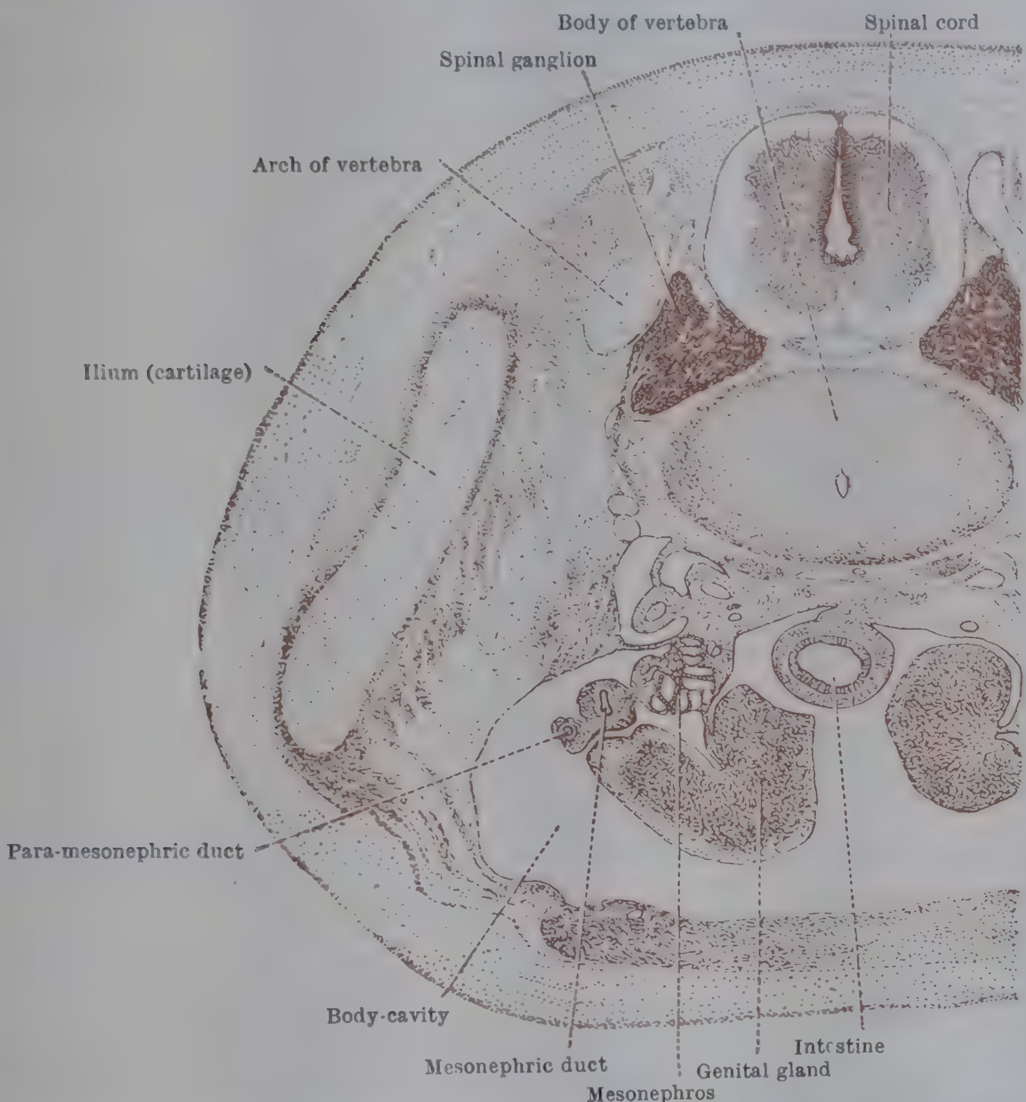

Fig. 669.—Transverse Section through Lower Part of Trunk of Human Embryo of about 7 Weeks. (Symington.)

Ureter and Permanent Kidney

The permanent kidney or **metanephros** has a double origin. The *secretory tubules* are developed from an extension of the tissue from which the mesonephros is derived—the metanephros proper; but the *collecting tubules* grew out from the ureteric bud of the mesonephric duct.

The ureter arises as a tubular diverticulum from the mesonephric duct close to the point where the duct joins the cloaca (Figs. 670 and 671). The diverticulum appears during the fifth week, and grows headwards, dorsal to the body-cavity. Even in its very early condition the portion of the outgrowth which lies nearest its origin from the mesonephric duct, and from which the adult ureter is developed, is more slender than the distal part, which becomes branched and grows out to form the pelvis and calyces of the ureter. From the calyces numerous collecting tubules grow out and acquire connexions with the glandular or uriniferous tubules of the kidney. The uriniferous tubules of the kidney arise independently of the ureter in the *metanephric cap*—a tailward prolongation of the tissue which, nearer the head, gives origin to the tubules of the mesonephros. The tissue in which the permanent kidney-tubules arise is caudal to the third lumbar segment. The blind, distal end of each tubule soon dilates to form a capsule which, becoming invaginated on itself, encloses a tuft of capillary blood-vessels. The renal corpuscles arising in this manner are found in the human kidney as early as the eighth week. It must be specially noted that the origin of the collecting tubules and their branches is different from the origin of the secreting tubules. The short junctional tubules of the adult lie in the

region where these developmentally distinct portions of the kidney unite. If the junctional tubules fail to develop, the secreting tubules have no outlet and a *congenital cystic kidney* is the result.

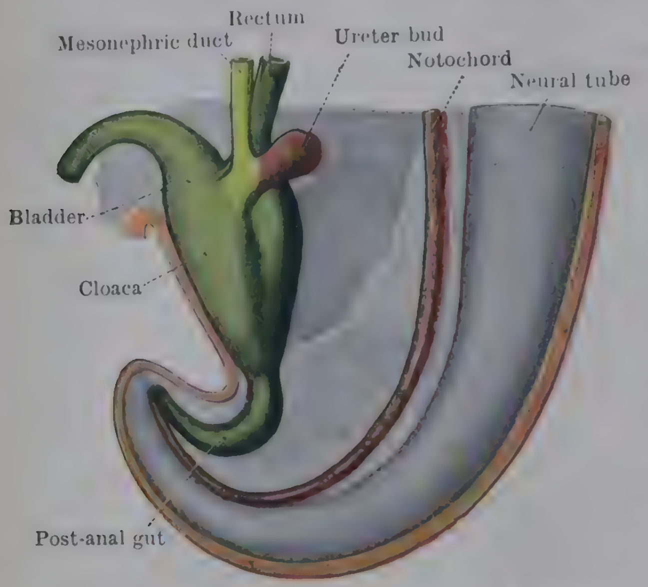

FIG. 670.—TAIL-END OF 6·5 MM. HUMAN EMBRYO.
The cloaca is dividing into rectal and urogenital parts. The ureter is arising as a bud from the mesonephric duct. (Keibel, 1896.)

As the ureter increases in length, it separates from the mesonephric duct, and acquires an independent opening into the ventral part of the cloaca nearer the head of the embryo than that of the mesonephric duct. The part of the cloaca which receives the ureters becomes the urinary bladder.

The metanephric cap, in which the uriniferous tubules arise, lies at first on the medial side of the bud-like outgrowth which represents the ureter; at a later time it comes to lie dorsally. As the ureter grows towards the head-end of the embryo the cell-mass which gives rise to the uriniferous tubules follows it; hence, the metanephric tissue ceases to lie at the caudal end of the mesonephros. Variations in the origin of the renal arteries are due to the change in position of the kidney during development; the blood-supply is at first from the internal iliac artery, but as the kidney moves head-wards it is supplied by branches from the common iliac and finally from the aorta.

As the ureter divides to form the calyces, the metanephric cap becomes broken up into numerous cell-masses—one for each branch of the ureter, and later one for each of the collecting tubes which grow out from the calyces. The formation of uriniferous tubules within the cell-masses is continued until a few days after birth. The kidney is at first a distinctly lobulated body, and shows at birth, and sometimes even in the adult, distinct traces of its original division into lobules (Fig. 679, p. 802).

URINARY BLADDER

The main portion of the urinary bladder is formed from the cephalic part of the ventral division of the cloaca. This, at an early time, becomes flattened dorso-ventrally and produced laterally into two horn-like projections in the region where the mesonephric ducts open (Fig. 671). Its tailward part becomes constricted to form the urogenital canal. Little by little the caudal ends of the mesonephric ducts open out and take part in the formation of the wall of the bladder and the upper portion of the prostatic part of the urethra. The openings of the ureters become shifted laterally, but the final position of the openings of the mesonephric ducts is close to the median plane in the prostatic part of the urethra. The urinary bladder has therefore a double origin: its main portion is derived from the cloaca and is therefore entodermal; the rest of it corresponds approximately to the trigone and is mesodermal in origin, for it arises from the opened-out caudal ends of the mesonephric ducts. The extreme cephalic end of the ventral part of the cloaca tapers gradually, and beyond the umbilicus is continuous with the allantois. This part of the cloaca is the *urachus*; it loses its lumen about the fifth week, and in the adult is represented by a fibrous cord—the median umbilical ligament (Begg, 1930).

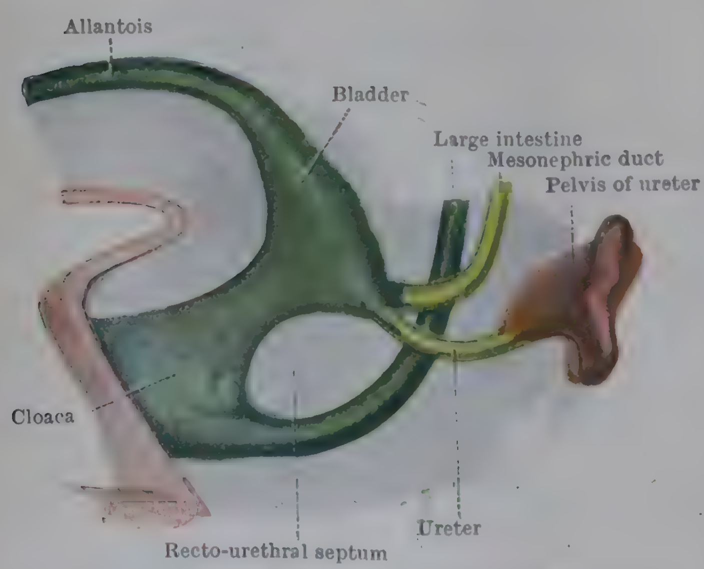

FIG. 671.—TAIL-END OF 11·5 MM. HUMAN EMBRYO.
The cloaca is becoming separated into rectal and urogenital portions by the formation of the recto-urethral septum. The ureter has acquired a separate opening into the ventral division of the cloaca. (Keibel, 1896.)

The cavity of the urachus is sometimes not lost so early, and in rare cases it persists in the child or adult as a pervious channel that extends from the apex of the bladder to the umbilicus. Here it may open on the surface of the body.

Malformations.—Simple malformations of the bladder are uncommon. The gross malfor-

mation called *ectopia vesicæ* or *extroversion of the bladder* is probably due to rupture of the cloacal membrane (p. 57) at a very early stage of development. The lower part of the anterior abdominal wall is deficient (in complete extroversion the pubic symphysis is absent) and the bladder is represented by an exposed, irregular area of mucous membrane—which corresponds roughly to the trigone—continuous with the surrounding skin. The ureters open on the exposed surface, and, in the male, the malformation is commonly associated with epispadias (see below).

Male Urethra

The first part of the male urethra has an origin similar to that of the basal part of the bladder, and is derived from the ends of the mesonephric ducts. The remaining portion—beyond the openings of the ejaculatory ducts of the adult—is derived from the urogenital canal or caudal division of the ventral part of the cloaca. The urogenital canal is early divided into a

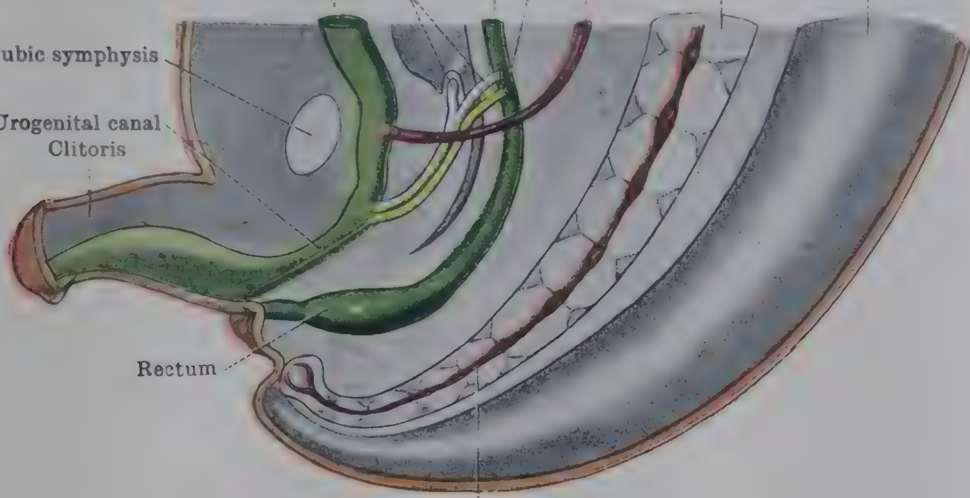

Fig. 672.—Tail-End of 25 mm. Female Human Embryo.

The rectum has acquired an external opening and the entoderm of the urogenital canal is continued into the genital eminence (clitoris). (Keibel, 1896.)

pelvic part which lies in the future true pelvis and a penile part which occupies the region where the corpus spongiosum is developed. The latter part of the urogenital canal becomes filled with closely and irregularly packed cells which later, breaking down, re-establish the canal and give origin to a slit-like opening in the region in front of the anus. The canal for some time opens at a rhomboidal fossa situated in the groove at the base of the glans penis. In the glans a septum composed of densely packed cells is formed, and these cells, at a later stage, break down and form a groove the lips of which unite and enclose the terminal portion of the urethra. It is doubtful if any portion of the male urethra owes its origin to the ectoderm, but there is some evidence that the septum of the glans is ectodermal, in which case the part of the canal which traverses the glans must have a like origin (Fig. 676 C).

Malformations.—Malformations of the male urethra are not uncommon. They are due mainly to failure of closure of the urethra at the two critical points—the junction of the membranous and spongy parts, and at the base of the glans penis. Such abnormal openings of the urethra on the under surface of the penis constitute the malformation known as *hypospadias*, which varies in degree; abnormal formation of the terminal part of the urethra in the glans with persisting opening at the base is the simplest and commonest variety. Complete hypospadias, associated with cryptorchism and failure of formation of the scrotum, gives rise to pseudo-hermaphroditism in the male. (See also the Development of the External Genital Organs, p. 794 and Fig. 676.)

The cause of simple *epispadias*, in which the urethra opens on the dorsal surface of the penis in front of the symphysis, is obscure; but it is often associated with extroversion of the bladder.

Female Urethra

In the female the part of the urethra near the internal urethral orifice is developed from the caudal ends of the mesonephric ducts and has an origin similar to that of the basal portion of the bladder. The lower part of the passage is derived from the urogenital canal. When the urogenital canal opens on the surface it is continued forwards as a sulcus on the genital eminence, as in the male sex. The margins of the slit-like opening do not unite, but form the labia minora of the adult, and the sulcus which appears on the glans clitoridis is closed without forming a canal. At first the fused caudal ends of the para-mesonephric ducts open into

the urogenital canal, but, later, a shortening and spreading out of the lower portion of the urogenital canal, to form a part of the pudendal cleft of the adult, is responsible for bringing the opening of the fused para-mesonephric ducts (the vaginal orifice) to the surface. The female urethra corresponds to the part of the male passage which lies above the opening of the prostatic utricle.

Genital Glands

In the development of the genital glands, male and female, a differentiated thickened portion of the peritoneal epithelium is first recognized. This specialized epithelium, known as the **germinal epithelium**, is situated to the medial side of the mesonephros and of the mesonephric and para-mesonephric ducts. It covers a longitudinally disposed elevation called the **genital ridge**. The germinal epithelium is not strictly limited to the ridge, but extends a little beyond its limits. The genital ridge is soon found to have numerous epithelial cells embedded in its stroma of fibrous tissue, and some of them appear to originate, in both sexes, by a proliferation from the deep surface of the germinal epithelium that covers the ridge. In both sexes, however, the earliest-formed epithelial cells appear to arise in the genital ridge independently and at first are not connected with the cells that cover the genital gland. From these epithelial cells the male seminiferous tubules and female vesicular follicles with their contained ova are developed. The tissue which gives rise to the genital ridge occurs in all the body-segments from the sixth thoracic to the second sacral, but the cephalic end of the ridge atrophies before the germinal epithelium can be recognized in the more caudal segments, and only about one-fourth of the ridge gives origin to the permanent genital gland.

Fig. 673.—Urogenital Passages at the Indifferent Stage of Development.

Ureter : solid green. Mesonephric duct : dotted green ; the origin of the seminal vesicle is indicated. Para-mesonephric ducts : orange. Rectum, bladder, and urogenital canal : red.

In the male, as early as the thirty-third day, the epithelial cells embedded in the stroma of the developing testis have become arranged into a network of cords within which certain larger cells are irregularly scattered. The larger cells are relatively few in number and are known as **primordial sperm-cells**. They undergo frequent division, and in the later stages they are not to be distinguished from the other cells of the cords. The cellular cords undergo direct transformation into the **convoluted tubules**, the **straight tubules**, and the **rete testis**. At a very early stage the superficial part of the stroma of the developing testis becomes denser, and gives origin to the **tunica albuginea**. The tissue surrounding the cellular cords becomes converted into the septa of the testis and the mediastinum. A lumen can first be recognized in the seminiferous tubules in the seventh month. The rete testis becomes connected secondarily with the efferent ductules of the testis, which are derived from tubules of the mesonephros, and thus the mesonephric duct becomes the passage for the secretion of the testis.

Fig. 674.—Male Urogenital Passages.

Ureter and vas deferens : solid green. Prostatic utricle : orange. Bladder, pelvic part of urethra and rectum : red. Penile part of urethra : black.

In the female, large epithelial cells are found in the stroma of the developing ovary beneath the germinal epithelium as early as the thirty-third day. These **primordial ova** are much more numerous than the primordial sperm-cells of the male, and they form a very characteristic feature of the developing ovary. At first they are isolated, but later—about the fifth week—they become surrounded by smaller cells which arise from the germinal epithelium. Each primordial ovum, surrounded by its cells, becomes a **primordial follicle**, the further development of which has already been described (pp. 21 and 772). During the later stages the epithelium has the appearance of growing down into the stroma in the form of long, branching, cellular processes which break up into little nests of cells to form the future follicles. The proliferation of cells from the surface epithelium goes on until birth, but the source of the ova themselves and whether any new ova are produced after birth are still unsettled questions (p. 24).

Descent of Testis and Ovary.—The descent of the testis into the scrotum and of the ovary into the pelvis have been considered in the main text (pp. 761 and 771).

Genital Ducts

As has been stated already, the male ducts arise from the mesonephric ducts and the female from the para-mesonephric ducts. The embryos of both sexes at first have well-developed mesonephric and para-mesonephric ducts, which are arranged in a very definite manner. The mesonephric ducts, communicating directly with the tubules of the mesonephros, lie at first parallel to each other, and at a considerable distance apart. As they pass towards the caudal end of the embryo they approach each other, and each becomes enclosed in a fold of peritoneum called the **plica urogenitalis.** More caudally the ducts become closely approximated to each other, and are embedded in a cord-like mass of fibro-areolar tissue to which the term **genital cord** is applied. They finally open into the ventral division of the cloaca.

The para-mesonephric ducts open freely into the body-cavity at their cephalic ends, and lie to the lateral side of the mesonephric ducts. As they are traced tailwards they cross ventral to the mesonephric ducts and enter the genital cord; in this cord they unite and form a median canal which opens into the ventral division of the cloaca between the mesonephric ducts (Fig. 673). The manner in which the ureters become separated from the mesonephric ducts has been described already.

Ducts in the Male.—The seminiferous tubules of the testis become connected with the mesonephric duct through a fusion of certain tubules of the mesonephros with the **rete testis.** The connexion is definitely established in the third month. The number of tubules that take part varies considerably, but corresponds to the number of **efferent ductules** found in the adult. The connecting tubules, becoming more convoluted where they join the mesonephric duct, form the **lobules of the epididymis.** The **canal of the epididymis** is directly formed from the cephalic part of the mesonephric duct, and the **vas deferens** from the more caudal portion. The **ducturi aberrantes** and the **paradidymis** are to be looked upon as persistent tubules of a more caudal portion of the mesonephros which have failed to become connected with the tubules of the testis.

The **seminal vesicles** are developed in the third month as evaginations from the mesonephric ducts near their caudal ends. Each at first is a longitudinal groove in the wall of the vas deferens, and then closes over and becomes cut off from the main tube except at the point where, later, the duct of the seminal vesicle joins the vas to form the **ejaculatory duct.**

The para-mesonephric ducts atrophy in the male embryo, but the appendices of the testis are vestigial remains of their cephalic portions, and the **prostatic utricle** represents the caudal fused portions which, in the embryo, occupy the genital cord (Fig. 674).

Ducts in the Female.—The para-mesonephric ducts in the female retain their openings into the body-cavity, and their cephalic portions become the uterine tubes. Their fused caudal parts, which at first join the urogenital canal, give rise to the **uterus** and **vagina.** The persisting portion of the septum which separates the extreme caudal ends of the ducts forms a plug that develops into the **hymen of the vagina.** The manner in which the original position of the opening of the para-mesonephric ducts becomes shifted, by the formation of a new passage or by the shortening of the urogenital canal, has been mentioned already (p. 792). The final position of the opening is in the pudendal cleft (Koff, 1933).

The mesonephric ducts and the mesonephros atrophy in the female, but traces of them are found in the ep-oöphoron and par-oöphoron (Fig. 675). In the fœtus the mesonephric duct can be traced along the side of the uterus as far as the upper end of the vagina.

Fig. 675.—Female Urogenital Passages.

Derivatives of para-mesonephric duct: orange. Ureter: solid and dotted green. The ep-oophoron is indicated in green between the uterine tube and the ovary. Bladder, urethra, and rectum: red.

Malformations.—Variations of the uterus have been mentioned on p. 780 as due to the arrest of the fusion of the para-mesonephric ducts. Such failure of union may be so complete that the uterus and vagina appear to be double, or a dividing septum may persist in one or other of these organs or in both. The vagina may fail to reach the surface, or the simple malformation of "imperforate hymen" may result from failure of the terminal plug to break down.

Accessory Glands

The glandular portion of the **prostate** arises as a series of solid outgrowths from the epithelium of the urogenital canal during the third month. The outgrowths are simple at first, but become branched and finally acquire a lumen. They are arranged in three groups—an upper and a lower dorsal, and a ventral group. The glands of the ventral group soon become reduced in number and often completely disappear; those of the upper dorsal group form the chief part of the prostate. The prostatic glands arise in both sexes; but in the female, where they are known as *para-urethral glands*, they are few in number and not densely packed as in the male. The muscular tissue of the prostate is derived from the muscular wall of the urethra.

The **bulbo-urethral glands** arise in the third month as outgrowths from the epithelium of the urogenital canal. The **greater vestibular glands** arise in the same manner.

External Genital Organs

The external genital organs are developed in the region of the ectodermal cloacal fossa, and the male and female are alike in the earlier stages (Spaulding, 1921). The fossa at first extends

A

B

C. Male Embryo.

D. Male Embryo at Later Stage.

Fig. 676.—External Genital Organs of Human Embryos.

A. Embryo of 20 mm.
B. Slightly larger.

Indifferent stage: the genital eminence and the labio-scrotal folds are evident.

Formation of scrotum. The labio-scrotal folds, formerly best marked at the sides of the genital eminence, have grown backwards and united behind the primitive urogenital opening to form the scrotal raphe. The genital folds embrace the base of the genital eminence or penis. The glans is very prominent.

Behind the glans penis the urethra opens in a diamond-shaped fossa at the proximal end of which the median raphe ends. The prepuce is formed behind the constriction which marks off the glans, and grows forwards to cover it.

A little horn-like process of epithelium is present on the summit of the genital eminence.

on the ventral aspect of the body almost from the tail to the umbilical cord. At its cephalic end there is a tubercle known as the **cloacal tubercle**, and at its caudal end there is a **coccygeal tubercle.** Immediately in front of the coccygeal tubercle the anus is formed, and between the anus and the cloacal tubercle the urogenital canal opens on the surface by a median slit-like aperture—the **primitive urogenital opening**—the margins of which are raised up to form the **genital folds.**

The cloacal tubercle early becomes divided into: (1) an apical **genital eminence**, which occupies the median line and lies at the cephalic end of the primitive urogenital opening; and (2) a **basal portion**, which lies nearer the umbilicus and also curves round the sides of the genital eminence. At a later time the basal part is continued to form a pair of prominent folds at the sides of the cloacal fossa. These folds are called the **labio-scrotal folds** and, *in the female*, give rise to the labia majora. The genital folds give origin to the labia minora, and the genital eminence becomes the clitoris. On the clitoris at a very early date a relatively large glans is marked off by a surrounding sulcus. *In the male* the labio-scrotal folds grow backwards, and, meeting behind the primitive urogenital opening, fuse together. In that way the opening is pushed forwards. The genital eminence elongates rapidly owing to a growth at its basal part, and a sulcus which is formed on its cloacal aspect gradually becomes converted into a canal by the progressive union of the genital folds. Soon the urogenital opening is found to lie nearer the apex than the base of the eminence, which has now given rise to the penis. For some time the opening in the male lies at the base of the glans penis and is rhomboidal in outline. At a later time, owing to the breaking down of a dense septum of epithelial cells which appears within the glans, a sulcus, and finally a canal, arises within that part of the penis; thus, the terminal part of the urethra is formed. When the opening at the base of the glans is closed the continuous urethral passage is established. The main portion of the urethra is entodermal

in origin, but there is some evidence that the part in the glans has its origin from the ectoderm (Fig. 676).

Hermaphroditism.—*True hermaphroditism*—the presence of both testis and ovary—is exceedingly rare in the human subject; in any case, the two glands, or the two constituents of a mixed ovo-testis, are never both functional.

Pseudo-hermaphroditism is defined as the association of the genital glands of one sex with external genital organs that resemble those of the other sex. Complete hypospadias in the male, as noted on p. 791, gives rise to the commonest variety; the external genital organs, through failure of the testes to descend and of the labio-scrotal folds to unite, may closely resemble those of the female. The opposite condition, with enlargement of the clitoris to simulate a penis and possible descent of the ovaries, is much less common. It is probable that these conditions, in which secondary sex-characters also are affected, are due to disturbance of the normal regulation of development by internal secretions.

MAMMARY GLANDS

The mammary glands are accessory organs connected with the female reproductive system. Each gland is situated on the front of the thorax in the superficial fascia of the hemispherical elevation known as the mamma or **breast**. It usually extends from the level of the second rib to that of the sixth rib, and it lies on the pectoralis major and, to a less extent, on the obliquus externus abdominis and the serratus anterior. The **nipple** is situated near the summit of the breast, usually at the level of the fourth intercostal space; the lactiferous ducts open on it by minute apertures, and it is surrounded by a coloured, circular area of skin called the **areola**. The skin of the nipple is thrown into numerous wrinkles, and on the areola it exhibits many minute, rounded projections due to the presence of underlying cutaneous glands. These **areolar glands** are considered to represent rudimentary portions of the mamma. The colour of the nipple and areola varies with the complexion, but in young subjects it is usually a rosy-pink, and it changes to a deep brown during the second and third months of the first pregnancy. Also, during pregnancy, the areola increases in size and its glands become more marked. The nipple contains a considerable number of plain muscle-fibres, and it becomes firmer and more prominent as a result of mechanical stimulation.

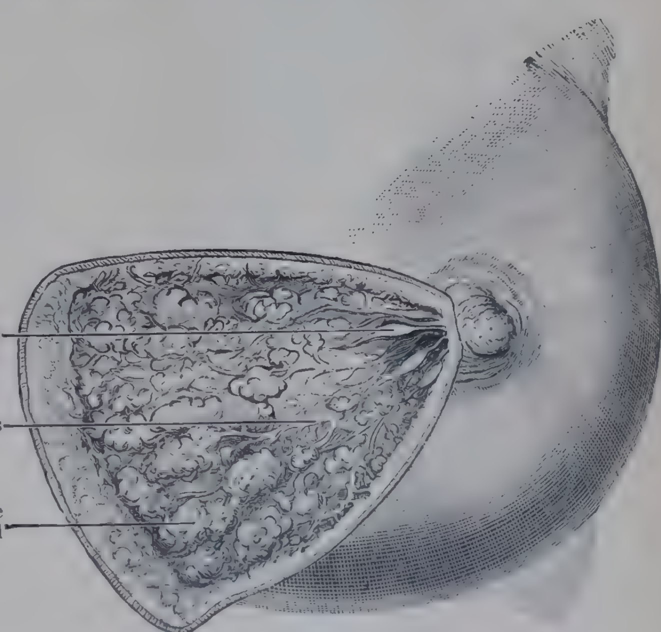

FIG. 677.—DISSECTION OF THE BREAST.

The size and appearance of the breasts vary much, not only in the different races of mankind but also in the same person under different conditions. In the young child they are small, and there is little difference between those of the male and female. Their growth is slow until the approach of puberty, and then the female mammary glands increase rapidly in size. At each pregnancy the breasts become large, and they attain their greatest development during lactation. The size of the breast depends partly on the amount of superficial fat and partly on the amount of glandular tissue present.

Structure of Breast.—The mamma is composed of a mass of glandular tissue traversed and supported by strands of fibrous tissue, and covered with skin and a thick layer of fat. The glandular tissue forms a flattened conical mass, the apex of which corresponds to the position of the nipple, while its base is loosely connected to the deep fascia of the muscles on which the gland lies. In section it is readily distinguished from the surrounding fat by its firmer consistence and by its pinkish-white colour. It is composed of fifteen to twenty lobes divided into

lobules, which make its superficial surface and edges very uneven—the inequalities of its surface being filled up by processes of the fatty tissue which covers the gland. The fatty covering is incomplete in the region of the areola, and here the lactiferous ducts pass into the nipple. The **lobes** radiate from the nipple, each lobe being quite distinct from the others and possessing its own duct; the **lobules** are bound together and supported by a considerable amount of fibro-areolar tissue, which forms the **stroma** of the gland (Figs. 677, 678).

The alveoli of the gland and the secretory epithelium which lines them vary much under different conditions. At puberty the mammary gland is composed chiefly of the ducts and the stroma of fibro-areolar tissue; at that time the alveoli are small and few in number. During lactation, when the gland is fully functional, the alveoli are enlarged, distended with fluid, and much more numerous. The epithelial cells are cubical and filled with fat-globules. When the gland is not secreting, the alveoli become small and reduced in number, and the cells of the lining epithelium, which are then small and glandular, do not contain fat-globules.

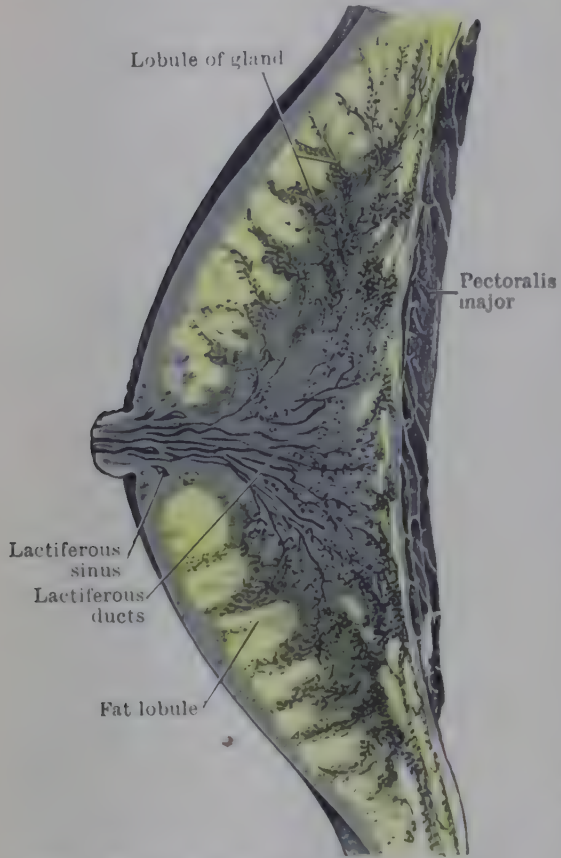

FIG. 678.—SECTION THROUGH A BREAST. Prepared after immersion in nitric acid as recommended by the late Sir Harold Stiles.

The **lactiferous ducts**, passing towards the nipple, become enlarged to form small, spindle-shaped dilatations called **lactiferous sinuses**; then, becoming once more constricted, each duct passes, without communicating with its neighbours, to the summit of the nipple, where it opens on the surface.

In the male the various parts of the breast are represented in a rudimentary condition.

The presence of milk-glands is characteristic of the class Mammalia; and the number of pairs of glands in each group of animals bears some relation to the number of young usually produced at each birth.

Variations.—Asymmetry in the development of the breasts is very common—the left mamma being very often larger than the right. Absence of one or both mammæ is a very rare abnormality which may or may not be associated with absence of the nipples. When one nipple only is present it is usually the left. The presence of supernumerary glands or nipples is not very uncommon. The term **polymasty** has been applied to cases in which more than the normal number of mammæ are present, and **polythely** to those in which additional glands, in a rudimentary condition, are represented by accessory nipples. Usually the accessory glands, or nipples, are present on the front of the thorax, and in most instances they occur below and a little to the medial side of the normal site. When the abnormal glands are found above the normal site they generally lie farther from the median plane. Much more rarely, accessory glands have been found on the abdomen, in the axilla, or in some other situation, including even the back of the trunk. As many as three extra pairs of mammæ have been found in the same person, and cases in which the probable representatives of mammary glands were even more numerous have been recorded. Asymmetry is very common in those abnormal structures. Examples of polymasty and polythely occur in the male as well as in the female. In some women the accessory breasts have yielded milk during lactation; in most cases the abnormal organs are very rudimentary—being represented only by a minute nipple or a pigmented areola. Polymasty and polythely are supposed to represent a reversion to an ancestral condition in which more than two mammary glands were normally present, and in which probably many young were produced at each birth. In this connection it is interesting to observe that usually the accessory glands occur in positions normally occupied by mammary glands in lower animals. In the course of the development of the breasts in man, specialized areas of the epidermis, similar to those which give origin to the mammæ, have been observed both above and below the region in which the adult mammæ are developed. These areas appear to be present normally, but usually they disappear at an early stage in the history of the embryo. In some other mammals rudimentary mammary glands may occur, as, for instance, in lemurs and in cows.

A slight functional activity of the mammary glands of the male about the time of puberty is stated to be a not very uncommon occurrence.

Vessels and Nerves of Breast.—The mamma receives its **arterial** supply from the perforating branches of the *internal mammary artery* and from the external mammary branches of the *lateral thoracic*. Additional supply is derived from some of the intercostal vessels. The **veins** from the gland pour their blood into the *axillary* and *internal mammary veins*. Some small superficial veins from the breast join tributaries of the external jugular.

The **lymph-vessels** of the breast are very numerous, and for the most part join the lymph-glands of the axilla. They take origin from an extensive *perilobular plexus*. The majority follow the lactiferous ducts and thus converge towards the nipple, and they join a plexus situated beneath the areola (*subareolar plexus*). From this plexus the main efferent vessels pass to the *anterior* (*pectoral*) *axillary glands*, but it is important to remember that free communication exists between all the subgroups of axillary glands. In addition, vessels pass from the deep surface of the lateral part of the breast directly to the lower axillary glands, and a few run either through or behind the pectoral muscles to the *apical axillary glands*. A few vessels from the medial part of the breast, following the course pursued by the perforating arteries, may join the lymph-glands situated along the course of the internal mammary artery. It is also to be remembered that a few, probably irregular, communications exist across the median plane with the lymph-vessels of the opposite breast; and, further, that under diseased conditions communications may exist with lymph-vessels in the upper part of the sheath of the rectus abdominis, and so with the *retrosternal* and *internal mammary* glands. The surgical importance of the facts regarding the lymphatic drainage of the breast cannot be exaggerated (see also p. 1430 and Fig. 1171).

The **nerve-supply** of the gland is derived from the **intercostal nerves** of the fourth, fifth, and sixth intercostal spaces. Along the course of these nerves sympathetic filaments reach the breast from the thoracic part of the sympathetic trunk. The nipple has a particularly rich nerve-supply (Cathcart *et al.*, 1948).

Development of Mammary Glands

The mammary glands are developed as ingrowths of the ectoderm into the underlying mesodermal tissue. In the human embryo a thickened raised area of the ectoderm can be recognized in the region of the future gland at the end of the fourth week. The thickened ectoderm becomes depressed in the underlying mesoderm, and thus the mammary area soon becomes flat, and finally sunk below the level of the surrounding epidermis. The mesoderm, where it is in contact with the ingrowth of the ectoderm, is compressed, and its elements become arranged in concentric layers which, at a later stage, give rise to the stroma of the gland. The ingrowing mass of ectoderm cells soon becomes flask-shaped and then grows out into the surrounding mesoderm as a number of solid processes which represent the future ducts of the gland. These processes, by dividing and branching, give rise to the future lobes and lobules, and, much later, to the alveoli. The mammary area becomes gradually raised again in its central part to form the nipple. A lumen is formed in each part of the branching system of cellular processes only at birth; and with its establishment is associated the secretion of a fluid resembling milk which often takes place at that time. The lactiferous sinuses appear as thickenings on the developing ducts before birth.

In those animals which possess a number of mammary glands—such as the cat and pig—the thickening of the ectoderm, which is the first indication of the development of those glands, takes the form of a pair of ridges that extend from the level of the forelimb towards the inguinal region. The ridges converge caudally, and at their terminations lie not far from the median line. By the absorption of the intervening portions the ridges become divided up into a number of isolated areas in connexion with which the future glands arise. Similar linear thickenings of the ectoderm have been recognized in the human embryo also, and the usual positions assumed by the accessory glands when present lead us to suspect that in all probability the ancestors of man possessed numerous mammary glands arranged, as in lower animals, in two lines that converge as they approach the inguinal region.

For a detailed study of the development of the mamary glands in the monkey, with full bibliography, see Speert (1948).

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DUCTLESS GLANDS

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The term "ductless" is applied to certain glands whose products reach the circulation without passing through any special channels or ducts. They differ widely in structure, function, and development, exhibiting a diversity similar to that of glands in general.

Glands.—From the functional point of view a gland may belong to one (or more than one) of the following categories:

(1) **excretory** (*e.g.*, kidney);
(2) **secretory**: A. *exocrine* (*e.g.*, salivary and intestinal glands);
B. *endocrine* (*e.g.*, thyroid, testis, hypophysis cerebri);
(3) **reproductive** (testis and ovary);
(4) **vascular** (*e.g.*, spleen, lymph-glands, thymus, tonsil).

Glands may be classified also with reference to their developmental history. Thus, they are referable to one or other of the primary germ-layers of the embryo—ectoderm, mesoderm, or entoderm. Later stages in development also provide a basis for classification. For instance, certain glands are described as "**pharyngeal derivatives**", with reference to their mode of development, namely, thyroid, parathyroids, thymus, and tonsils. In a similar manner the hypophysis cerebri and the pineal body have been associated in a "cerebro-glandular" group.

The reproductive and vascular glands are sometimes grouped together as "**cytogenic**", with reference to their cell-producing functions.

The same gland may belong to more than one category. The pancreas, for example, has both exocrine and endocrine functions; and the testis and ovary belong to both reproductive and endocrine categories. There is reason to believe that the thymus, which belongs to the vascular group, serves also as an endocrine organ.

Of the *ductless glands*, some have endocrine functions and others belong to the vascular group. But in different ways both of these varieties of ductless glands are intimately related to the vascular system.

Endocrine Glands.—These organs produce chemical substances, commonly known as hormones [ὁρμᾶν (horman) = to excite], which control and modify the functional activity of the cells of other tissues in specific ways. They are the basis of a great chemical system which co-ordinates the activities of the various tissues; and their physiological and clinical importance is such that special text-books are devoted to them (Sharpey-Schafer, 1924-1926; Goldzieher, 1939; Selye, 1947). The study of the various aspects of these organs is now generally known as *endocrinology*.

The effects produced by hormones may be either excitatory or inhibitory, and the general term "autacoid" [αὐτός (autos) = self; ἀκέομαι (akeomai) = repair or make good] is thus sometimes employed to describe the products of endocrine glands.

Histologically the endocrine glands exhibit various grades of specialization (Cowdry, 1932, 1944). These grades probably illustrate the steps by which the structural and functional differentiation of endocrine organs took place in the course of evolution. The production of a hormone has, indeed, fundamental resemblance

to an activity displayed by all living cells, for these all give off substances into the circulation which affect the activities of other cells. Hormones are distinguished by the specific nature of the effects they produce; in some instances they are recognized only by these effects.

The first stage in the differentiation of a tissue as an endocrine organ is illustrated by certain tissues (*e.g.*, gastric and duodenal mucosa) which, though primarily adapted by their structure to some other function, also produce a hormone as a secondary function without any evident cytological differentiation of the cells concerned. The placenta and plain muscle-tissue may be mentioned as other examples of this stage.

A second stage in differentiation is illustrated in organs such as the pancreas, in which there is a recognizable specialization of structure as well as of function. In this organ some of the cells remain epithelial in structure and act as an exocrine secretory organ, whilst other cells are budded off from the epithelium in the course of development to form the "islets of Langerhans", which act as a purely endocrine organ. The testis and the ovary (ovarian follicles and corpus luteum) also are examples.

It is not yet settled whether the specific hormone of the testis is produced by the interstitial cells or by the tubular genital epithelium. If the latter view proves to be correct, the testis as an endocrine gland would fall to be graded in the first stage.

A further stage of differentiation is seen in the thyroid and parathyroid glands; for in the development of these glands there comes about a complete separation from the pharyngeal epithelium of masses of cells destined for specialization with an endocrine function. Chromaffin tissue and the thymus may perhaps be included here.

Lastly, two masses of cells, each of specialized structure and function, may come into such intimate relation in the course of development as to constitute a single organ from the topographical point of view. Examples are furnished by the buccal and neural parts of the hypophysis cerebri, and by the cortex and medulla of the suprarenal gland. It has been suggested that such close approximation may perhaps allow important interactions which influence the respective functions.

In this chapter the more specialized endocrine glands alone are described, namely, those which belong to the third and fourth grades. Certain other organs of doubtful hormone-producing function are included, namely, the carotid body, the glomus coccygeum, the pineal body, and the thymus.

Vascular Glands.—These are organs which develop in intimate relation to the vascular and reticulo-endothelial systems (p. 831). They serve as reservoirs and germinating centres for the cellular constituents of these systems. Certain of these glands exhibit a special structure which fits them to act also as filtering organs—the lymph-glands for lymph, the hæmolymph-glands and spleen for blood; but in certain others, such as the lymphatic nodules in the walls of the alimentary canal, there is no such provision.

The tonsil, lymph-glands, and lymphatic nodules are dealt with elsewhere in this text-book: the thymus and spleen are included in this Section.

The organs described in this Section are taken in the following order:—

(1) The *Suprarenal Glands*, which are compound organs including chromaffin and cortical tissue.

(2) The *Chromaffin System*, of ectodermal origin, including the medulla of the suprarenal gland and various "paraganglionic" masses of chromaffin tissue.

(3) The *Cortical System*, of mesodermal origin, represented by the cortex of the suprarenal gland and by the occasional "accessory cortical bodies".

(4) The *Organs of the Pharyngeal Pouches*, of entodermal origin and developed from the walls of the pharynx, including the thyroid and parathyroid glands and the thymus.

(5) The *Cerebro-Glandular Organs*, of ectodermal origin, consisting of the hypophysis cerebri and the pineal body.

(6) The *Spleen*.

Form and Development of Glands.—In the living body, glands are soft, plastic structures, and the details of their form are continuously subject to modification by the pressure of adjacent structures. Many of them have a lobulated shape which arises from their mode of development, but in some instances this appearance is eventually obscured or disappears (cf. young and adult kidneys, Figs. 611 and 679).

The special secreting cells of an exocrine gland are developed from the walls of a tubular structure which may be of simple form (p. 579) or may exhibit an elaborate system of branches such as is seen in compound racemose glands. The tubular structure with its branches eventually forms the gland-duct and its tributaries. In some instances the tubular form is not seen while the secreting cells are developing, but instead elongated columns of cells are first formed which only later become canalized (*e.g.*, in the development of the liver, p. 681). The secreting cells of some of the endocrine and vascular glands likewise arise from the walls of tubular structures which later disappear—a mode of development that is the outcome of a progressive specialization of function (*e.g.*, the organs of the pharyngeal pouches).

As glands grow, the glandular tissue accommodates itself between adjacent structures, and, if deeply embedded in the body, the whole mass may become moulded to reflect their contours, *e.g.*, the thymus (Fig. 702). A gland thus frequently shows impressions made by adjacent blood-vessels or bones; or it may even surround structures, as in the case of the parotid salivary gland.

The majority of glands are extremely vascular, especially those of the endocrine and vascular categories. The glandular cells are thus brought into intimate physiological relationship with the whole of the blood of the body in a relatively short time.

The nerves which supply glands terminate in two ways. They may end in the walls of blood-vessels and influence the functions of the gland through their control over the blood-supply (*e.g.*, the thyroid and the suprarenal cortex); or they may end in direct relation with the actual secreting cells (*e.g.*, the suprarenal medulla).

SUPRARENAL GLANDS

The **suprarenal glands** (Figs. 679-686) are normally two in number, situated one on each side of the vertebral column in intimate relation with the supero-medial aspects of the kidneys.

Each gland consists of a relatively thick layer of cortex enclosing a medulla. It is extremely vascular: the amount of blood that passes through it, relative to its size, surpasses that in any other organ in the body, with the possible exception of the thyroid gland. Arterial blood enters the gland from a plexus on the surface of the cortex and passes through the cortical tissue to the medulla, whence it is drained by the venous system (Fig. 685).

The cortex and medulla are of different developmental origin; they are in effect two distinct endocrine organs—though it is possible that the function of the medulla is influenced by its intimate vascular relationship with the cortex. The *cortex* plays an indispensable rôle in the body. Interference with its function affects distribution of water in the body; the endothelium of capillaries becomes more permeable and tissue fluid increases. It secretes hormones (*cortins*) which are closely related to the sex-hormones and are included with them in the 'steroid' group. The cortex also stores vitamin C and lipoids. The *medulla* secretes a hormone (*adrenalin*) which reinforces the action of the sympathetic nervous system and facilitates carbohydrate metabolism. This is perhaps the only hormone which has so far been actually recognized in its cells of origin and whose discharge into the blood-stream can be followed microscopically (Fig. 684).

The cortex is essential to life; the medulla is not essential. Nor does the medulla display the functional changes of size which are seen in the cortex under various circumstances (*e.g.*, during menstruation, after extirpation of the contra-lateral gland, in certain disturbances of metabolism, and under the influence of one of the hormones of the hypophysis cerebri).

In colour the cortex is yellow, owing to the contained fatty substances. The medulla is seen in a section of the fresh healthy gland as a dark streak within the yellow cortex; it becomes brown on treatment with a dilute solution of chromic acid (chromaffin reaction).

The post-mortem size of the gland varies within wide limits, mainly on account of the great modifications produced by certain pathological conditions.

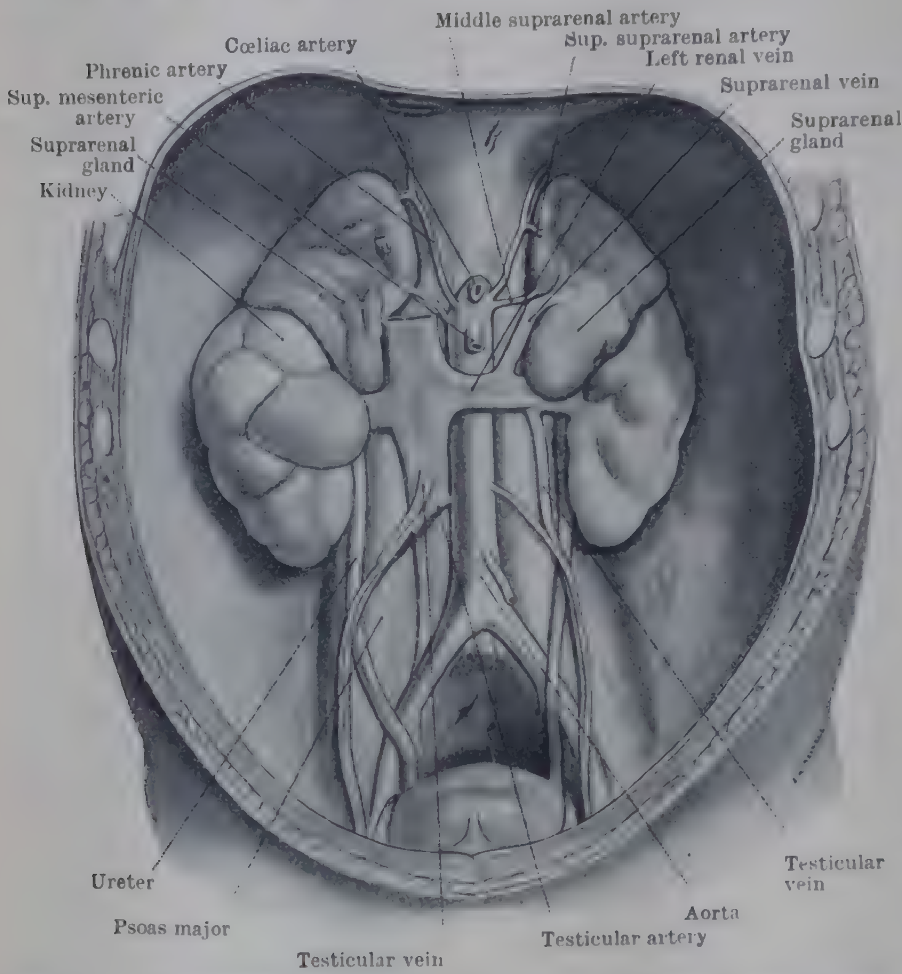

FIG. 679.—POSTERIOR ABDOMINAL WALL OF FULL-TERM FŒTUS, ILLUSTRATING THE RELATIVELY LARGE SIZE OF THE SUPRARENAL GLANDS AND THE LOBULATION OF THE KIDNEYS.

The average dimensions of the suprarenal glands are as follows: height, 3-5 cm.; breadth, 2·5-3 cm.; thickness, slightly under 1 cm.; and the weight is 7-12 gm. The medulla forms only about one-tenth part of the whole gland. The glands are relatively much larger in the fœtus than in the adult. Even at birth they are still relatively large (Fig. 679); they are indeed little smaller than in the adult.

Rarely only one gland is present; occasionally one is quite small, the other unusually large; as a rule they are unequal in size, the left being more frequently the larger. Sometimes the two glands are fused (cf. horseshoe-kidney).

Frequently there are accessory glands. These develop in the neighbourhood of the main gland and usually remain there, but may become attached early in embryonic life to originally adjacent organs which subsequently change their position. As a result, they may be found not only beside the main gland but also in the broad ligament of the uterus, on the spermatic cord, or even attached to the epididymis. Like the main glands, true accessory suprarenals are compounded of cortex and medulla, and require to be distinguished from the purely chromaffin bodies and accessory cortical bodies which may be found in any of the positions in which accessory suprarenal glands occur.

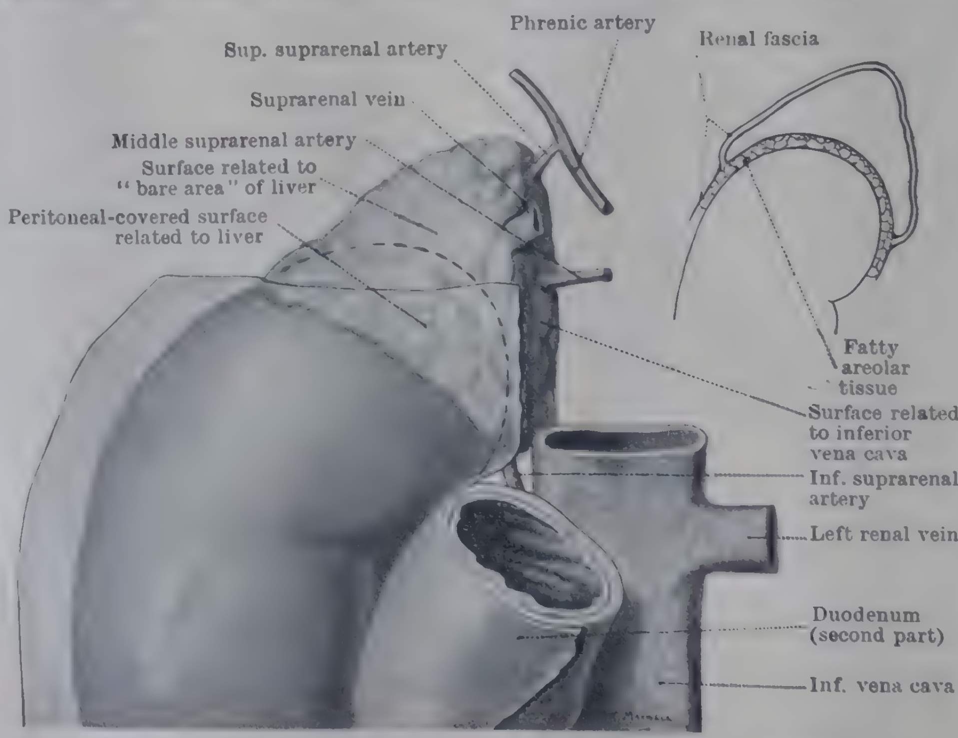

FIG. 680.—RIGHT SUPRARENAL GLAND WITH ITS RELATION TO PERITONEUM AND SOME ADJACENT STRUCTURES. The small diagram is a schematic vertical section illustrating the relation of the gland to the kidney and the renal fascia.

Form and Relations.—The suprarenal glands differ slightly in their form, which is moulded by adjacent structures. The right gland is more or less triangular, the left is semilunar and extends farther down the medial side of the kidney than the right one. Each presents a posterior and an anterior surface: the right one has also an antero-medial surface. The posterior surface comprises a lower portion, which is moulded on the medial part of the upper pole of the kidney, and an upper portion which lies against the diaphragm. The anterior relations differ on the two sides. The left gland (Fig. 681) is situated behind the lesser sac of peritoneum, which separates it from the stomach; the infero-medial extremity is, however, sometimes separated from the lesser sac by the splenic artery and the body of the pancreas. The right gland is related by its antero-medial surface to the inferior vena cava. Its anterior surface is related to the liver, being in immediate contact with it in its upper part but separated from it in its lower part by peritoneum. The cœliac plexus and ganglia are situated between the two glands.

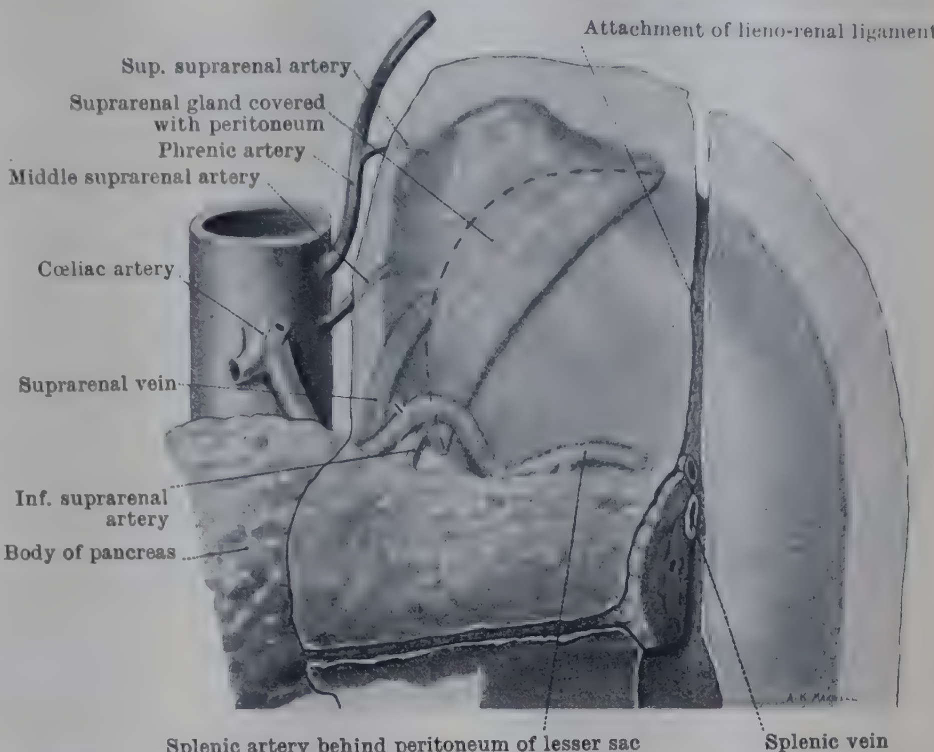

FIG. 681.—LEFT SUPRARENAL GLAND WITH ITS RELATION TO PERITONEUM AND SOME ADJACENT STRUCTURES. (See also Fig. 616, p. 732.)

The suprarenal gland is separated from the kidney by a small amount of fatty areolar tissue, and is enclosed along with the kidney by the renal fascia (Fig. 680).

A cleft is found in each gland where the suprarenal vein leaves it. The cleft or *hilum* is situated in the right gland on the antero-medial surface, in the left one near the lower end of the medial margin.

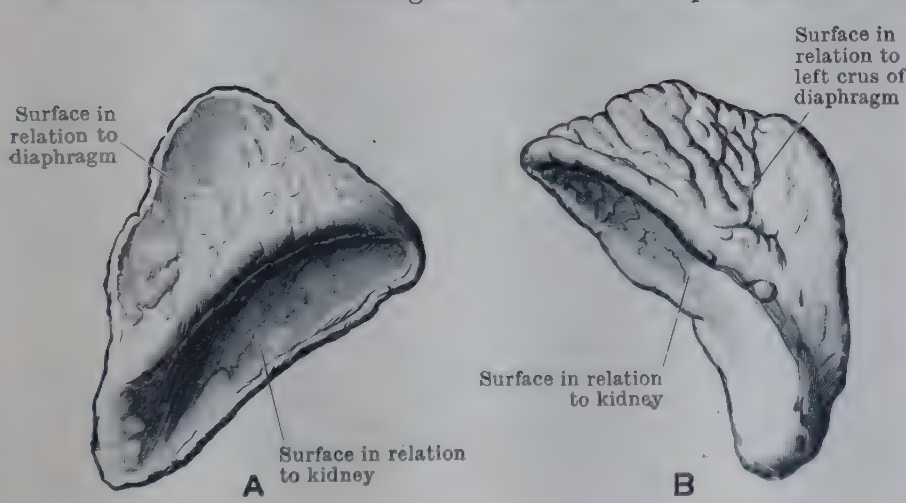

FIG. 682.—SUPRARENAL GLANDS ISOLATED AND VIEWED FROM BEHIND.
A. Right. B. Left.

The level of the gland varies in relation to the adjacent structures. Thus, the infero-medial part of the right gland is sometimes overlapped by the duodenum, and the area covered with peritoneum is correspondingly restricted. On the left side the pancreas and splenic artery sometimes lie at a lower level than the gland. In the infant the spleen makes contact with the upper part of the left suprarenal; sometimes it still does so in the adult. Respiratory movements bring about modifications in the relations, for the suprarenal is displaced along with the kidney by movements of the diaphragm.

Vessels and Nerves.—The abundance of the blood-supply of the suprarenal glands should be emphasized again. Each gland receives three **arteries**—one direct from the aorta, one above from the phrenic artery, and one below from the renal artery (Figs. 680, 681). Each gland is drained by a single large **vein** which emerges through the hilum, the right one to join the inferior

vena cava, the left to join the left renal vein behind the body of the pancreas. The arrangement of the blood-vessels within the gland is described with its structure. Numerous **lymph-vessels** pass from the suprarenal glands to the aortic lymph-glands.

The *medulla* of the gland is more richly supplied with nerves than any other organ; they come from the last few thoracic segments and reach the gland through the *splanchnic nerves* and the *cœliac plexus.* The nerve-filaments form a plexus of medullated and non-medullated nerve-fibres in the fibrous capsule before they pass into the gland. Some of the fibres are postganglionic fibres from nerve-cells scattered along the sympathetic nerves or in the gland itself (Swinyard, 1937); others are preganglionic fibres which end in synaptic relation with the secretory cells of the medulla (Hollinshead, 1936). It has been shown that stimulation of the nerve-filaments that enter the gland results in an increased outflow of adrenalin into the blood.

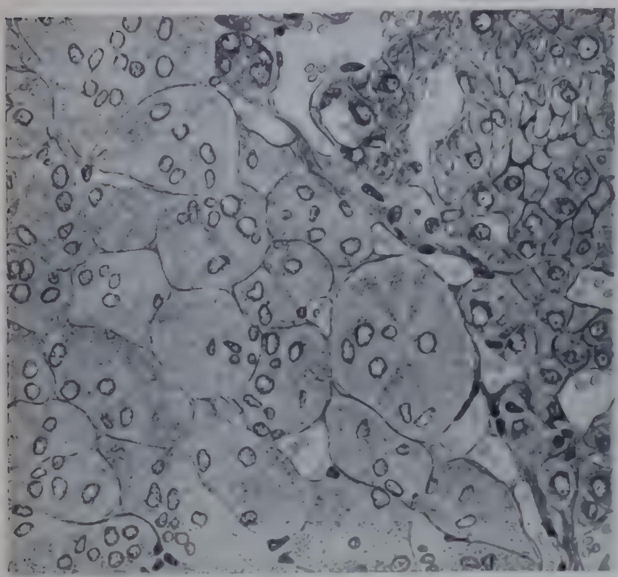

FIG. 683.—SECTION OF SUPRARENAL GLAND OF RABBIT, showing medulla and adjacent reticulate zone of cortex. (Cramer, 1919.)

There is no evidence that the *cortex* receives any nerve-supply. Fibres in the cortical zone in Bielschowsky preparations appear to be reticular and not nerve fibres (Swinyard, 1937).

Structure.—The suprarenal gland consists of a highly vascular central mass of chromaffin tissue—the *medulla*—enclosed within a thick parenchymatous layer of cortical substance—the *cortex*—which in turn is enveloped in a capsule of fibrous tissue.

The **cortex** of the human suprarenal is so folded or convoluted as to increase its surface of contact with the medulla. From the deep aspect of the capsule, trabeculæ of fibrous tissue pass inwards to support the glandular parenchyma. In the superficial part of the cortex the trabeculæ interlace freely so as to enclose a series of small rounded clusters of cortical cells, thus forming the *zona glomerulosa* (Fig. 685, 1); in the intermediate region of the cortex elongated cell-columns, usually formed of two or three rows of cortical cells, lie at right angles to the surface, forming a *zona fasciculata* (Fig. 685, 2); in the

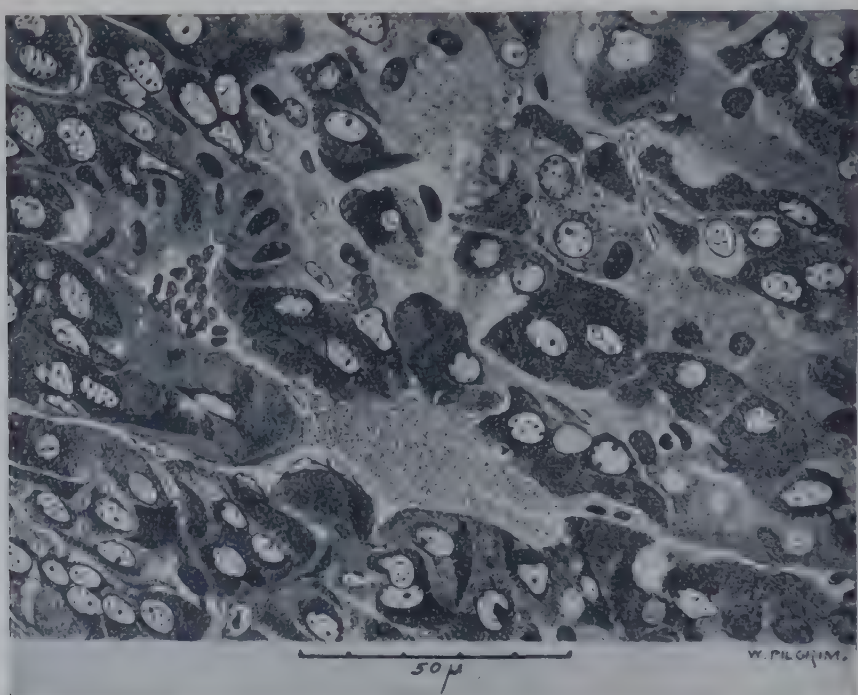

FIG. 684.—MEDULLA OF MOUSE'S SUPRARENAL GLAND, showing discharge of adrenalin in asphyxia. Granules of adrenalin blackened by osmic acid are seen in the medullary cells (in different phases of activity) and in the venous spaces. (Cramer, 1928.)

deepest part of the cortex the cell-columns are more irregularly arranged and form a reticulum—*zona reticulata* (Figs. 683, 685, 3). The zone of cortex adjacent to the medulla is intimately involved in the sex-hormone mechanisms in mice and has been termed the X zone or androgenic zone. Injection of certain gonadotropic hormones causes degeneration of this zone in young mice (McPhail & Read, 1942). Senile degeneration of cells occurs in the zona reticulata while new formation occurs at the junction of the glomerular and fasciculate zones (Hoerr, 1931).

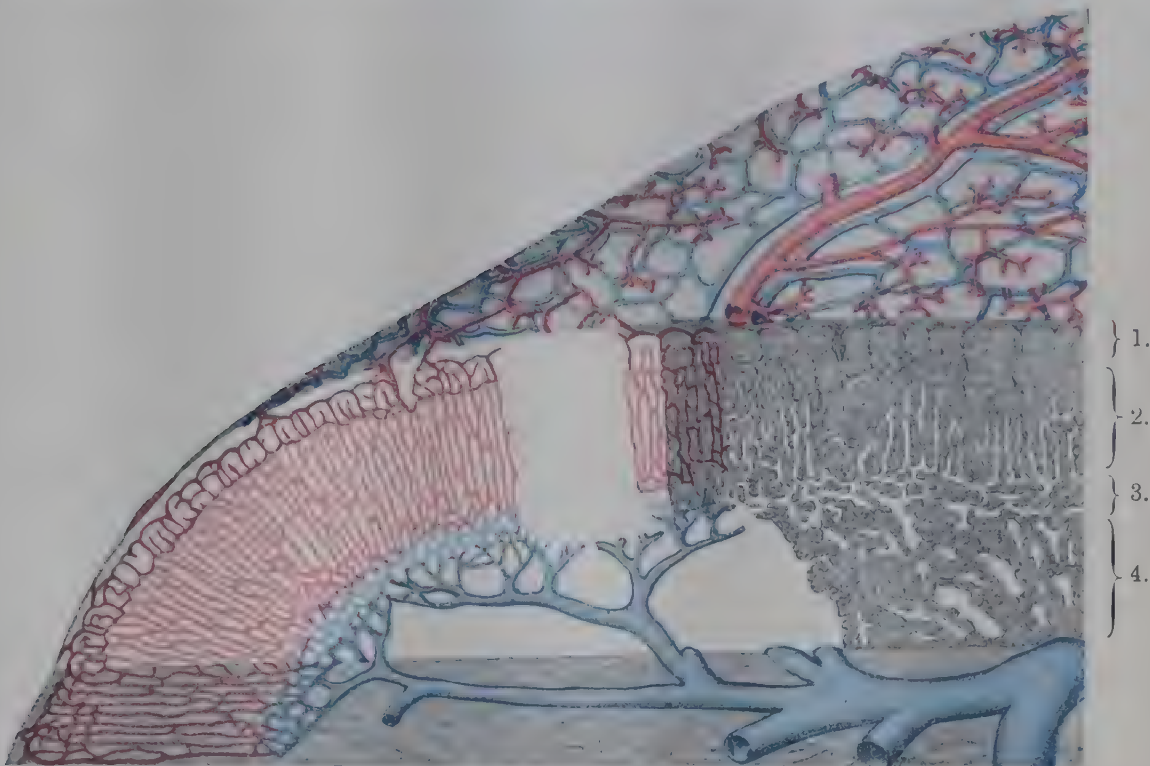

FIG. 685.—RECONSTRUCTION OF SUPRARENAL GLAND OF A DOG. (Flint, 1900.)
The upper part of the figure shows the arrangement of blood-vessels on the surface of the gland, the lower part their arrangement within its substance.
1. = Zona glomerulosa. 2. = Zona fasciculata. 3. = Zona reticulata. 4. = Medulla.

The cortical parenchyma consists of large polyhedral cells arranged in the interstices of the fibrous trabeculæ. The cells contain more or less granular lipoid material, fat, and pigment which gives a yellow colour to the cortex as a whole. The cortex is richer in cholesterol than any other tissue in the body. Ascorbic acid (vitamin C) is stored in the fasciculate and reticulate zones. The glomerular zone is larger and richer in fat in females than in males, and swells with each menstruation and pregnancy. As the blood passes between the columns of the fasciculate zone it gains cortical hormones and undergoes a form of filtration or detoxication; a reticulo-endothelial kind of function is thus attributable to the cortical cells (Hartman, 1942).

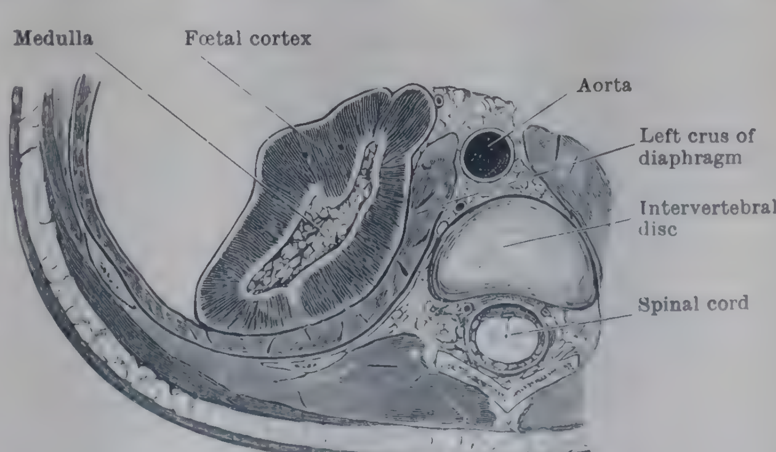

FIG. 686.—TRANSVERSE SECTION THROUGH SUPRARENAL GLAND OF A NEW-BORN CHILD *IN SITU*.

The **medulla** (Fig. 685, 4) is formed of a spongework of cell-columns separated by anastomosing venous sinusoids. The cells are large and granular and exhibit the characteristic chromaffin reaction. In a fresh gland the medulla is of a dark-red colour owing to the presence of blood in its sinusoidal spaces.

Adrenalin is produced by the cells of the medulla. Its precursor can be demonstrated as granules within the cells either by the chromaffin reaction or by blackening

with osmic acid. During actual secretion the granules blackened by osmic acid can be seen also in the venous spaces (Fig. 684—see also Bennett, 1941).

Vascular Pattern.—From the main blood-vessels, smaller vessels enter at numerous points in the fibrous capsule and run in the trabeculæ, forming a close network around and between the cell-masses and columns of the zona glomerulosa and zona fasciculata (Fig. 685). In the zona reticulata the blood-vessels open up to form a venous plexus which is continuous with the sinusoidal plexus in the medulla, and thus with the central efferent vein of the medulla which emerges at the hilum of the organ as the suprarenal vein. Few of the arterioles that enter the cortex pass directly through into the medulla. Most of the blood which reaches the medulla first passes through capillaries in the cortex. Endothelial cells which line these capillaries are of the "specific endothelial" type (see p. 832), showing pronounced phagocytic properties.

These vessels thus act as a filter or shield to the blood which reaches the medulla. The medulla is, moreover, the first tissue in the body to receive *cortin* or vitamin C from the cortical tissue.

Development of Suprarenal Glands.—The cortical system is a derivative of the cœlomic epithelium (mesoderm). Proliferative activity in this layer between the root of the mesentery and the mesonephros is evident at the 7 mm. stage, when numerous buds of cells develop from the deep surface of the mesothelium. These cells rapidly form a mass of cortical cells separate from the mesothelium. In Man the greater part of that tissue is ultimately included in the suprarenal cortex, but small masses may separate off, sooner or later, to form either independent cortical bodies or portions of accessory suprarenals (see p. 802). At the 12 mm. stage the main cortical mass is seen to lie in a tailward prolongation of the dorsal portion of the pleuro-peritoneal membrane called the suprarenal ridge (Zuckerkandl, 1912).

Meanwhile the sympatho-chromaffin primordium of the medulla has appeared, as early as the 5 mm. stage. The cells of that tissue early make contact with the cortex-primordium and commence to invade it at the 14 mm. stage. About this time adrenalin can be identified in the gland but the chromaffin reaction does not develop until considerably later, in the 22nd week (Lucas Keene & Hewer, 1927). Not until the 19 cm. stage does the immigrant chromaffin tissue reach the neighbourhood of the central vein and form a true medulla (Zuckerkandl, 1912). Envelopment of the medulla by the cortex is incomplete for a long time; this is probably due as much to progressive cortical overgrowth as to chromaffin invasion. Nerve-fibres and nerve-cells migrate into the gland at an early stage of development—fourteenth day of pregnancy in the mouse, one day after the primordium of the medulla first (McPhail & Read, 1942).

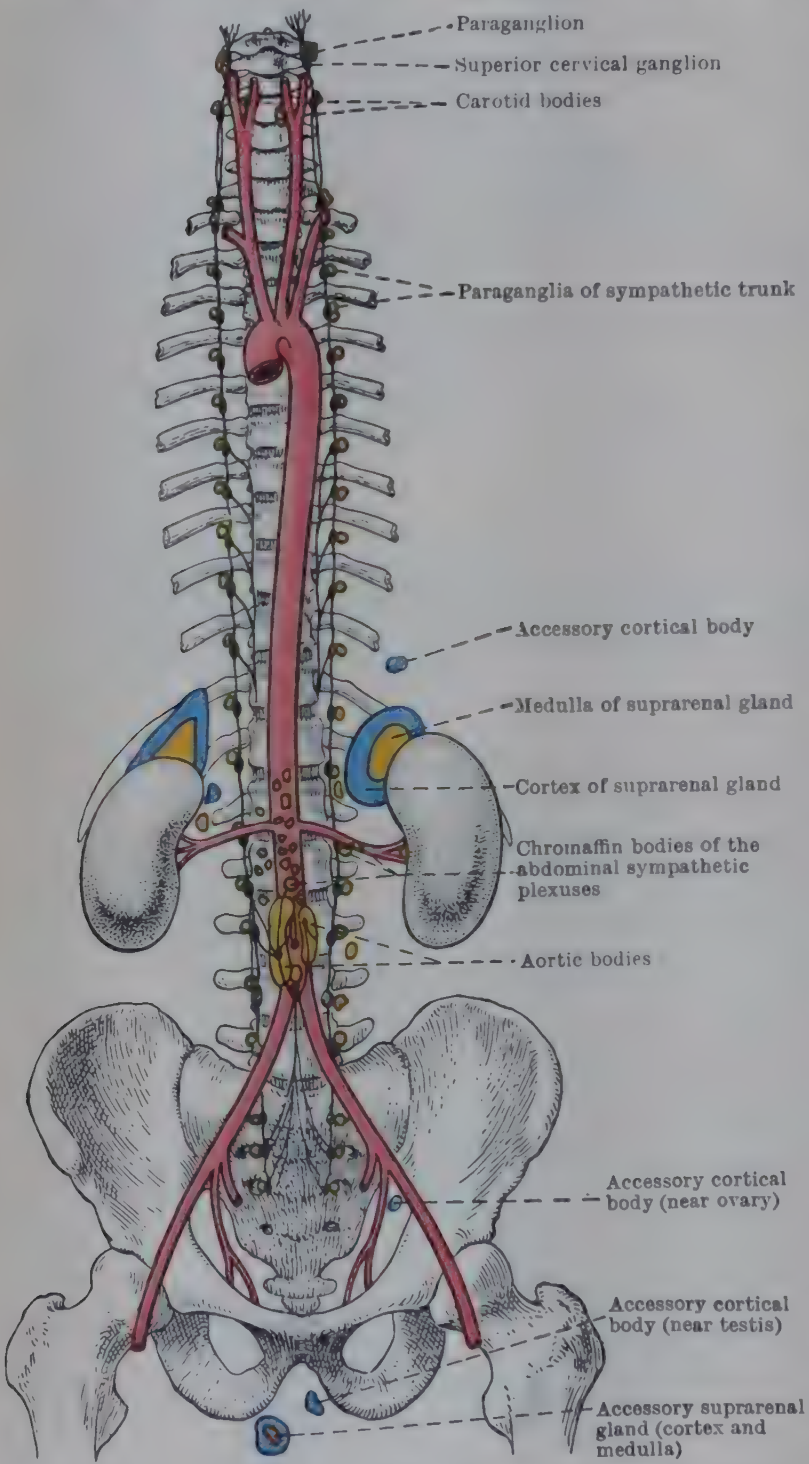

FIG. 687.—DIAGRAM OF THE CHROMAFFIN AND CORTICAL SYSTEMS. Modified from Swale Vincent (1922). Chromaffin tissue = yellow; cortical tissue = blue.

The relatively bulky *foetal cortex* degenerates progressively during the last ten weeks of intra-uterine life. At birth two parts of the cortex are distinguished, a still bulky fœtal cortex and a thin, overlying true cortex (Fig. 686). The characteristic cortical tissue of the fœtus disappears in the course of the first year and the volume of the entire cortex thus diminishes rapidly for a time. It is worthy of note that the small size of the suprarenal glands of anencephalic human fœtuses is due to the absence or the early atrophy of the fœtal cortex (Elliott & Armour, 1911); but the relation of this fact to the maldevelopment of the brain is obscure.

The final specialization of the cortex is not complete until much later. The definitive zona reticulata does not begin to appear until the fourth post-natal month, although the inner zone of the fœtal cortex is sometimes so named. The zona fasciculata is differentiated as such within three weeks after birth, but the zona glomerulosa not until the second or third years. Until then it appears to be represented by a layer of incompletely specialized cells immediately underneath the fibrous capsule. In the prepuberty period there is accelerated growth of the cortex; and in middle age its involution begins.

CHROMAFFIN SYSTEM

This system comprises a large number of masses of tissue similar in development, structure, and micro-chemical reactions to the medulla of the suprarenal gland.

The tissue is called chromaffin, or chromaphil, on account of its affinity for chromium salts, which give a brownish reaction with it. The general distribution of the masses of tissue which form the system is shown in Fig. 687. They all originate in intimate

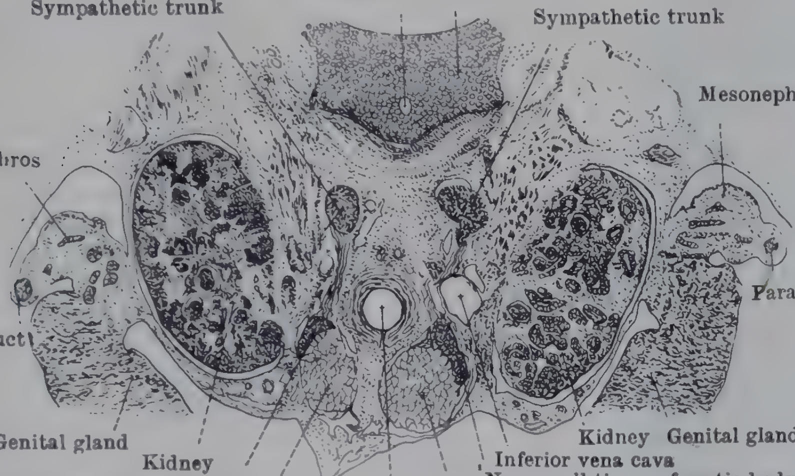

Fig. 688.—Transverse Section of Part of Abdominal Region of a 25 mm. Human Embryo. Seen from below, showing aortic bodies.

association with the rudiments of the sympathetic nervous system. Indeed, the characteristic chromaffin cells and the neurons of the sympathetic ganglia are derivatives from a common mother-cell. Chromaffin cells are innervated by preganglionic fibres and in this respect are comparable with postganglionic neurons.

The chromaffin system includes **paraganglia** associated with the ganglia of the sympathetic trunk and with the collateral ganglia of the abdominal region, but none, so far as is known, associated with the terminal sympathetic ganglia. It includes also the medullary portions of the suprarenal glands, and possibly the carotid bodies and the glomus coccygeum. While the similarity of all chromaffin tissue points to a common function, it is by no means certain that the paraganglia secrete a hormone like the adrenalin of the suprarenal medulla; but, like the secretory cells of the medulla, the paraganglia are innervated through preganglionic fibres (Hollinshead, 1937).

(i) The *paraganglia associated with the ganglia of the sympathetic trunk* are rounded masses of chromaffin tissue, 1-3 mm. in diameter, placed inside, half inside, or immediately outside the capsules of the ganglia. Typically one paraganglion, but occasionally more than one, is associated with each ganglion.

(ii) The *paraganglia of the sympathetic plexuses* occur both in association with the prevertebral ganglia and scattered throughout the plexuses. They may be very numerous—as many as seventy have been counted, though the number is usually much smaller. Increase in the number may be due to subdivision.

The most prominent paraganglia of the sympathetic plexuses are the two **aortic bodies** (aortic paraganglia) which lie anterior to the aorta in the region of the origin of the inferior mesenteric artery (Fig. 687). In the new-born child they are paired elongated structures, usually about a centimetre in length. Up to the age of 12-18 months they show increase in growth and in secretory activity. After the middle of the second year they—with many other paraganglia —undergo retrogressive changes. By the period of puberty they have practically ceased to be visible to the naked eye, though vestiges may be recognized, at least under the microscope, to a much later period of life. Even at the height of their development the aortic bodies are subject to considerable variation in size, form, and arrangement. They are commonly more or less asymmetrical and are often connected by a commissure. That appears to be a typical embryonic feature and is characteristic of the growth period, becoming progressively rarer during the period of decline. After the fourth year the commissure is no longer met with. In the vicinity of the aortic bodies there are numerous smaller masses of like character and of varying size and shape. Fig. 688 illustrates the relations of the aortic bodies to the structures in their vicinity. The darker stippled areas along the periphery of the bodies represent developing sympathetic ganglia of the abdominal plexus.

Paraganglia are found also in relation to viscera, where they may have originated in common with the 'peripheral' sympathetic ganglionic groups. The viscera to which they have been found related include the kidney and ureter, the suprarenal gland, the prostate, the paroöphoron and ovary, and the epididymis.

Carotid Body.—The carotid body is situated in close but slightly variable relation to the bifurcation of the common carotid artery (Fig. 689), adjacent to the carotid sinus (p. 1121). Frequently the gland lies deep to the bifurcation; sometimes it is wedged in between the roots of the internal and external carotids; sometimes it is placed between them at a slightly higher level.

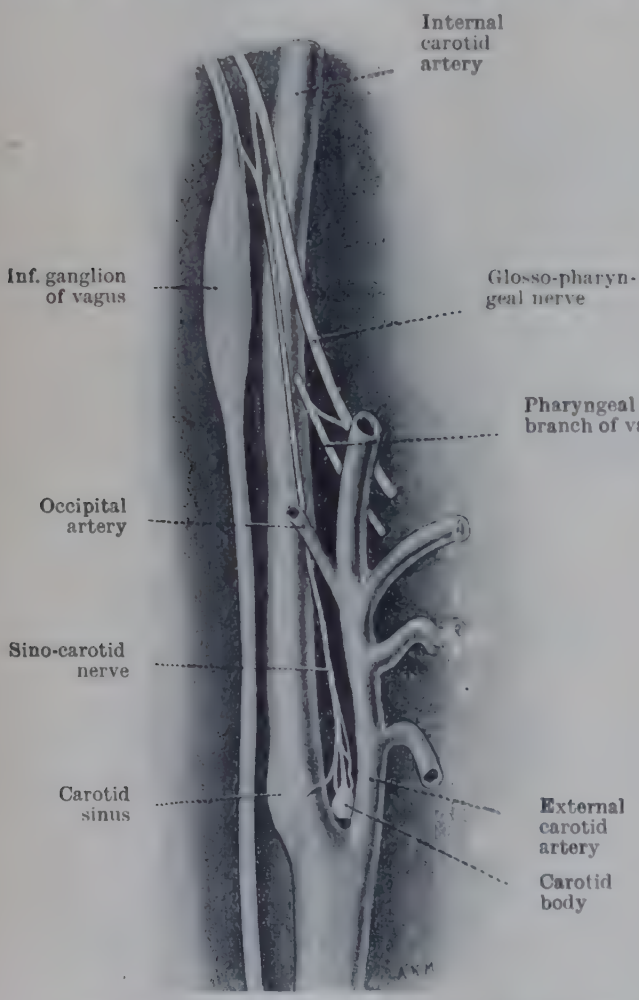

Fig. 689.—Carotid Body and the Sino-Carotid Nerve with its Principal Connexions.

It is a small neuro-vascular structure of a shape that varies with its position. When free from pressure from its surroundings it is oval; when situated between the internal and external carotids, it is wedge-shaped. On the average its height is about 7 mm., its breadth 1·5-5 mm. It sometimes comprises two or more separate nodules. Its colour is yellowish-grey to brownish-red.

Structure.—The carotid body consists of cellular groups or nodules surrounded by, and interspersed with, fibro-areolar tissue. The nodules are permeated by small arteries which are provided with abundant sensory nerve-endings. Some large chromaffin-like cells are present, and for this reason the carotid body has commonly been regarded as a part of the chromaffin system. Its structure and the abundant sensory nerves which pass into the sino-carotid nerve-plexus point, on the other hand, to a close relationship with the reflex depressor functions of the carotid sinus.

Nerve-Supply.—Numerous afferent nerves pass from the carotid sinus and carotid body to a *sino-carotid plexus*. From this plexus an *intercarotid* or *sino-carotid nerve* (Fig. 689) passes upwards with the pharyngeal branch of the glosso-pharyngeal nerve and divides into two branches, one of which joins the inferior ganglion of the vagus, the other the glosso-pharyngeal nerve. Other nerve-filaments from the plexus pursue an independent but similar course, and join the glosso-pharyngeal and vagus nerves and the cervical sympathetic trunk. The afferent fibres pass mainly to the glosso-pharyngeal nerve; but some of those from the *carotid sinus* join the vagus, and it is probable that some afferent fibres from the carotid body do so also.

Development.—The carotid body is developed as a condensation of mesenchyme around the third aortic arch (Boyd, 1937). Nerve-fibres of the glosso-pharyngeal nerve enter this condensation, and neuroblasts derived from the ganglion of the nerve subsequently migrate along the fibres into the developing organ.

Similar structures are developed in relation with the fourth and sixth aortic arches and form bodies which, on the left side, are adjacent to the aorta and the ductus arteriosus.

Glomus Coccygeum.—This is a small vascular body measuring 2-3 mm. in diameter. It lies immediately anterior to the tip of the coccyx in intimate relation with a branch of the median sacral artery and with the ganglion impar of the sympathetic trunks. Usually it is associated with a group of smaller bodies of similar structure.

Structure.—The glomus and its satellite bodies are enclosed in a fibrous capsule which ensheaths them individually. The characteristic feature of the glomus is the presence of masses of polyhedral cells, with large nuclei, surrounding the lumina of tortuous sinusoidal blood-spaces. From these spaces capillary channels extend among the investing masses of closely packed cells. Though they resemble the cells of the carotid body, none of the cells appear to give the characteristic chromaffin reaction ; hence, the paraganglionic nature of the glomus is extremely doubtful if not wholly excluded.

Development of Chromaffin System.—All chromaffin tissue develops in intimate relation with the sympathetic nervous system. The cells of both appear to be derivatives of a common mother-tissue whose elements in all probability originate from cells which migrate at an early period from the neural crest, or from the wall of the neural tube, or from both of those sources (see Development of Autonomic Nervous System, p. 1146).

In the 16 mm. embryo, sympatho-chromaffin tissue is met with in situations which more or less correspond to the distribution of the sympathetic nervous system. Differentiation of chromaffin cells from sympathetic neuroblasts begins about the 18 mm. stage (eighth week), but is not completed till late in the period of gestation, if then. The process is characterized by increase in the size of the chromaffin cells and a diminution of the intensity of their reaction to ordinary stains. Later, the specific chromic-staining reaction develops, but its period is uncertain and it may even fail to appear at all, as in the carotid body in some animals. It is stated that if any cells in a given area differentiate as chromaffin cells, all do ; so that, in spite of their intimate relationship and common origin, an intermixture of chromaffin and sympathetic cells is extremely rare.

The aortic bodies develop as the chief masses of a paired discontinuous series associated with the prevertebral plexuses. Cranially this series is originally continuous with the primordium of the medulla of the suprarenal gland on each side. The aortic bodies are prominent structures in the two-months embryo (see Fig. 688). The paraganglia associated with the ganglia of the sympathetic trunk appear a little later.

The earliest stages of development of the glomus coccygeum are still obscure. Its presence has not been recognized with certainty before the end of the fourth month of intra-uterine life. In support of the view of its sympathetic derivation is its indubitably intimate nervous connexion with the terminal ganglion impar of the sympathetic trunks.

CORTICAL SYSTEM

The single constant representative of this system in higher vertebrates is the mass of tissue that forms the **cortex of the suprarenal gland**. Masses of similar tissue, however, are not infrequently met with in various situations, forming **accessory cortical bodies**. The positions in the human body which may be occupied by accessory cortical masses are indicated in Fig. 687.

Accessory cortical bodies may be associated with chromaffin medullary tissue, as is the case in the suprarenal itself, but the majority, including the smaller bodies, are purely cortical. The justification for regarding the suprarenal cortex, with the occasional accessory cortical masses, as representing a distinct system, is based upon both phylogenetic and ontogenetic considerations. These warrant the conception of an originally more extensive distribution of cortical tissue, distinct from the chromaffin system. In the higher vertebrates the cortical system would appear to have undergone concentration, thus coming to be represented mainly by the cortex of the suprarenal gland.

COMPARATIVE ANATOMY OF CHROMAFFIN AND CORTICAL SYSTEMS

A knowledge of the main facts of the comparative anatomy of these systems throws light on their arrangement and function in man. Chromaffin tissue similar to that of mammals is found throughout the vertebrates, but its situation is different in various groups. In the Cyclostomata (*e.g.*, the lamprey) it is arranged in thin strips on the walls of the larger arteries. Cortical tissue, rich in lipoids, also is recognized ; it is arranged in small lobulated masses (the "inter-renal corpuscles") in the walls of the posterior cardinal veins and renal arteries. In the Elasmobranchii—the cartilaginous fishes of which the dog-fish is representative—chromaffin bodies are arranged segmentally (the so-called "suprarenals") in close relation to the ganglia of the sympathetic trunk. The cortical tissue in these fish is represented by a pair of yellow "inter-renals" in the region of the kidney.

It is only in the Tetrapoda (vertebrates possessing paired limbs) that cortical tissue and chromaffin tissue come into intimate topographical relation. Thus, in the Amphibia there is a composite organ—the "adrenal"—which is applied to each kidney. The greater part of each mass is made up, as in Man and other mammals, of columns of cortical cells, but at the borders of the gland collections of chromaffin cells occur. Among the higher Tetrapoda the detailed relation of the cortical and chromaffin tissues varies. In the Sauropsida (reptiles and birds) the chromaffin tissue almost completely surrounds the cortical or "inter-renal" tissue, whereas in Mammalia the cortical tissue encloses the chromaffin tissue.

The very long phylogenetic history of both chromaffin and inter-renal tissues points to the fundamental part played by endocrine systems similar to that of the human suprarenal gland in the co-ordinating hormone-apparatus of vertebrates generally. It seems possible that the paraganglia and the accessory cortical bodies of Man have endocrine functions similar to, if not identical with, the medulla and cortex respectively of the suprarenals, but definite confirmation of this is not yet available. Nor is it yet known what differences of function are brought about by the difference of topographical relationship between the "inter-renal" and chromaffin tissue in Amphibia, Sauropsida and Mammalia respectively. Differences of detail in the Mammalia include a tendency to folding or convolution of the suprarenal cortex in Man and various other primates, and variations in the number of accessory cortical bodies. In some mammals (*e.g.*, the rabbit) they are numerous; in others (*e.g.*, the dog) they are rare—facts which have a bearing on the interpretation of the results of extirpation experiments.

For further information, consult the monographs of Bourne (1949) and Hartman & Brownell (1949).

Organs of the Pharyngeal Pouches

This group of organs is developed from epithelium derived from the embryonic pharynx, and they illustrate an advanced stage in the histological differentiation of endocrine glands (see pp. 799, 800).

In an early phase of vertebrate evolution, entodermal epithelium lined the recesses of the pharyngeal cavity, and in one instance—the thyroid—it was sufficiently elaborated to justify the appellation of an exocrine gland (as still seen in the larval lamprey—see p. 815). Subsequently the epithelium of the recesses acquired specific endocrine functions and was isolated during embryonic development from the general pharyngeal epithelium to form separate extra-pharyngeal organs.

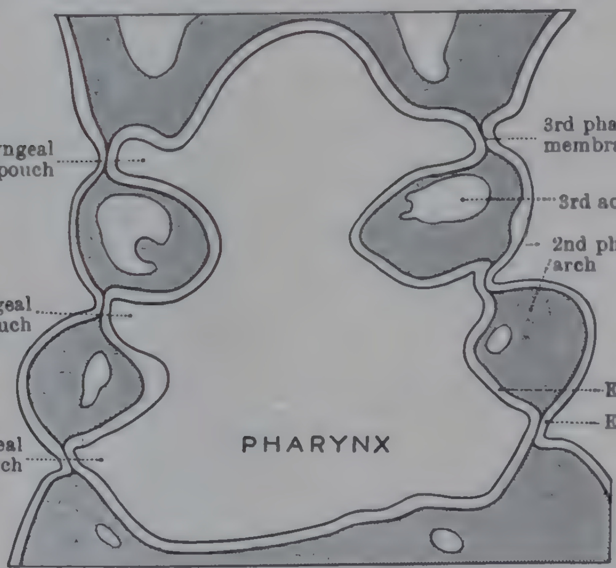

Fig. 690.—Section through Pharynx of 4 mm. Human Embryo, showing the Pharyngeal Pouches and Membranes. (After Norris, 1938.)

Early Development of Pharynx.—In the Section on Embryology, a description is given of the processes which lead to the formation of the embryonic mouth and pharynx (pp. 62-65). The primitive pharynx is formed from the cephalic part of the fore-gut and is brought into continuity with the oral pit by the breaking down of the *bucco-pharyngeal membrane* (Fig. 75). The position of that membrane is such that the greater part of the floor of the mouth is derived from the fore-gut and is therefore lined with entoderm.

The part of the fore-gut which forms the primitive pharynx is flattened dorso-ventrally and has narrow side-walls that consist of alternate thick and thin portions (Fig. 83, p. 68). The thickenings are termed **pharyngeal arches**, and they contain the *aortic arches* (p. 91 and Figs. 85, 690, 691).

The first pair of thickenings form the caudal boundary of the mouth, and each is called a **mandibular arch**; the second pair are the **hyoid arches**. Externally the arches are separated by depressions called *external pharyngeal grooves*; internally they are separated by pockets of the cavity called *pharyngeal pouches* (Fig. 690). Between successive pharyngeal arches the ectodermal lining of the grooves makes contact with the entodermal lining of the pouches, so that there is merely a thin "pharyngeal membrane" separating the cavity of the pharynx from the exterior (Figs. 690). In gill-breathing animals these

membranes disappear when the gill-slits are formed. At a later stage branchial branches of certain cranial nerves (5th, 7th, 9th, and 10th) grow ventrally through the pharyngeal arches (Fig. 912, p. 1048); and later still cartilaginous bars (pp. 204, 207) are formed within the arches.

Only the first four *separating membranes* become so thinned that entoderm and ectoderm make contact, and in the case of the fourth membrane this phase is of short duration. The fifth and other pharyngeal pouches are probably represented by a ventral diverticulum known as the *ultimo-branchial recess* or "caudal pharyngeal complex", which opens along with the fourth pouch and at no time comes close to the surface; there is, indeed, no external pharyngeal groove corresponding to it (Fig. 691).

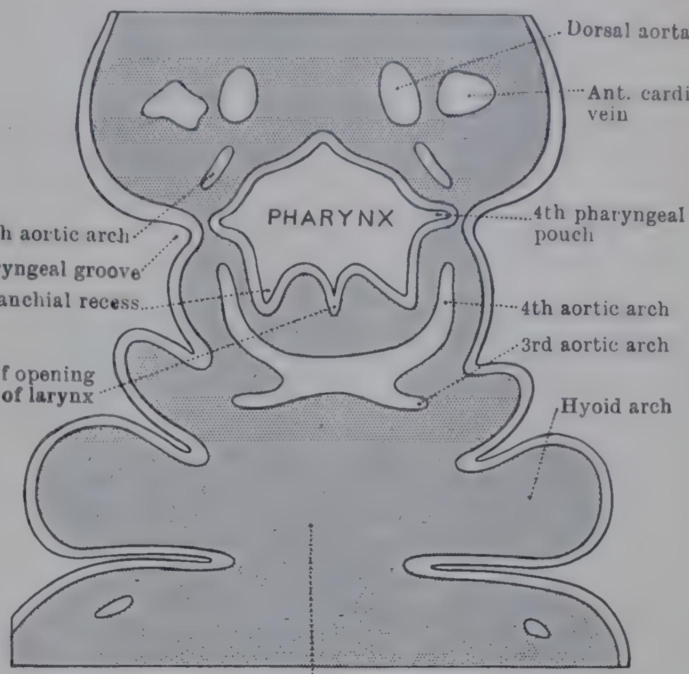

FIG. 691.—SECTION THROUGH PHARYNX OF 4·9 MM. HUMAN EMBRYO, showing the Fourth Pharyngeal Pouch and the Ultimo-Branchial Recess. (After Norris, 1938.)

In embryos of 6 mm. length the second or hyoid arch is already becoming more prominent externally than the third arch. It gradually overlaps this arch and the pharyngeal wall behind it, so as to enclose a deep external recess—the *cervical sinus*—which communicates with the exterior only by a small opening (Fig. 81). Eventually this opening becomes closed and a small cavity, derived from the cervical sinus and therefore lined with ectoderm, remains embedded in the wall of the pharynx; it is known as the *cervical vesicle*. The vesicle is situated opposite the third pharyngeal pouch, but for a short time a narrow passage or "branchial duct" leads forwards from this vesicle to the second separating membrane. The epithelial cells of the vesicle later acquire an intimate relation with the epithelium of the third pharyngeal pouch, forming with it the primordium of the thymus (Norris, 1938). Portions of the cervical sinus may occasionally persist in the form of a slender tubular channel (branchial fistula) which opens to the exterior on the lower part of the neck, or a portion may be closed off within the neck to form a "branchial cyst".

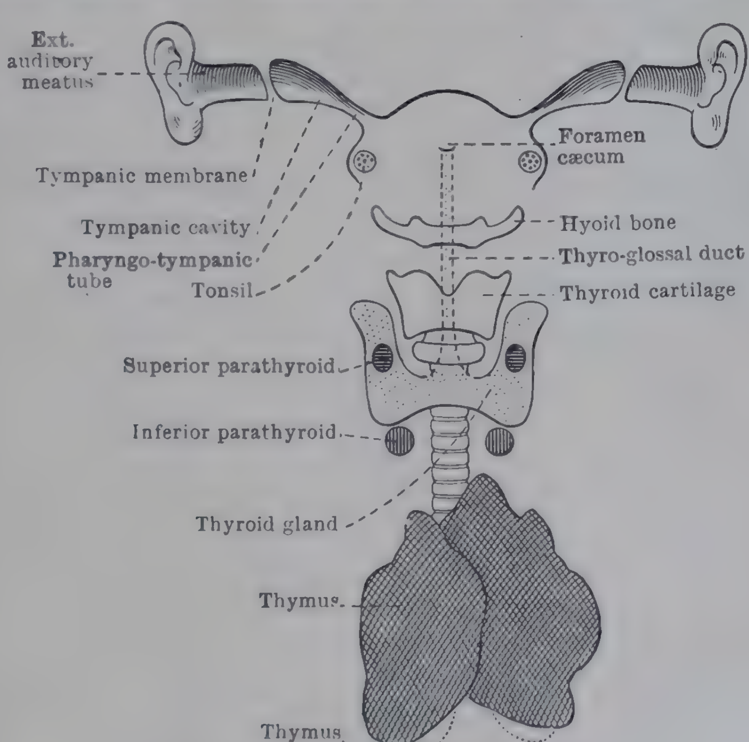

FIG. 692.—SCHEMA SHOWING SOME OF THE DERIVATIVES OF THE PHARYNGEAL POUCHES, AND THE THYRO-GLOSSAL DUCT.

Fate of Pharyngeal Pouches (Fig. 692).—The **first** and **second pharyngeal pouches** are concerned in the development of the *tympanum* and the *pharyngo-tympanic tube* (p. 67).

The third and fourth pouches, in embryos 10 mm. in length, have become small cavities connected to the pharynx only by narrow canals (Fig. 696); shortly afterwards the stalks of connexion are interrupted, leaving small balls of cells (of entodermal origin) embedded in the pharyngeal wall. At the time of its isolation from the pharyngeal wall the **third pouch** consists of (1) a small, hollow, dorsal diverticulum, from which a *parathyroid gland* develops, and (2) a caudally directed cylinder of cells which grow from its ventral

side and are destined to contribute to the formation of the *thymus* (p. 821). The cervical vesicle, which is closely applied to this thymic diverticulum (as described above), probably also contributes to the thymus.

The **fourth pharyngeal pouch** (with the ultimo-branchial body) of each side forms a small, hollow mass at the time of its separation from the pharynx. This becomes differentiated into two parts—a dorsal portion from which a *parathyroid gland* is developed (p. 817), and a ventral portion which is believed to contribute to the *thyroid gland* (p. 814).

Floor of Pharynx.—At a stage when the cephalic part of the fore-gut is still cut off from the exterior by the bucco-pharyngeal membrane, there is to be seen a minute diverticulum in its floor, known as the **median thyroid diverticulum** (Fig. 75). The margins of the opening become raised up to form a swelling called the *tuberculum impar* (pp. 70 and 814)—a mass of tissue which is eventually incorporated in the tongue. The original site of formation of the median thryroid diverticulum is marked permanently by the foramen cæcum.

THYROID GLAND

The **thyroid gland** is situated in the lower part of the front of the neck, and is enclosed in a fascial compartment formed by the sheath of pretracheal fascia which fixes it firmly to the trachea and larynx. The thyroid is an endocrine gland which produces a hormone of the greatest importance for the proper growth and function of most of the tissues in the body. This hormone is known as *thyroxin*. Characteristic of this organ is the storage of its secretion within small closed cavities—the vesicles of the thyroid. It is an organ of very ancient history, yet one that exhibits remarkably little evolutionary change, for its histology and endocrine action are similar throughout the whole series of vertebrates. The gland is yellowish red, soft, and extremely vascular; in this last respect it surpasses all other organs in the body excepting possibly the suprarenal glands. It varies in size with age, sex, and general nutrition, being relatively large in youth, in women, and in the well nourished. In women it increases temporarily with menstruation and pregnancy. Its average dimensions are: height 5 cm., breadth 6 cm., thickness of each lobe 1-2 cm.; and its weight is 18-31 gm. (Nolan, 1938). The maximum weight is attained in the young adult, apart from abnormal enlargements.

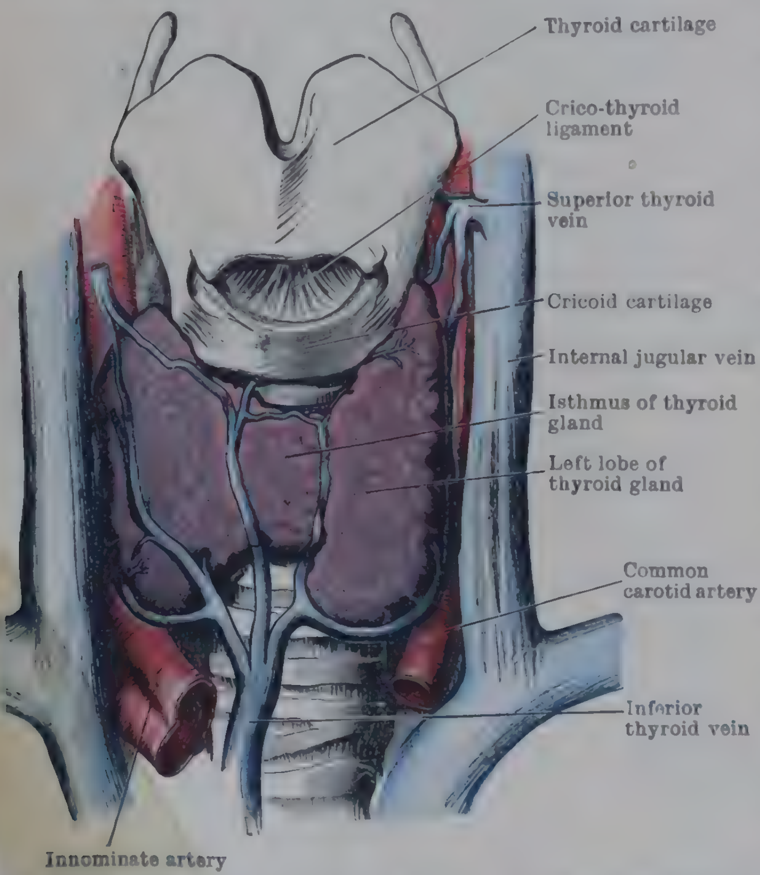

FIG. 693.—DISSECTION OF THYROID GLAND AND OF STRUCTURES IN IMMEDIATE RELATION TO IT.

Usually the thyroid gland consists of a pair of conical **lobes** united across the median plane by a short band of gland-tissue called the **isthmus**. But to many thyroid glands this description is inapplicable. In men and thin elderly women the gland is not uncommonly horseshoe-shaped; in young well-nourished women and during pregnancy its general contour is more rounded, deeply notched above to accommodate the larynx and deeply grooved behind for the trachea and œsophagus. Rarely, the gland is in two separate parts. Not infrequently, it is asymmetrical. In about 40 per cent of specimens, a process of gland-tissue called the **pyramidal lobe** extends upwards from the upper border

of the isthmus, in front of the cricoid and thyroid cartilages, towards the hyoid bone. That process is seldom median, lying more often on the left than on the right ; in rare cases, it is double ; less rarely, it is double below and single above ; sometimes it is represented by a strip of fibrous tissue or a narrow muscle (m. levator glandulæ thyreoideæ). The muscle may, however, be present independently of the pyramidal lobe (see Development, p. 815).

Small oval accessory thyroid glands are common in the region of the hyoid bone, and are occasionally met with in relation to the right and left lobes. They may occur also in the superior mediastinum of the thorax.

Relations.—The gland itself has an external layer of fibrous tissue—the fibrous capsule—which is loosely connected by areolar tissue to the fascial sheath ; the gland with its capsule is thus readily taken out of its sheath of pretracheal fascia. It is under cover of the sterno-thyroid, sterno-hyoid, and omo-hyoid muscles, and, more laterally, it is overlapped by the sterno-mastoid (Fig. 380). The isthmus is, however, comparatively superficial between the margins of the sterno-thyroid muscles a short distance above the suprasternal notch. The isthmus usually lies on the front of the 2nd, 3rd, and 4th rings of the trachea ; but occasionally it lies as high as the cricoid cartilage or as low as the 4th, 5th, and 6th rings of the trachea. The lobes extend down to the level of the 6th ring of the trachea or even lower, and up as far as the middle of the thyroid cartilage. Superficially they are covered by the muscles mentioned, along with twigs of the ansa hypoglossi and the anterior jugular vein. The upper part of each lobe is moulded medially on the thyroid and cricoid cartilages together with the crico-thyroid and inferior constrictor muscles ; the external laryngeal nerve passes across the surface of the constrictor. The lower part is moulded on the sides of the trachea and œsophagus and thus comes into close relation with the recurrent laryngeal nerve.

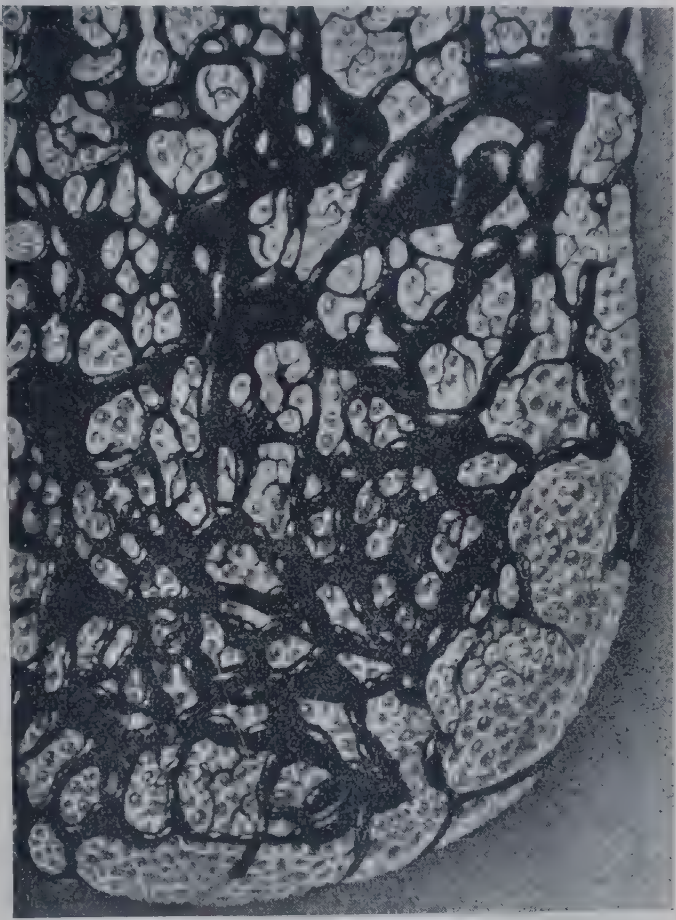

Fig. 694.—Surface View of Dog's Thyroid Gland (slightly magnified) showing individual vesicles and the injected extraglandular plexus of lymph-vessels. (Rienhoff, 1931.)

The posterior surface of each lobe is variable in width. It is in relation to the longus cervicis muscle, and more laterally to the carotid sheath, which becomes displaced in a postero-lateral direction by simple enlargements of the gland. The inferior end of the left lobe approaches or even makes contact with the thoracic duct. Closely applied to the posterior surface, within the fibrous capsule, are the two pairs of parathyroid glands ; they may even be embedded within the substance of the thyroid.

Vessels and Nerves.—The extraordinarily rich **arterial supply** is effected through the *superior* and *inferior thyroid arteries*. Occasionally (10 per cent. of cases) **a** fifth artery—the *thyroidea ima*, normally present in the embryo—persists in the adult. It is usually a branch of the innominate. The pyramidal lobe, if well developed, receives a special branch from one of the superior thyroid arteries, usually the left. The arteries are remarkable for their large size and for the frequency and freedom of their anastomoses. An anastomosing trunk courses up over the back of each lobe within the fascial sheath and unites the inferior and superior thyroid arteries ; it is of interest in connection with the identification of the parathyroid glands (q.v.). Typically, three pairs of **veins** drain the gland. The upper two pairs—the *superior* and *middle thyroid veins*—join the internal jugular veins ; the lower pair—the *inferior thyroid veins*—join the innominate veins. The veins take origin from the venous plexus on the surface of the gland or, in the case of the inferior, from a downward extension of the plexus in front of the trachea. When the gland is very large, accessory veins are present, sometimes in considerable

numbers. Most of them pass to the internal jugular veins. A free, transverse, venous anastomosis is effected along the borders of the isthmus through superior and inferior communicating veins.

The **lymph-vessels** pass directly from the subcapsular plexus to the *deep cervical lymph-glands*; a few descend in front of the trachea to the *pretracheal lymph-glands*, through which they are connected with *innominate glands* behind the manubrium sterni.

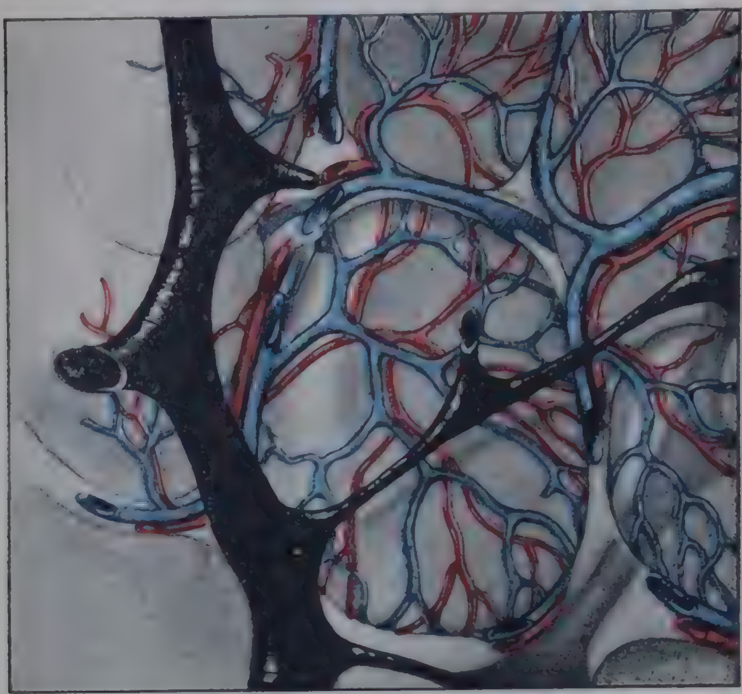

FIG. 695.—INJECTED SPECIMEN OF DOG'S THYROID GLAND. Enlarged drawing demonstrating the relative size of the lymph-plexus and blood-capillary plexus and their relation to the individual vesicles. Note that the lymphatic plexus (black) lies external and in less intimate contact with the individual vesicles than the blood-capillary plexus, which is specific for each vesicle. (Rienhoff, 1931.)

The **nerves** are non-medullated post-ganglionic fibres which come from the *superior* and *middle cervical sympathetic ganglia*. They reach the gland by way of the cardiac and the superior and recurrent laryngeal nerves, and along the superior and inferior thyroid arteries. Some of the nerve-fibres are vasomotor, and others end in close relation with the epithelial cells of the vesicles of the gland—though as yet they have not been shown to be secretory in function.

Structure.—The gland consists of a mass of minute, rounded vesicles, of various sizes and commonly about 300 μ in diameter (Figs. 694, 701). Each vesicle consists of a layer of epithelial cells enclosing a mass of colloid. Microscopic study of living cells has shown that the epithelial cells produce cytoplasmic processes which extend into the lumen of the vesicle, a process which is associated with the addition of colloid to the lumen (Williams, 1941; see also de Robertis, 1942). They are embedded in a framework or stroma of fibrous tissue which is continuous externally with the capsule. Numerous lymph-vessels, arteries, veins, and nerves course in the stroma. The lymph-vessels appear to be mainly concerned in the drainage of the intervesicular tissue (Figs. 694, 695); the larger trunks pass to a dense plexus on the surface of the gland.

Development.—The thyroid gland is developed from a median ventral diverticulum of the floor of the pharynx (p. 812 and Fig. 75); a contribution is possibly derived also from the caudal pharyngeal complex (ultimo-branchial recess, p. 811). According to Weller (1933) the median diverticulum forms the isthmus and a small part only of each lobe. It appears in embryos less than 2 mm. in length (possessing about six mesodermal somites) as a small out-pocketing of the pharyngeal floor. The tuberculum impar (p. 812) at first surrounds the opening of the diverticulum but later is entirely anterior to it. The diverticulum by rapid downgrowth soon forms a plate-like structure ventral to the trachea, connected by a narrow tube called the *thyro-glossal duct* with the pharyngeal floor.

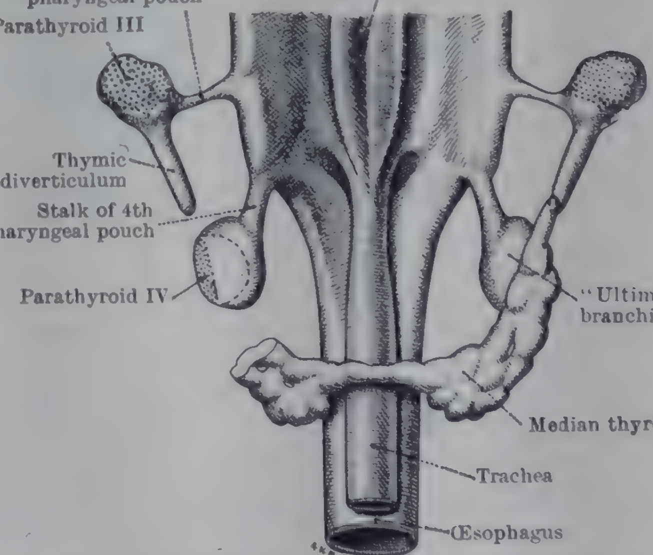

FIG. 696.—DIAGRAMMATIC VENTRAL VIEW OF WALL OF PRIMITIVE PHARYNX, SHOWING THE "PHARYNGEAL DERIVATIVES" IN AN EMBRYO OF THE SIXTH WEEK.

This duct disappears normally in embryos of six weeks, but a vestige of its original opening into the pharynx persists in the adult as the foramen cæcum of the tongue (p. 575). In the sixth week the fourth pharyngeal pouch, with its ventral diverticulum, is still connected by a narrow tubular stalk with the pharynx. At this stage the caudal pharyngeal complex becomes closely applied to the lateral portion of the thyroid gland. Weller (1933) and Norris (1937) confirm the view that it makes a contribution of thyroid tissue to the definitive gland. Even when, as occasionally happens, the median thyroid diver-

ticulum is defective in its development and fails to extend down the neck, there are nevertheless small portions of thyroid tissue formed in the neck, possibly derived from the ultimo-branchial recess.

Histological differentiation of the gland proceeds by the arrangement of the embryonic epithelial cells in two sheets, with disappearance of the original lumen of the diverticular primordium; this stage is followed by the formation of definite follicles in the 50 mm. foetus, which later become vesicular. Colloid material is present in the vesicles, and the lining cells are apparently active, in the foetus of eleven weeks. The median portion of the gland passes through the earlier stages of histological differentiation before the lateral portions, which, as stated above, are believed by some to arise from the caudal pharyngeal complex. Additional 'secondary' follicles are added throughout fœtal life but the process slows down before birth and probably ceases about puberty. Postnatal growth of the gland consists mainly in an increase in size of the vesicles.

The developmental history of the gland affords a ready explanation of its variations in the adult. Thus, the development of a pyramidal lobe and its variations, partial and complete duplication, are due to the development of gland-tissue from that part of the thyro-glossal duct which has a double lumen and the more or less complete fusion or separation of the masses thus formed. *Accessory thyroid glands* near the hyoid bone are the result of development of gland-tissue from isolated remnants of the duct. Their occurrence behind the sternum above the arch of the aorta is probably due to a downward displacement of thyroid tissue along with that vessel, with which the median thyroid diverticulum is in close relation at an early stage.

The occurrence in the adult of a duct that leads from the foramen cæcum to, or towards, the hyoid bone (*lingual duct*) is due to a persistence of the upper part of the thyro-glossal duct. Similarly, *thyro-glossal cysts* are due to the persistence of short segments of the duct. The thyro-glossal duct may be continuous with the pyramidal lobe (p. 812). It usually passes behind the hyoid bone although it is initially anterior to the second pharyngeal arch of the embryo; the change of relation is due to extension and growth of the primordium of the hyoid. A cyst-like derivative of the ultimo-branchial diverticulum is sometimes found in the adult in close relation with the lower pole of the lateral lobe of the gland.

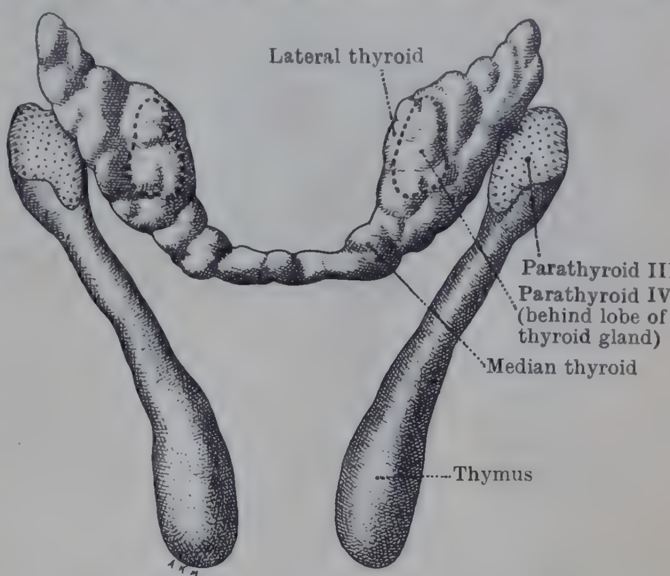

Fig. 697.—Thymus, Thyroid and Parathyroid Glands in an Embryo of the Seventh Week.

Comparative Anatomy.—A thyroid gland similar in structure and probably also in function to that of Man and other mammals is found throughout the vertebrates. In Cyclostomata (p. 809) it is isolated from the pharyngeal epithelium only in the adult; in the larval stage the specific thyroid tissue is situated at the sides of a diverticulum which has an opening on the floor of the pharynx. This diverticulum is elsewhere lined with ciliated epithelium and it appears to be representative of the same organ as the endostyle of the subvertebrate *Amphioxus*. The thyroid gland consists of two separate structures, right and left, in certain fish, amphibia, birds, and mammals. When this arrangement occurs in a mammal (as usually in the dog) it is probably the result of atrophy of the isthmus. It is uncertain whether any part of the thyroid is developed from a median pharyngeal diverticulum in submammalian vertebrates as it is in Man. Structures which appear to correspond to the human ultimo-branchial bodies are seen in vertebrates generally, forming in many of them small isolated **suprapericardial bodies** close to the pericardium.

Methods of Clinical Anatomical Examination.—The lateral lobe of the thyroid gland is felt indistinctly as a soft mass at the anterior border of the sterno-mastoid muscle on the side of the posterior part of the cricoid cartilage and of the adjacent part of the thyroid cartilage. The isthmus also can be felt as a soft swelling over a small part of the front of the trachea a short distance below the cricoid cartilage. When the larynx and trachea are pulled up in the movement of swallowing, the thyroid gland accompanies them. The gland is often large enough to produce an evident fullness of the neck; the sterno-mastoid can then be felt to lie superficial to the postero-inferior part of the lateral lobe.

PARATHYROID GLANDS

The **parathyroid glands** are two pairs of small glands closely applied to the back of the thyroid gland within its fibrous capsule (Fig. 698). They are distinguished as the superior and inferior parathyroid glands; but in reference to their developmental origin (q.v.), the upper pair are known also as the parathyroids IV and the lower pair as the parathyroids III.

The parathyroid glands produce a hormone which plays a part in maintaining the relation between the blood and the skeletal calcium. Possibly they produce another hormone. Extirpation of all four of the glands in a mammal causes death within a few days, but such is the margin of safety that removal of two of them produces no obvious effect. Parathyroids, unlike most glands, become enlarged as a result of underfeeding.

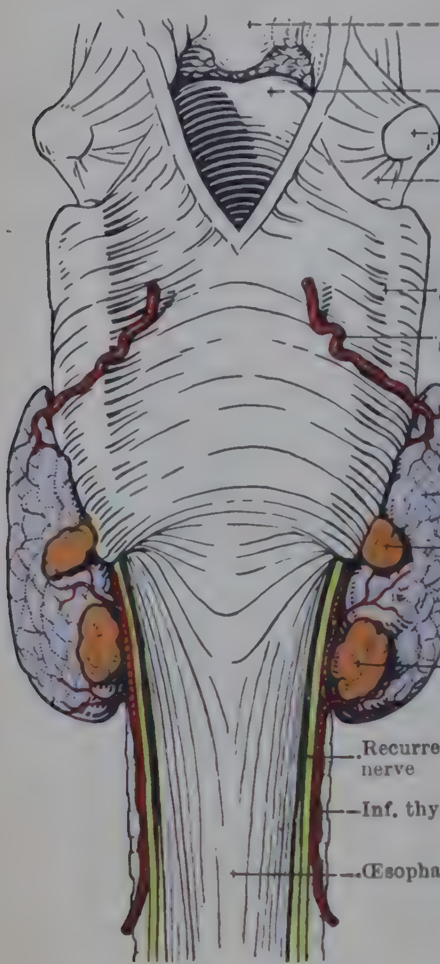

Fig. 698.—Dissection showing Thyroid and Parathyroids of Adult from Behind.

The parathyroid glands are yellowish-brown, ovoid or lentiform structures, varying in size between extremes of 1 to 20 mm. in their long (generally vertical) diameter. Most commonly they are from 5 to 7 mm. in length, 3 to 4 mm. in width, and 1 to 2 mm. in thickness. Their individual weights vary within wide limits. The total amount of parathyroid gland-tissue has been stated to show a mean variation from 0·8 to 1·2 gm.

The normal number of parathyroids may be diminished to three, two, or even one. In some such cases, however, it is not easy to be certain that a minute ectopic gland may not have escaped notice. On the other hand the number may be increased, probably as a result of division of the original primordia. Thus five to eight—even in an extreme case as many as twelve—have been recorded: the distinguishing numerals are then applied to the gland-groups attributed to the respective pouches. Six per cent of subjects have only three parathyroid glands, and in 6 per cent also there are five (Gilmour, 1938).

The **superior parathyroid gland** is usually embedded in the capsule of the thyroid gland at the back of the corresponding lobe, about its middle. The **inferior parathyroid gland** is similarly embedded on the back of the lower end of the lobe (Welsh, 1898). As a rule the anastomosing arterial channel which connects the inferior and superior thyroid arteries passes near both parathyroids and furnishes the best guide to them; but the range of exceptional positions which the glands may occupy is wide. Thus, the superior parathyroid may be found (1) behind the pharynx or œsophagus, (2) in the fibrous tissue at the side of the larynx, above the level of the thyroid gland, (3) behind any part of the corresponding lobe of the thyroid gland (Fig. 699) or even embedded in the thyroid substance ("internal parathyroid")

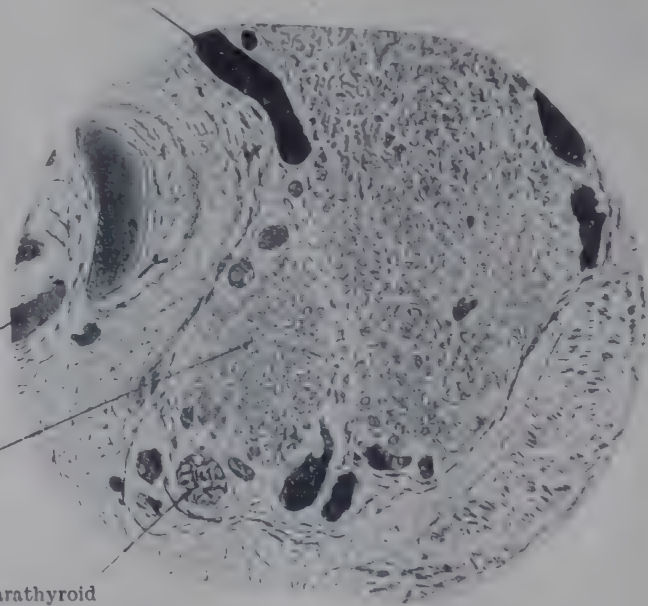

Fig. 699.—Oblique Section through Part of Trachea and Right Lobe of Thyroid Gland of Human Fœtus 60 mm. long, showing a Parathyroid embedded in the Capsule of the Thyroid Gland.

(Fig. 700); whereas the inferior parathyroid may be found (1) near the bifurcation of the common carotid artery, (2) behind any part of the corresponding lobe of the thyroid gland, (3) on the sides of the trachea, or (4) in the thorax close to the thymus. This wide range of variation in position is explicable by the close association of the inferior parathyroid with the main thymus element in development (see below).

Fig. 700.—Oblique Section through Part of Trachea and Left Lobe of Thyroid Gland of Human Fœtus 60 mm. long, showing a Parathyroid embedded in the Thyroid Gland.

Vessels and Nerves.—The **artery** to each parathyroid may spring from any branch of the *inferior* or *superior thyroid arteries*, but most commonly is a branch of the large anastomosing vessel between them. The **lymph-vessels** drain with those of the thyroid gland. The **nerve-supply** is abundant and comes from the plexus surrounding the thyroid gland (*v. supra*). The parathyroids produce their hormone after transplantation; the nerves are apparently vasomotor and not secretory.

Structure. — The parathyroids are built up of interconnected trabeculæ of epithelial cells with only a little vascular tissue between them. Sometimes the cellular arrangement is of a more compact character, or again, some of the cells may be arranged in follicle-like clumps enclosing a colloid material (devoid of iodine). The "principal" cells, which contribute the majority, are large and clear; but, after the age of eight or nine, some of the cells contain acidiphil granules and are believed to be degenerating principal cells (Morgan, 1936).

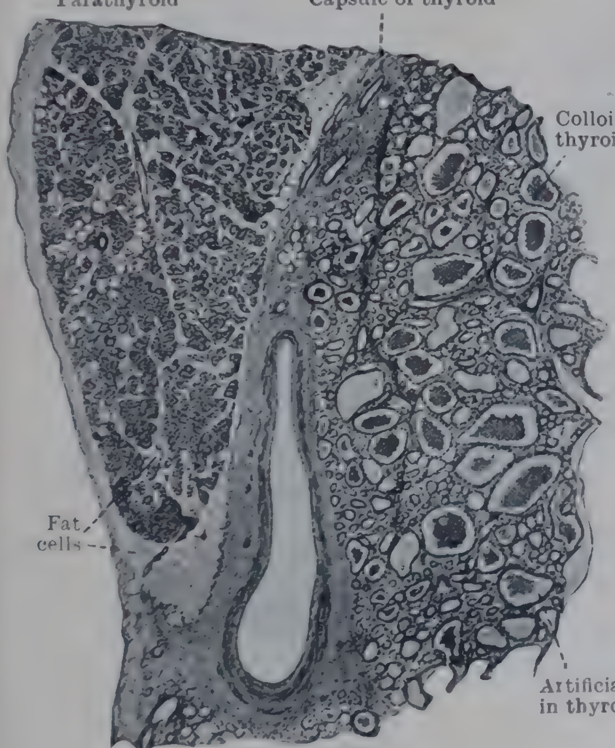

Fig. 701.—Section through Thyroid and Parathyroid Glands (Maximow and Bloom, *Text Book of Histology*, after Braus).

Development. — The parathyroid glands develop from the dorsal diverticula of the third and fourth pharyngeal pouches (Fig. 696). The first indication of their development is a proliferation and thickening of the epithelium on the cephalic and lateral aspects of the diverticula. This thickening may be seen as early as the 10 mm. stage. Its cells are vacuolated, difficult to stain, and indistinct in outline. Cords of cells grow out from the thickening, and fibrous tissue penetrates between the outgrowing cords, which soon lose their connexion with the pharynx.

Parathyroid III—the inferior parathyroid of the adult—is normally drawn by the thymus, as it migrates, caudal to parathyroid IV. As a rule it halts at the level of the lower end of the lobe of the thyroid gland, but may continue its descent into the thorax. On the other hand it may not descend at all. In the latter case it remains near the bifurcation of the common carotid artery, where it is liable to be mistaken for the carotid body. (For details of development, consult Norris, 1937.)

Comparative Anatomy.—Parathyroid glands occur throughout the Tetrapoda (p. 810). In some reptiles they are stated to develop from the second pharyngeal pouch as well as from the third and fourth. In certain mammals, *e.g.*, the mole, only those which are formed from the third pouches are developed.

History.—The parathyroid glands are notable historically as the last of the essential organs of the higher vertebrates to be described. They were discovered in 1877 by Ivar Sandstrom,

then a student of Medicine in Upsala. He published his account in 1880 (when he was Prosector in the Department of Anatomy at Upsala) with illustrations of the glands in the dog, cat, ox, horse, rabbit, and Man.

THYMUS

The **thymus** is situated in the superior mediastinum between the sternum and the great vessels; and it usually extends down for a short distance into the anterior mediastinum in front of the pericardium. In the new-born child (in which it is relatively much larger than in the adolescent or adult) it commonly extends laterally between the thoracic wall and the anterior borders of the pleuræ and lungs (Fig. 702).

The thymus is essentially an organ of the growth-period of life. In the course of a few years after birth it shows a rapid diminution in the rate of its growth; but it continues to grow until puberty, and it is only after that period of life that it undergoes a gradual diminution in size (Young & Turnbull, 1931).

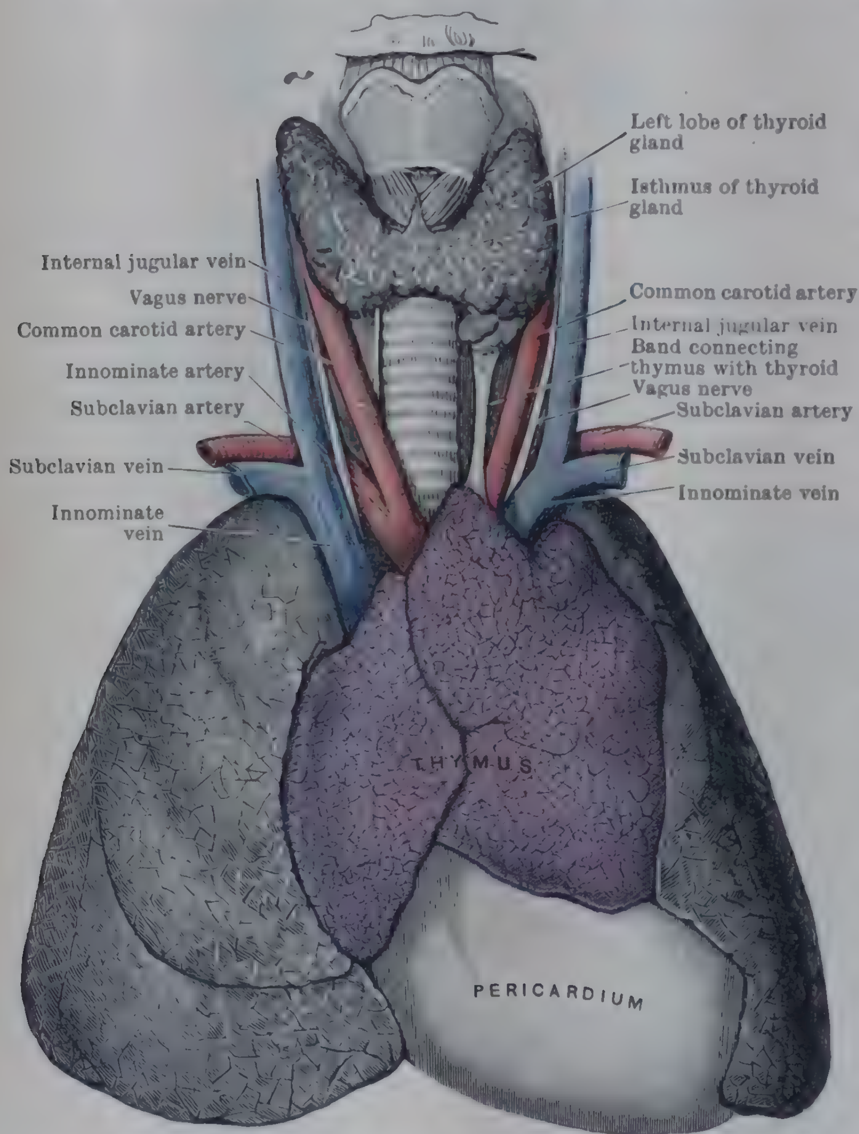

Fig. 702.—Thymus and Thyroid Gland in a Full-Time Fœtus hardened by Formalin Injection.

During the period of its fuller development the thymus appears as a pinkish mass (yellower in later life), consisting of a pair of laterally compressed, more or less pyramidal, asymmetrical lobes. The lobes are connected with each other, not by any bridge of glandular tissue but by areolar tissue.

The surface of the organ, in the young, more actively glandular condition, is finely lobulated.

The thymus is soft in consistence, and the details of its shape are determined by its size and by the structures upon which it is moulded, namely, the pericardium and the great vessels of the superior mediastinum and the root of the neck. Its shape varies with its size and the age of the individual. In infants (with short thoraces) it is broad and squat; in adults (with long thoraces) it is drawn out into two irregular but more or less flattened bands (Fig. 703).

It is in relation posteriorly from below upwards with the pericardium, ascending aorta, left innominate vein and the trachea with inferior thyroid veins. Anteriorly it is related to the sternum and the lower ends of the sterno-thyroid muscles. In the young child the lateral margin is insinuated between the pleura and the upper costal cartilages, intercostal spaces and internal mammary artery.

There is great individual variation in its size at any given age. Thus, at birth it ranges in weight from 2 to 17 gm. with an average of about 13 gm. At puberty the thymus is usually at the height of its development with an average weight of 37 gm.; but sometimes it has already undergone considerable retrogression. In the young adult the average weight is reduced to about 25 gm. even at the age of 30, but the organ is occasionally still quite large.

In old age it commonly weighs only about 10 gm. These age-changes point to some relationship with growth and the attainment of maturity (see Structure, p. 820).

Variations of the form as well as in the size of the thymus sometimes occur,

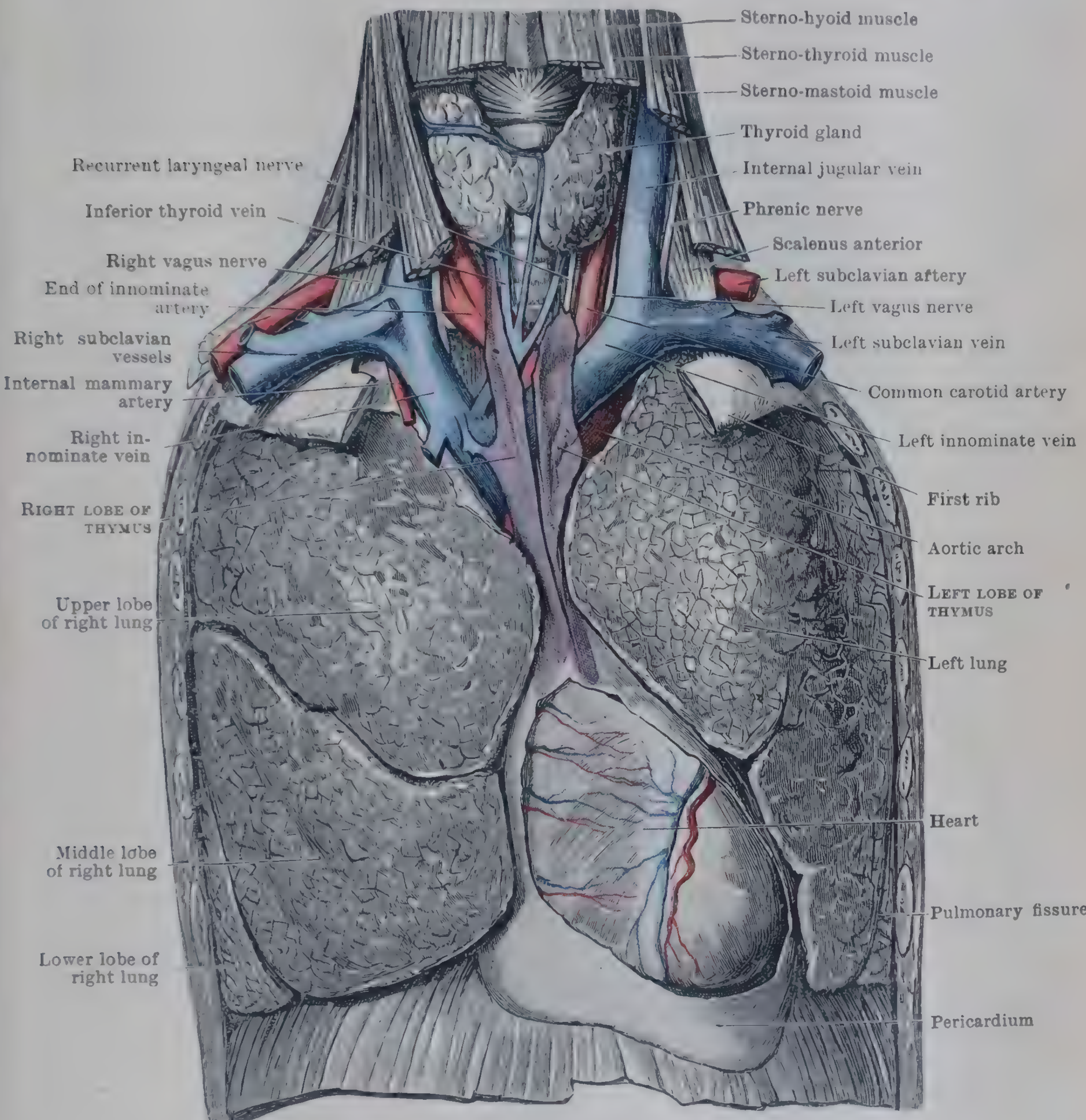

FIG. 703.—DISSECTION TO SHOW THYMUS IN AN ADULT FEMALE.

attributable to a partial persistence of the slender stalks by which at first the developing thymus remains attached to the third pharyngeal pouches. Thus, the thymus may exhibit slender prolongations into the neck on each side, antero-lateral to the trachea. These processes may be connected to the lower parathyroid glands by strands of fibrous tissue (Fig. 705); or again, the whole of the cervical processes may be represented by fibrous strands (atrophic cervical thymus). An isolated portion of thymus tissue may persist in close relation with the lower parathyroid (accessory cervical thymus III).

Vessels and Nerves.—The **arterial** supply of the thymus is effected through inconstant branches, chiefly of the *internal mammary arteries* and their branches. Its **veins** are irregular and mostly join the internal mammary and left innominate veins. Its **lymph-vessels** are abundant. Although they are not related to the organ in the same manner as in a lymph-gland,

they have been found filled with lymphoid corpuscles presumably derived from the gland. They enter the *innominate lymph-glands.*

Its **nerves** are minute and are derived from the vagus and the sympathetic. The branches of the *vagus* descend directly to the thymus from about the level of the thyroid cartilage; the *sympathetic* fibres run with the blood-vessels. The fibrous capsule of the thymus receives small irregular branches from the phrenic nerves, but they do not supply the gland-tissue.

Structure.—The thymus is invested by a fibrous capsule which sends septa into its substance between its constituent lobules. The two "lobes", though really independent paired glands, are also bound together more or less intimately by their capsular investments. If the young gland is dissected so as to liberate its *lobules* from the fibro-areolar tissue between them it will be found to consist of an elongated series of lobules, each connected with a central parenchymatous cord along which they are arranged in irregular necklace fashion. The cord, mainly

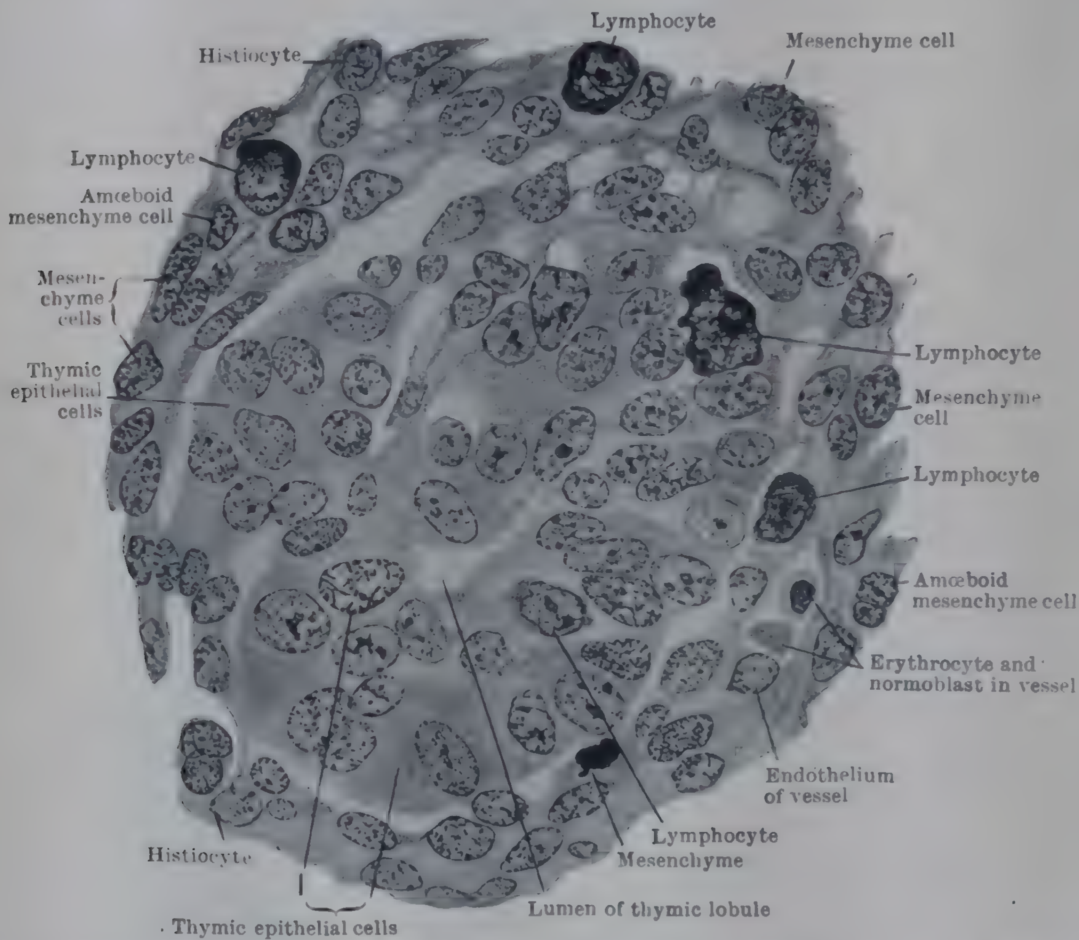

FIG. 704.—SECTION OF EMBRYONIC THYMUS OF RABBIT. (Maximow and Bloom, *Text Book of Histology.*) A hollow lobule is surrounded by mesenchyme in which some histiocytes of the reticulo-endothelial system are seen. Lymphocytes are present both around and among the thymic epithelial cells.

of medullary substance, represents the original thymic diverticulum of which the lobular masses are secondary derivatives.

The lobules of the thymus are further subdivided into *secondary lobules* which average a little over a millimetre in diameter. They are imperfectly separated from one another by delicate areolar tissue. These are the units of thymic structure: each shows a cortex and a medulla. The *cortex* consists of closely packed lymph-cells ("thymocytes") embedded in a delicate fibrous reticulum. It contains no lymph-vessels. The cortex completely surrounds the medulla, which is continuous with that of adjacent lobules and, through the lobular stem, with the central cord of the gland.

In its intimate structure the *medulla* differs from the cortex in the presence of many reticular cells and fibres but only few lymphocytes. The medulla, further, contains the so-called "corpuscles of Hassall", which are concentrically arranged nests of epithelioid cells varying in size from about 25 to 75 μ in diameter. The central cells often show granular degeneration. They vary in number not only in different individuals but also at different periods of life. In a general way the structure of the thymus follicle resembles that of a lymph-gland, but there are neither lymph-sinuses nor germinal centres. The vascular tissue elements and some associated areolar tissue are derived from invading mesenchyme during the course of development.

The thymus appears, then, to have some special relation with the cellular constituents of the vascular system. It has been claimed that it has an endocrine function with an influence on the growth of the gonads; and there is little doubt that it plays a part in regulating the growth of the body as a whole (Rowntree *et al.*, 1935). The process of involution, by which there comes

about a great reduction in the size of the gland after puberty, is influenced by the secretions of various endocrine glands. A persistently enlarged thymus is associated with delayed sex-development and obesity.

Development.—As has been stated, there are in reality two organs. The paired thymus glands, or "lobes", right and left, arise from the ventral diverticula of the third pharyngeal pouches and the adjacent cervical sinus (p. 811). The first indication of the thymus is seen in the 9 mm. embryo, when the third pouch has developed a caudally-directed cylindrical elongation. At this stage the part of the cervical sinus adjacent to the pouch remains connected to the exterior by a narrow stalk only, which is immediately afterwards interrupted, leaving a "cervical vesicle" adjacent to the pouch.

The pharyngeal pouch at the 9 mm. stage displays a differentiation of the cells in its dorsal wall—the primordium of the parathyroid (III) gland. The remainder of the pouch-wall shows no specific histological differentiation. For a considerable time the only further sign of thymic development is seen in an extension of the area of contact of ectodermal cells of the cervical vesicle with the entodermal cells of the pharyngeal pouch.

The elongated thymic portion of the third pouch migrates tailwards to reach the pericardium at the 15 mm. stage. As a result of the migration the upper part becomes drawn out and normally disappears. It is in that process that parathyroid III is involved; it is attached to the upper part of the migrating thymus—the part which disappears (Fig. 697). The relative time of the disappearance determines the permanent level of parathyroid III, for until it happens that gland is dragged in the wake of the thymus (see p. 817). Sometimes a small detached mass of formative tissue of the thymus may persist beside parathyroid III, and may differentiate to form an Accessory Cervical Thymus III (Fig. 705).

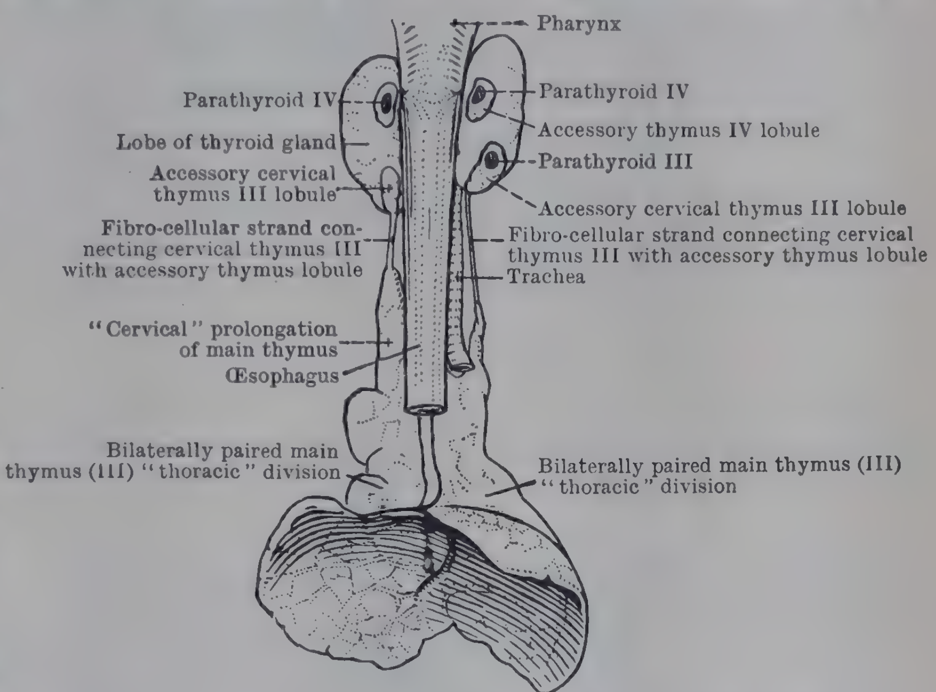

FIG. 705.—ILLUSTRATING ACCESSORY THYMUS LOBULES DESCRIBED BY GROSCHUFF (1900).

The thymus soon becomes isolated from the parathyroid (22 mm. embryo) and becomes a closely packed cellular mass. The mass of cells is penetrated shortly afterwards by mesenchyme and blood-vessels; and reticular fibres, apparently derived from the blood-vessels, make their appearance between endodermal cells (Norris, 1938). Thymocytes appear in the 8th week, probably derived from the invading mesenchyme. The differentiation of cortex and medulla is visible soon afterwards. The concentric corpuscles are derived from the endoderm of the pharyngeal pouch.

The growth of the thymus and its involution after puberty have been described above (p. 818).

THYMUS IV VESTIGES (*vide* Fig. 705).

Small accessory masses of thymus tissue are, in very rare instances, found in close relation to parathyroids IV. They are developed from the ventral diverticula of the fourth pharyngeal pouches in a manner generally similar to that in which the main thymus gland develops from the third. Although extremely rare in Man, such accessory thymic derivatives from the fourth pharyngeal pouch are not uncommonly met with in other mammals. They must not be confused with the accessory thymic lobules referred to in the preceding paragraph, which are to be regarded as detached portions of the cervical part of the main thymus. The accessory thymus IV may, as in some animals (*e.g.*, the cat), be enclosed, along with an "internal" parathyroid IV, in the substance of the thyroid gland, thus forming a so-called "internal thymus".

Methods of Clinical Anatomical Examination.—In children the apex of the thymus extends above the level of the manubrium sterni; but it is only occasionally recognizable on palpation as a soft mass situated in front of the trachea slightly to the left of the median line and behind the infrahyoid muscles.

HYPOPHYSIS CEREBRI

The **hypophysis cerebri** is a small gland of duplex origin. It forms a median basal appendage of the hypothalamns, behind and below the optic chiasma

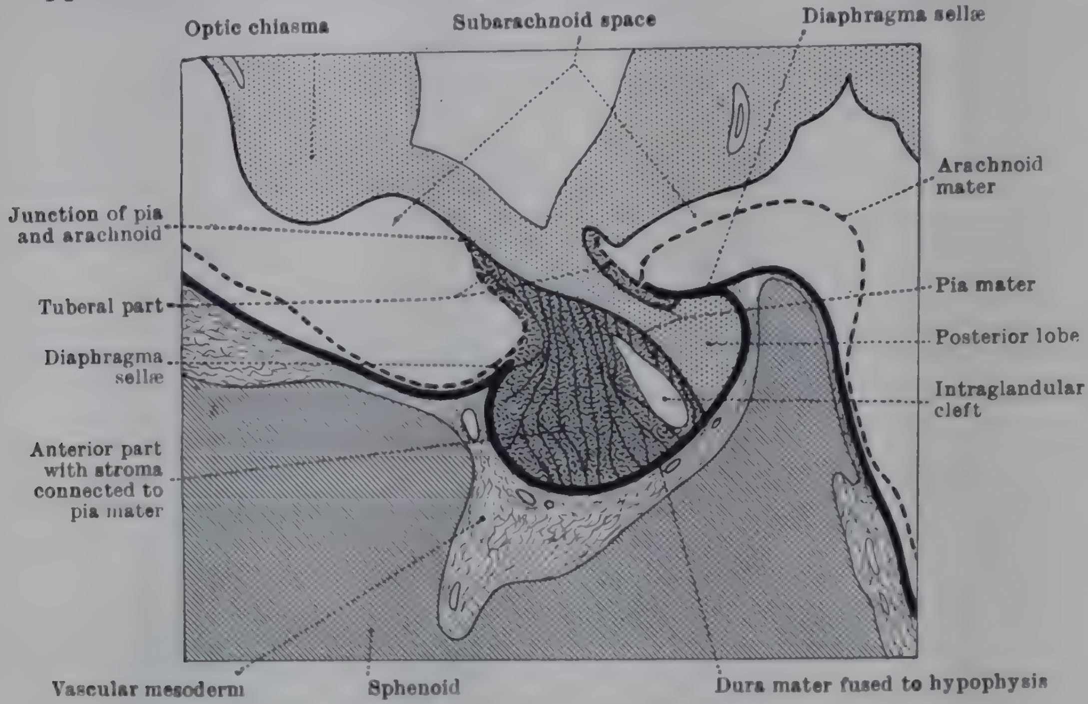

FIG. 706.—DIAGRAM OF RELATION OF MENINGES TO HYPOPHYSIS IN 160 MM. HUMAN FŒTUS. (After Wislocki, 1937.)

(Figs. 707, 708). It is lodged in the hypophysial fossa, between the cavernous sinuses and above the hinder part of the sphenoidal air-sinuses. It was formerly known as the *pituitary body* from an old notion that it secreted the nasal mucus.

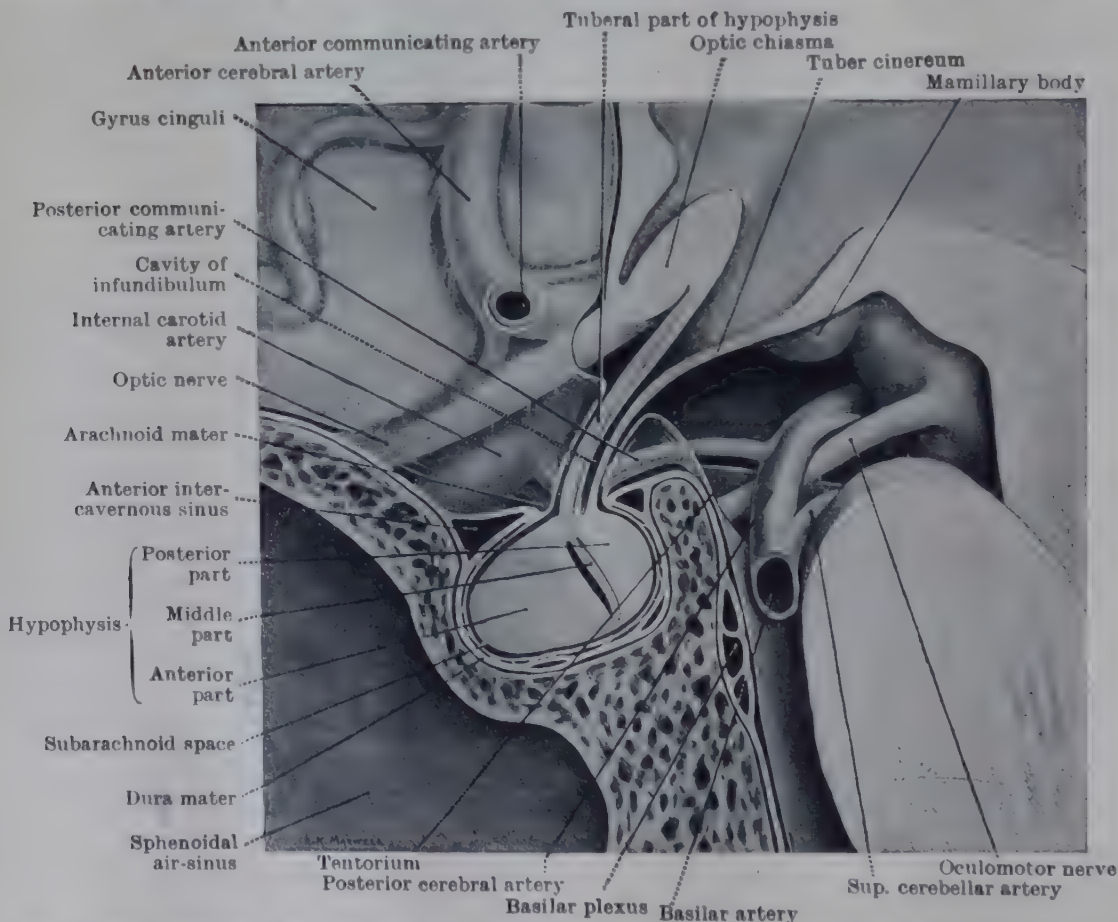

FIG. 707.—DIAGRAMMATIC MEDIAN SECTION OF HYPOPHYSIS *IN SITU*, SHOWING THE PARTS OF THE ORGAN AND ITS RELATIONS TO ADJACENT STRUCTURES. (The existence of a subarachnoid space around the gland in the hypophysial fossa is doubtful, cf. Fig. 706.)

Relations.—It occupies the hypophysial fossa (Pl. LXXIII, p. 944) between the dorsum sellæ behind, and the tuberculum sellæ in front. This cavity is lined with dura mater and roofed over by the diaphragma sellæ. According to Wislocki (1937), no separate arachnoid or pial covering is formed around the hypophysis (Fig. 706) below the level of the diaphragma sellæ (see Development, p. 827). Through a small aperture in the diaphragma sellæ, the infundibulum connects the main portion of the hypophysis with the tuber cinereum of the floor of the third ventricle. The cavernous sinus is lateral to the hypophysis, and the intercavernous sinuses pass below, behind, and in front of it. The internal carotid artery, in the cavernous sinus, is a fairly close lateral relation to the hypophysis, and more distantly, to the lateral side, are situated the oculomotor, trochlear, and abducent nerves and the ophthalmic division of the trigeminal nerve. The anterior part of the diaphragma sellæ intervenes between the anterior part of the hypophysis and the optic chiasma, which, however, is about one-third of an inch above the diaphragma. The interpeduncular cistern, with the contained circulus arteriosus, surrounds the infundibulum above the diaphragma sellæ. The sphenoidal air-sinus is situated below and in front of the hypophysial fossa, separated merely by a thin wall of bone; if small, it is an antero-inferior relation only. The close proximity of important structures to the hypophysis accounts for various symptoms associated with pathological enlargement of the gland (as in acromegaly). Enlargement of the anterior part of the hypophysis tends to thrust the forepart of the diaphragma sellæ upwards and to cause bitemporal hemianopsia through pressure on the more anterior fibres in the optic chiasma. An enlarged hypophysis sometimes also gives rise to symptoms which are due to encroachment upon the roof of the sphenoidal air-sinus or to pressure upon the cavernous sinus and the oculomotor and abducent nerves. Enlargement may be recognized radiographically through the expansion of the hypophysial fossa produced by it.

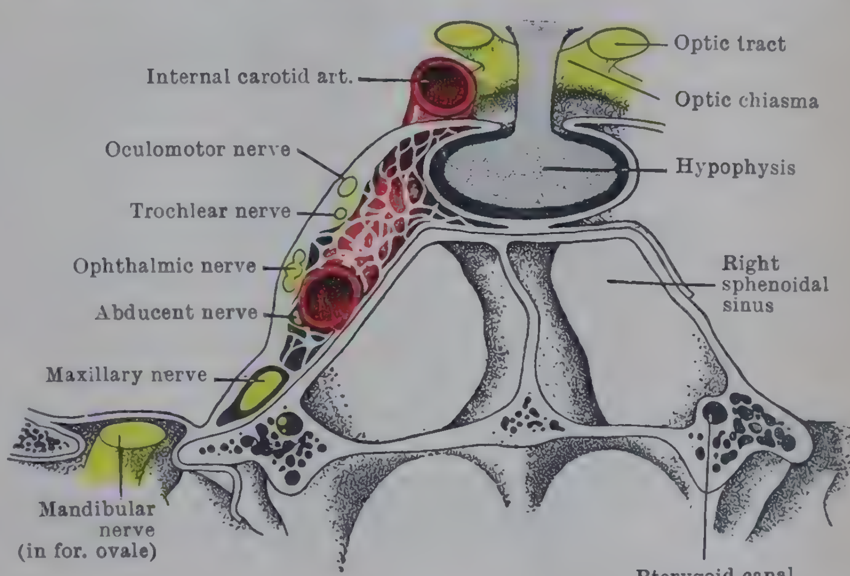

Fig. 708.—Diagrammatic Coronal Section through Cavernous Sinus showing the Relations of the Hypophysis. (Beesly and Johnston's *Manual of Surgical Anatomy*.)

The hypophysis is a rounded structure with the following average dimensions: 14 mm. transversely, 9 mm. antero-posteriorly, and 6 mm. vertically. It usually weighs a little over half a gramme. It undergoes some enlargement during pregnancy.

The following parts are distinguished (Figs. 707, 711):—

ANTERIOR LOBE: (1) Anterior part; (2) Tuberal part; (3) Middle part.

POSTERIOR LOBE: (4) Posterior or "nervous" part.

The **anterior part** of the anterior lobe forms the greater part of the entire gland and comprises its anterior and lateral portions (Fig. 712). It is separated (at any rate until middle age) by a cleft from the **middle part**, which is a very thin layer of tissue applied to the surface of the **posterior lobe** (Fig. 707). The **tuberal part** is a thin layer of tissue which encircles the front of the infundibulum, and extends as far as the tuber cinereum. When the infundibulum is cut across in the removal of the brain, most of the tuberal part usually remains adherent to the tuber cinereum. The weight of the middle part ranges

from $\frac{1}{2000}$ to $\frac{1}{50}$ gm. The anterior part weighs over half a gramme, and slightly more in women; it is five times as large as the posterior part, which contributes most of the remainder of the entire organ.

The hypophysis comprises two parts of different developmental origin, distinguished as the anterior lobe and the posterior lobe (Fig. 710). The anterior lobe is derived from Rathke's pouch, a diverticulum of the oral (stomodæal) pit (p. 63), the posterior lobe from a diverticulum of the floor of the diencephalon. The two parts are different in structure and function, but the line of demarcation between them becomes obscured by their very intimate union, and the infiltration of the part of neural origin by cells derived from the part of oral origin (Fig. 713). The hypophysis occupies a position of pre-eminence in the endocrine system in virtue of the control it exerts over most of the other endocrine glands by means of the various hormones it produces. For this reason it has been termed the " Master Gland ".

Vessels and Nerves.—The anterior and tuberal parts of the gland have an abundant **arterial supply**; that of the middle and posterior parts is relatively poor. A branch of the *internal carotid* artery enters the gland on each side at the junction of anterior and posterior lobes, and is distributed to both lobes. Other small arteries arise from the circulus arteriosus and reach the gland by passing down the surface of the infundibular stalk. Blood leaves the gland by means of **veins**

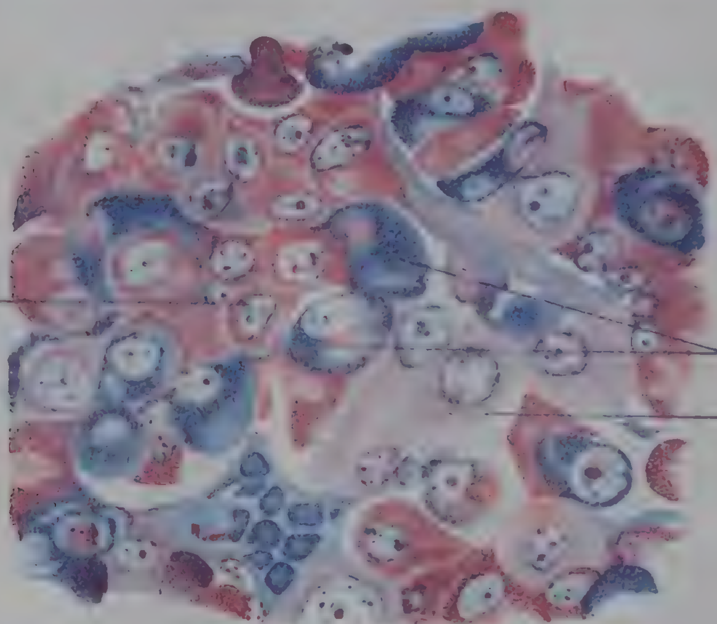

FIG. 709.—SECTION OF ANTERIOR PART OF PIG'S HYPOPHYSIS, stained with safranin-acid violet to show the three principal kinds of cell. (Maurer & Lewis, 1922.)

which pass into the *cavernous* and *intercavernous sinuses.* There is a series of fine channels in the walls of the infundibular stalk in which small particles of colloid are sometimes seen. According to Popa & Fielding (1930, 1933) these constitute a " portal " blood-system which conveys blood from the vessels of the hypophysis to a system of capillaries in the hypothalamus. Wislocki & King (1936), however, have adduced evidence which indicates that the flow of blood is in the reverse direction, viz., from the infundibular venules to the tributaries of the cavernous sinus; and this view has been confirmed by Harris (1947). **Lymph-vessels** have not been demonstrated in the gland.

The **nerves** of the anterior part are a rich supply of non-medullated fibres from the carotid plexus. While many of these are vasomotor in function, there are some nerve-fibres which have terminals in intimate relation with the epithelial cells and may be secretory in function. That the nervous connexions are not essential to all its endocrine functions is shown by the fact that grafts of the gland produce active secretions. The posterior lobe receives fibres from the supra-optic nucleus (Cajal) and from the paraventricular nucleus by a well-marked tract which runs along the infundibulum. The fibres end by forming a dense network around the small cells of the posterior lobe (see p. 825). Functionally there is a close connexion between the hypophysis and the hypothalamus (p. 948).

Structure and Function.—The *anterior part* of the **anterior lobe** is composed in the adult mainly of columns of epithelial cells supported by areolar tissue. In the central part of each half there is a vascular pocket of areolar tissue which contains vessels of considerable size. Capillaries pass from these vessels into intimate relation with the epithelial cells, and they eventually reach a vascular plexus on the periphery of the anterior part. The tubular arrangement of the epithelial cells seen in fœtal life disappears before birth. Vesicles of colloid

material are to be seen at all ages from the fourth month of intra-uterine life; colloid also appears in the intraglandular cleft.

Three principal kinds of cells are recognized: *Chromophobe, Acidiphil, Basiphil.* The chromophobe cells form about half the total number (Fig. 709); most of the remainder are acidiphils, basiphils forming only about one-tenth of the total.

The anterior part is known to produce numerous distinct hormones, several of which influence the activity of other endocrine glands. Since there are only three principal types of cell it is evident that one or more of them must produce more than one hormone. The growth-hormone appears to be derived from the acidiphil cells, and the hormone which influences the sex-glands from the basiphil. The precise source of the others is not known. The unequal distribution of basiphils and acidiphils in the anterior part (the former mainly peripherally and near the cleft) assists the comparative study of experimental injuries. Tumours consisting of the different types of cell produce different effects—basiphil ones causing obesity and various other changes, known collectively as Cushing's syndrome, acidiphil ones causing acromegaly. Various conditions have been recognized which appear to depend on hyposecretion, *e.g.*, the types of infantilism described by Simmonds and Lorain. A relation to periods of the œstrous cycle is indicated by the cyclic variations of cell-type in guinea-pigs. The condition of diabetes insipidus is thought to be due to a lesion of the posterior lobe or of the hypothalamus or of both.

Absence of the acidiphils is found to be related in mice to defect in respect of a certain gene; the effect on the sex-glands is then found to be present but not the growth-stimulating effect.

The *middle part* is almost avascular. It appears to be the least specialized portion of the hypophysis; it grows less, shows an accumulation of colloid, and occasionally has ciliated cells. No acidiphil cells are differentiated; chromophobes and basiphils are present. In the fœtus gland-tubules are present and open into the cleft, which is a vestige of the lumen of the buccal diverticulum (Rathke's pouch). These gland-tubules subsequently extend into the posterior lobe (Fig. 713); and basiphil cells also migrate from the middle part into the posterior lobe (Lewis & Lee, 1927).

The *tuberal part* consists mainly of small basiphil cells with small accumulations of colloid.

The **posterior lobe** or "nervous part" consists of a mass of neuroglia, and of small cells that resemble neuroglial cells. The invasion of this part by gland-tubules and basiphil cells from the middle part of the anterior lobe has been mentioned above. Thousands of nerve-fibres enter it from the hypothalamus; interruption of continuity gives rise to diabetes insipidus (p. 948). Small hyaline bodies described by Herring (1908), are found among these fibres (see Development, p. 827). Potent hormones are produced in the posterior lobe; *vasopressin* raises the blood-pressure and *oxytocin* causes uterine muscle to contract. It is not known whether the immigrant basiphil cells have the same function as those of the anterior lobe.

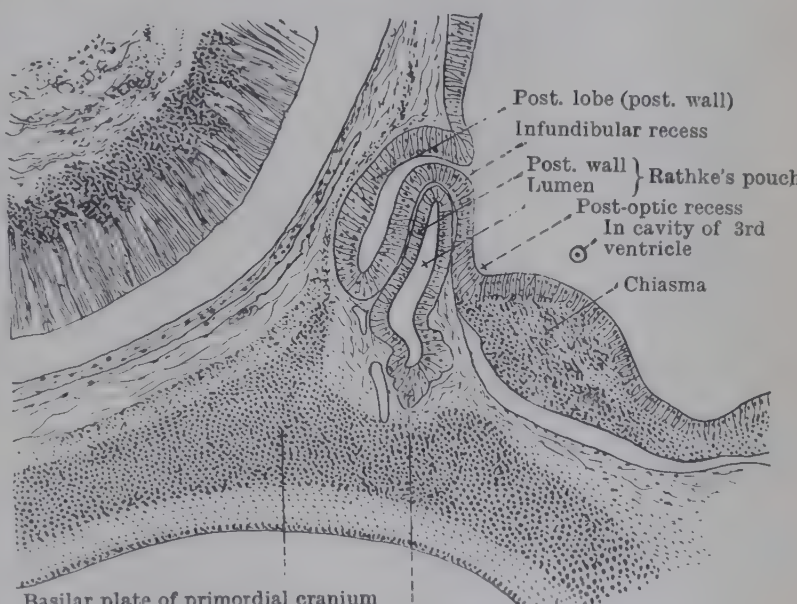

Fig. 710.—Paramedian Sagittal Section of Hypophysial Region of a Human Embryo (20 mm. CR Length).

Development.—As already mentioned, the hypophysis originates from two entirely distinct rudiments. Both of these are hollow ectodermal diverticula, one neuro-ectodermal, derived from the floor of the primary fore-brain, the other from the ectodermal lining of the primitive mouth-cavity. The buccal diverticulum, known as "Rathke's pouch", gives origin to the whole of the anterior lobe. The other diverticulum gives origin to the posterior lobe and the infundibulum.

The first indication of the appearance of the hypophysis is met with in embryos of 2-3 mm. in the shape of an angular depression at the bottom of the oral pit (p. 63) immediately in front of the dorsal attachment of the bucco-pharyngeal membrane. It deepens progressively, and in the 7 mm. embryo it has become a deep and wide saccular diverticulum, compressed antero-posteriorly, and opening by an aperture of equal width into the primitive mouth-cavity. The earliest indication of the appearance of the posterior lobe is a slight funnel-like depression in the floor of the fore-brain vesicle (Fig. 87, p. 71) in the 4-5 mm. embryo. At the 10-12 mm. stage the recess has become deeper and more sharply marked, and its anterior wall is already in close apposition with the fundus of the saccular anterior lobe. After the 12 mm. stage the portion of the buccal diverticulum nearest its mouth rapidly narrows and elongates to form a slender tubular stalk. By the stage of the 20 mm. embryo this stalk has become interrupted,

separating the embryonic anterior lobe from its original connexion with the epithelium of the mouth. Remnants of the obliterated stalk persist, not only at that stage but up to much later periods of intra-uterine life, and may sometimes be detected in the postnatal period. In some cases the basilar plate remains incomplete immediately around the stem of the hypophysis, so that a cranio-pharyngeal canal may be found later in the osseous cranial base and sometimes even containing vestiges of the epithelial tissue of the stalk.

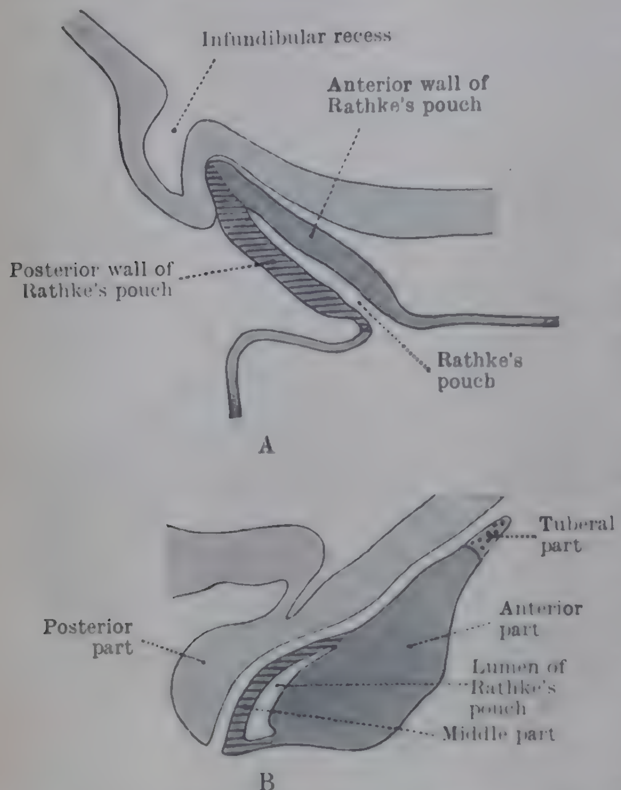

FIG. 711.—DIAGRAMMATIC MEDIAN SECTIONS OF HYPOPHYSIS IN EARLY STAGES OF DEVELOPMENT, showing (A) approximation of the infundibular recess to Rathke's pouch, and (B) the origin of the various parts of the organ. The posterior wall of Rathke's pouch develops into the middle part of the hypophysis, its anterior wall into the anterior and tuberal parts.

At the end of the second month the anterior lobe is a broad compressed sac, deeply notched for the reception of the posterior lobe. On each side of that notch the fundus of the sac is prolonged backwards in the form of paired hollow cornual extensions of the anterior lobe at the sides of the neck of the posterior lobe (they are already conspicuous in that situation in transverse sections as early as the 14 mm. stage). At the two-months period the original anterior surface of the sac has become secondarily cupped, its concavity now looking towards the floor of the brain in front of the infundibular region. The concavity is partially divided by a prominence in the middle into two fossæ which are occupied by tissue continuous with the surrounding mesoderm. These fossæ are presently invaded by the proliferating glandular cell-cords of the anterior wall of the sac during the process of formation of the anterior part of the organ. The bilateral pockets of areolar tissue, representing these mesodermal accumulations, were noted on p. 824 in the course of the description of the anterior part of the adult gland.

The recurved margin of the anterior lobe extends forwards and upwards towards the brain and eventually reaches the tuberal region of the floor of the diencephalon, where it spreads out to a greater or lesser extent as the tuberal part.

Up to about the 20 mm. stage the wall of the anterior lobe preserves its simple epithelial character. Already, however, it has begun to show indications of a process of proliferative budding (Fig. 710) and in this manner the cell-cords become intermingled with highly vascular mesenchyme which will form the sinusoidal stroma of the fully developed anterior part. In a fœtus of the third month (Fig. 712) the epithelial posterior wall of the anterior lobe is closely applied to the anterior surface of the posterior lobe and shows very little, if any, proliferative increase in thickness. It is this epithelial lamina which forms the middle part of the anterior lobe. In front of it the lumen of the anterior lobe of the hypophysis is still quite roomy. Later, it undergoes reduction and at least partial obliteration, for the "intraglandular cleft" or clefts which represent it become occupied by globules and irregular masses of colloid. The lumen shown in Fig. 712 does not, however, represent the whole of the earlier cavity of the anterior lobe, for portions of the sac become involved in the proliferative activity that produces the solid tissue of the anterior part.

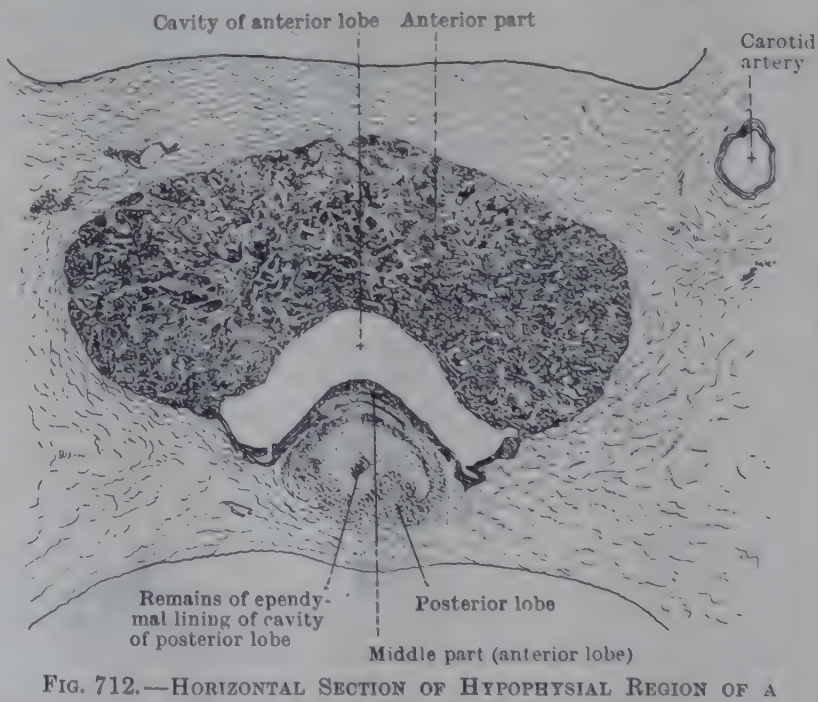

FIG. 712.—HORIZONTAL SECTION OF HYPOPHYSIAL REGION OF A HUMAN FŒTUS (71 MM. CR LENGTH).

During the course of development from the 20 mm. stage onwards the cavity of the posterior lobe in the human hypophysis tends to become obliterated, and finally the lobe becomes solid,

as does the infundibular stalk also. The lumen persists in the root of the stalk as the infundibular recess of the third ventricle.

In the later stages of antenatal growth there is a progressive invasion of the posterior lobe by glands and by basiphil cells that belong to the middle part of the anterior lobe, *i.e.*, to the posterior wall of the original buccal diverticulum. These glands undergo atrophy in the adult. The basiphil cells give rise to colloid and the hyaline bodies of Herring (1908), which have been supposed to consist of the same material in a different state. Replacement of worn-out cells is apparently not a feature of the adult hypophysis, for cell-division and degeneration of cells are seldom seen. The intraglandular cleft, commonly filled with colloid in the child, becomes obliterated in many adults, though in others it persists as a space still filled with colloid.

In the 20 mm. embryo the two lobes of the hypophysis are surrounded by mesenchyme, except where the infundibulum remains connected to the brain. This mesenchyme eventually differentiates into a lamina of dura mater which is firmly united both to the hypophysis and to the hypophysial fossa (Fig. 706).

Comparative Anatomy.—The hypophysis cerebri is an organ possessed of a very ancient history (de Beer, 1926). Its essential features are similar throughout the vertebrates, even those most primitive of all surviving vertebrates—the Agnatha (the class to which the Cyclostomata (p. 809) belong). An anterior lobe and a posterior lobe, developed in a manner similar to that described for Man, and with similar cellular constituents, are found in all of them. It has been settled experimentally that in the lower Tetrapoda (p. 810), *e.g.*, Amphibia, the hypophysis is an endocrine organ which produces hormones like some of those described in Man. The anterior lobe appears to have been originally an exocrine gland. Its essential cells are always developed from the epithelial wall of Rathke's pouch. In the Agnatha, as indeed in the modern fish *Polypterus* and probably also in various fossil ones, it remains in communication with the exterior throughout life, but the presence of masses of acidiphil and basiphil cells along the dorsal wall of the blunt end of the hypophysial sac suggests that already it possesses typical endocrine functions.

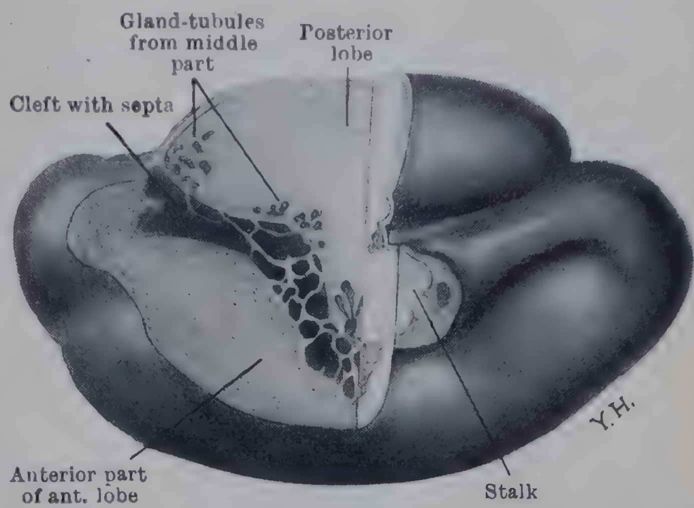

FIG. 713.—HYPOPHYSIS OF A CHILD, aged one year, with part removed to show the stalk and glandular tubules projecting from middle part of anterior lobe into posterior lobe (pars nervosa). (Lewis & Lee, 1927.)

This exocrine gland of the pre-vertebrates is perhaps represented by the ciliated organ of Müller in *Amphioxus*. To this organ endocrine functions were added in the evolution of the vertebrates, and an intimate relationship was established with the *neural hypophysis* or infundibulum, with the formation of the compound hypophysis characteristic of the vertebrates.

The actual orientation acquired by various parts of the hypophysis differs considerably in the various vertebrates. Thus, the anterior lobe of Reptilia acquires a position caudal and ventral to the middle part and posterior lobe. Amphibia exhibit a similar orientation of parts. In various Mammalia the hypophysis retains features which are lost in the course of human development. Thus, in the cat the posterior lobe remains patent and is lined with ependyma, and its cavity communicates with the third ventricle through a tubular infundibulum. Mammals differ greatly in the size and form of the middle part of the anterior lobe. It may, as in Man, form merely a thin sheet of tissue behind the intraglandular cleft. On the other hand, it may enclose the posterior lobe almost completely, as in the cat. Or it may be extremely thick, as in the ox.

PINEAL BODY

The **pineal body** is a small oval or cone-shaped structure, attached by a short, hollow stalk to the hinder end of the roof of the diencephalon, between the habenular and posterior commissures (p. 945 and Figs. 714, 764). It is moderately firm in consistence, reddish-brown in colour, and measures 5-10 mm. anteroposteriorly, 3-7 mm. in its other diameters. It weighs about one-fifth of a gramme. Much discussion has centred around its supposed endocrine function. There is, however, no definite evidence that it has any internal secretion; it appears to be a vestigial structure (see Comparative Anatomy). It commonly becomes calcified in middle age (see below).

Relations.—It is covered with pia mater, and it lies in the sulcus between the superior corpora quadrigemina. It is below the splenium of the corpus callosum,

from which it is separated by the great cerebral vein. Its posterior end is free, and is a short distance in front of the vermis of the cerebellum and the free edge of the tentorium (Fig. 827, p. 945).

The cavity of the stalk is the pineal recess of the third ventricle. On the dorsal lip of this recess is the habenular commissure. Immediately above the habenular commissure and the stalk of the pineal body is another and larger recess of the third ventricle called the suprapineal recess.

Structure.—The pineal body consists mainly of a mass of distinctive cells (the pineal parenchyma) interspersed with neuroglial cells. This tissue becomes divided into lobules by the ingrowth of septa of fibrous tissue from the pia mater—a process which takes place mostly during childhood. Vascularized fibrous tissue invades the organ during early intra-uterine life. The characteristic parenchyma-cells have long processes which end in bulbous extremities, some of which are on the surfaces of the lobules next to the intervening fibrous septa, and others within the lobule on the fibrous tissues which enclose the blood-vessels.

The body of each cell is rounded and has a large round nucleus and granular cytoplasm. They offer a marked contrast with nerve-cells—which are wanting in the pineal body except close to the habenular commissure. The granules of the cytoplasm have been claimed as being secretory in character, but they show no variation in number at different ages, nor does the pineal body display any differences in appearance under different physiological conditions. There is no evidence of histological change at puberty. Evidence in support of a suggested endocrine function is lacking. The non-medullated nerves which are found in the organ appear to be distributed to the blood-vessels. Calcareous deposits usually make their appearance in the organ from adolescence onwards, and the pineal body thus becomes visible in radiographs (Pls. LXXIII, p. 944, and LXXIV, p. 945).

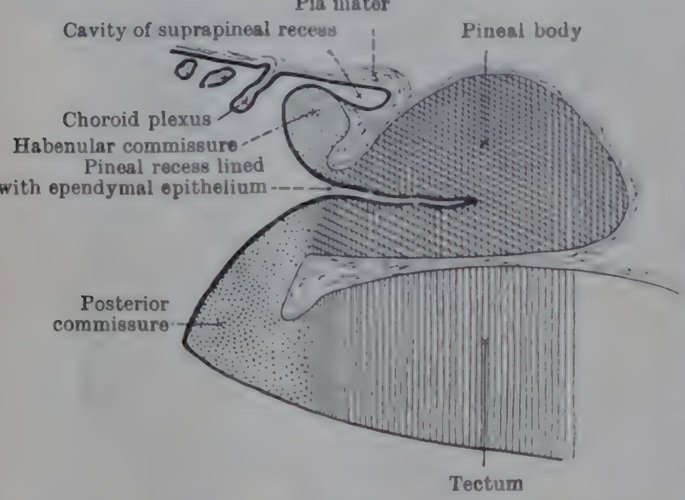

FIG. 714.—DIAGRAM OF MEDIAN SAGITTAL SECTION THROUGH PINEAL BODY AND ITS IMMEDIATE ATTACHMENTS.

Development.—The pineal body develops as a pouch-like evagination of the hinder part of the roof of the diencephalon, separated from the mid-brain by the posterior commissure only. Its epithelial wall becomes thickened, with restriction of the lumen to the stalk of attachment. Later, this epithelial mass is invaded by cellular sprouts from the ependyma around the cavity; these form the characteristic pineal parenchyma. Blood-vessels also invade the organ. The development of the septa takes place actively in early postnatal life.

Comparative Anatomy.—A pineal structure is present throughout the vertebrates. In certain groups (*e.g.*, Agnatha and certain Reptilia) it takes the form of a "pineal eye" or parietal organ. This organ may have a gland-like structure at its base similar to the mammalian pineal body. The pineal body of man is similar to that of other mammals. The reptilian forerunners of mammals also appear (from a study of their skulls) to have possessed a well-developed parietal organ.

The suprapineal recess is the vestige of a similar structure ("parapineal eye") which is situated in front of the parietal organ in certain vertebrates. There are grounds for believing that the parapineal and parietal organs were originally the left and right members respectively of a pair of organs, visual in function, in the pre-vertebrates. This view finds support in the nerve-connexions of the two organs. Further, certain fossil remains of the dermal roofing bones of primitive vertebrates show a pair of depressions which are believed to represent the position of these organs. (For further details, see the monograph by Gladstone & Wakeley, 1940.)

SPLEEN

The **spleen** (**lien**) (Fig. 715) is a soft, contractile organ of purplish colour. It is freely movable, situated far back in the upper part of the abdominal cavity on the left side, behind the stomach and in close relation with the diaphragm.

The spleen is the headquarters of the reticulo-endothelial cells or macrophages —that great system of scavengers that cleanse the blood. It acts as a great blood-filter in which a slowly moving stream of blood is brought into an intimate relation of unique character with tissue-cells and tissue-fluids, for the endothelial barrier between blood and tissue-fluid is here incomplete. Lymphoid tissue is present, but differs from that of the lymph-glands and lymphatic nodules

inasmuch as it is interposed in the arterial system and is not drained by lymph-vessels. The spleen serves also as a blood-reservoir on account of the large amount of blood it accommodates when expanded and the very material contribution it is capable of making to the amount of blood in the general circulation when it contracts. If removed from the living subject after ligation of its vessels it is found to be about three or four times as heavy as the spleen of the cadaver. The average weight after sudden death in the healthy subject (as after accidents) is about 150 grammes.

Form and Relations.—The form and position of the spleen are influenced largely by changes in adjacent structures. The stomach and colon show great variations of size, with corresponding effects upon its form; and the descent of the diaphragm during inspiration results in a downward displacement of the spleen. Notches are developed on the upper border, sometimes also on the lower border when the spleen is shrunken to a small size as in the cadaver: fissures, indeed, may extend across the diaphragmatic surface from the one border to the other. Two principal **surfaces** are recognized—the diaphragmatic and the visceral. The *diaphragmatic surface* is closely related to the under surface of the diaphragm. It is separated by upper and lower **borders** from the visceral surface. The *visceral surface* exhibits renal and gastric impressions separated by a more or less distinct but blunt border. The spleen has *medial* and *lateral* **ends**: the lateral end shows a flattening of varying extent—the colic impression — for the left flexure of the colon (Fig. 715). When the stomach is distended and the colon relaxed the spleen is similar in form to a segment of an orange, while distension of the colon causes it to assume an irregular tetrahedral form owing to the flattening of the lateral end. A *hilum* is recognized at the junction of the gastric, renal, and colic impressions. It is here that branches of the splenic artery enter the gland, and tributaries of the splenic vein leave it. At the hilum the spleen is moored by its peritoneum and its vessels to the fold of peritoneum which originally formed the dorsal mesogastrium; this constitutes its sole attachment. Elsewhere than at the hilum the spleen is completely invested with peritoneum which is firmly adherent to its capsule. The portion of the dorsal mesogastrium which is behind this attachment of the spleen is the lieno-renal ligament; the part in front is the gastro-splenic ligament. Exceptionally, the lieno-renal ligament is opened up so that the lower part of the renal impression comes into direct contact with the kidney. The tail of the pancreas makes contact with the spleen immediately below the lateral part of the hilum.

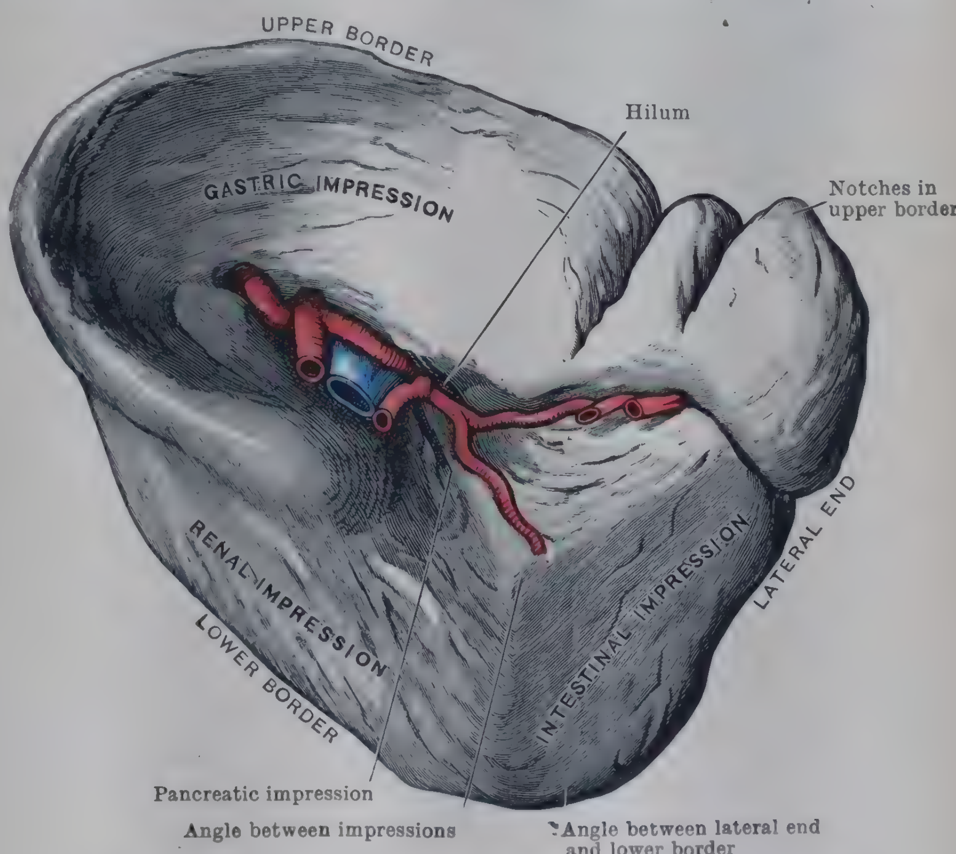

Fig. 715.—The Spleen—Visceral Aspect, Tetrahedral Form.

The *gastric impression* of the spleen lies against the upper part of the posterior

surface of the *stomach*, separated from it by the gastro-splenic ligament; the *renal impression* against the upper lateral part of the left kidney. In the young child the spleen touches the left suprarenal gland also. The *colic impression* rests upon the left flexure of the colon and the phrenico-colic ligament. The diaphragmatic surface is separated by the diaphragm from the pleura and the lower border of the lung. The medial end of the spleen is situated about one and a half inches from the median plane, at the level of the tenth thoracic spine in the cadaver and somewhat lower in full inspiration. The lateral end is just above the costal margin immediately behind the mid-axillary line. The long axis of the spleen is opposite the tenth rib (separated from it by diaphragm and pleura) when the body is in a supine posture, but in the erect attitude the long axis of the spleen tends to be more vertical, especially in women.

Fig. 716. — Sectional Surface of Adult Human Spleen, from which the Pulp had been removed by washing with Water so as to show the Arrangement of the Trabecular and Main Vascular Structures.

The size of the spleen is subject to great changes in life. It is a storehouse for blood and can expel its contents by the action of the muscle in its trabeculæ; it thus plays a part in the adjustment of circulating hæmoglobin to the needs of the body. Observation on the "exteriorized" spleen of the dog has shown that it exhibits reflex contraction in response to various stimuli. After a meal the spleen slowly increases in size for some hours and then gradually shrinks. Exercise diminishes the size. The living spleen exhibits slow rhythmic contractions, and it has been stated that these take place even when the nerve-supply is interrupted, as in the excised and perfused spleen.

Small rounded *accessory spleens* are often present, attached like the spleen to the dorsal mesogastrium, usually on the gastro-splenic ligament.

Radiographic Examination of Spleen.—The normal spleen may be visible radiographically if there are large amounts of gas in both the stomach and the left flexure of the colon. The spleen, like the liver, may also be made semi-opaque to the passage of X-rays by the injection of "thorotrast" into the circulation; but this is a very dangerous procedure and is rarely used clinically (see Appendix on Radiographic Anatomy).

Enlargement of the spleen may be diagnosed by downward displacement of the left flexure of the colon, and in such cases its outline may be seen in the radiograph.

Vessels and Nerves.—The spleen receives its blood from the **splenic artery**, which reaches it through the lieno-renal ligament. At the hilum the artery breaks up into six or more branches which enter independently. The **splenic vein** is formed within the lieno-renal ligament by the union of several tributaries which emerge from the hilum. By the splenic vein the blood is carried to the portal vein. The **lymph-vessels** also leave the spleen at the hilum. They are small and come only from the capsule and trabeculæ, not from the gland substance, which is devoid of lymph-vessels. They drain into the *splenic lymph-glands* placed near the hilum and into the *left suprapancreatic* glands.

The **nerves** are almost entirely non-medullated. They come through the cœliac plexus from the *greater splanchnic nerve* and possibly from the lesser splanchnic nerve. Some of these nerves are vasomotor in function; others supply the plain muscle of the organ. It is probable that *afferent* nerves pass from the spleen into the greater splanchnic nerve. The contractions of the spleen are in some circumstances brought about through the nervous system, but they take place also without its intervention, *e.g.*, the slow, rhythmic contractions. The strong contraction which takes place on stimulation of the greater splanchnic nerve is due in part to the action of the adrenalin liberated from the suprarenal glands.

Structure.—There is an elastic contractile framework of trabeculæ which radiate from the hilum to the surfaces, where they become continuous with the fibrous capsule (tunica albuginea). The trabeculæ contain plain muscle-fibres; and the larger arteries and veins pass along them from the hilum. The peritoneal covering (serous coat) covers almost the

whole organ and is firmly bound to the underlying tunica albuginea. The essential substance of the spleen is a spongy network of tissue together with small vessels. The ultimate subdivisions of the trabecular framework outline small areas of splenic pulp (lobules of Mall) (Fig. 717) which are most evident on and near the surface of the organ. These are about 1 mm. in diameter, irregular in shape and at best very imperfectly circumscribed. Each splenic lobule comprises a central *lymphatic nodule*—an irregularly ovoid mass, the "white pulp", and a surrounding marginal zone or "red pulp" which contains capillaries and a peripheral zone of venous sinuses. The lymphatic nodules vary in size from 0·2 to 0·7 mm., and they undergo individual alterations of size. Some atrophy takes place in middle age as in the lymphatic nodules elsewhere in the body.

Vascular pattern (Fig. 718).—*Arterial.* The lymphatic nodule is supplied by an artery which reaches it from the trabecular framework. It can contract sufficiently to obliterate its lumen. After giving rise to capillaries in the nodule it divides into branches which leave the nodule, and each branch divides into a few parallel "penicillate" vessels. These soon acquire

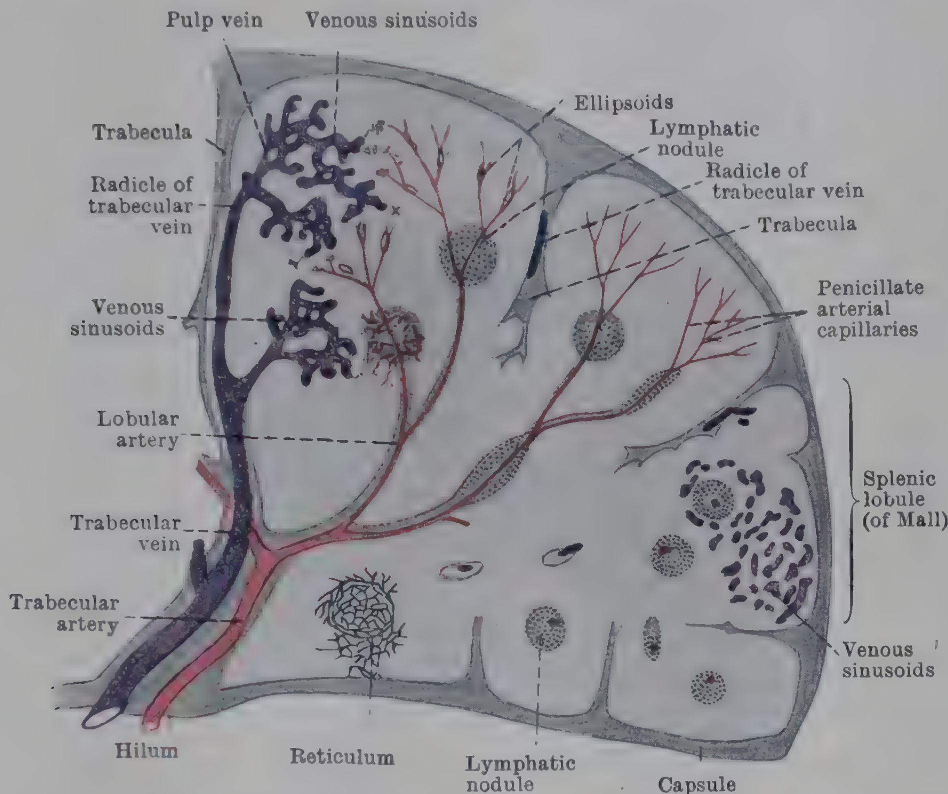

FIG. 717.—SCHEMATIC REPRESENTATION OF SPLENIC STRUCTURE, MUCH SIMPLIFIED BY THE SUPPRESSION OF RAMIFICATIONS OF THE TRABECULÆ AND VASCULAR TREE. (After Stöhr, *Lehrbuch der Histologie*, Fischer.)

NOTE.—Both the pulp-reticulum and the system of venous sinusoids supported by it must be understood as pervading the entire extent of the area figured except the trabeculæ and the splenic nodules; and, further, that the meshes of the reticulum itself are occupied by a varying content of red blood-corpuscles, together with various types of splenic cells.

thickened walls and have been termed "sheathed" arteries. A capillary network extends between capillary branches of the penicillate vessels and the capillaries of the lobule.

Venous. The sheathed arteries end in arterial capillaries. These are connected to the larger trabecular veins either (1) by means of long fine capillaries or (2) by bulbous venous sinuses, according to Knisely (1936) who has observed the circulation in the living spleen. He has described sphincter mechanisms in the sheathed arteries, and at the entrances and exits of the venous sinuses.

The venous sinuses may be expanded or narrowed and the spleen accordingly varies in size while the venous sinuses serve alternately as storage or as conducting structures. Red corpuscles pass through the walls of the venous sinuses into the intervening tissue (sometimes known as "pulp-cords"), and are thus "filtered" from the trabecular plasma. According to Knisely there is a complete endothelial lining to the vascular system of the spleen.

No special cells are found in the spleen which are not found elsewhere. The distinctive feature of the spleen is the large number of reticulo-endothelial cells (macrophages). The red pulp contains abundant red corpuscles, monocytes (often called splenocytes) and macrophages which are to be seen ingesting fragments of red corpuscles. Lymphocytes are formed in the lymphatic nodules, whence they migrate into the red pulp and finally reach the venous sinuses. The blood of the splenic vein contains many macrophages and is richer in lymphocytes than that of the splenic artery.

Reticulo-endothelial cells are found in the blood; they form the wall of blood-vessels in certain parts of the body; and they are found in the loose areolar tissues. They show great

differences of form in various places, and at different times; one morphological type will at times change into another type. They act as the scavengers of the body. They are engaged in the destruction of blood-cells, in bile-pigment production, in the metabolism of iron, fats, and proteins, in the elaboration of antibodies, and in the clearing of the body of bacteria, protozoa, and non-living bodies. In the blood they are represented by the lymphocytes and by the monocytes, which are perhaps derived from the lymphocytes. In the walls of blood-vessels, as *specific endothelial* or *reticular cells*, they lie in wait for foreign bodies where the blood-stream is slowed, as in the spleen, the lymph-glands and the sinuses of the liver (where they are known as the "stellate" cells of von Kupffer). Such endothelial cells are distinguished from ordinary endothelial cells in their phagocytic properties, and in the avidity with which they take up trypan-blue dye—a property in which they are like other reticulo-endothelial cells. Endothelial cells intermediate in properties between those of ordinary and "specific" endothelia also occur. Under certain conditions, indeed, ordinary endothelium acquires phagocytic properties. The distinction between the ordinary and specific endothelia is therefore not a hard-and-fast one.

Cells which belong to the reticulo-endothelial system are to be found also in the loose areolar tissues in the form of "histiocytes" or "resting wandering cells". These are the last to be mobilized when foreign matter in the circulation has to be dealt with; they may then migrate into the blood-stream.

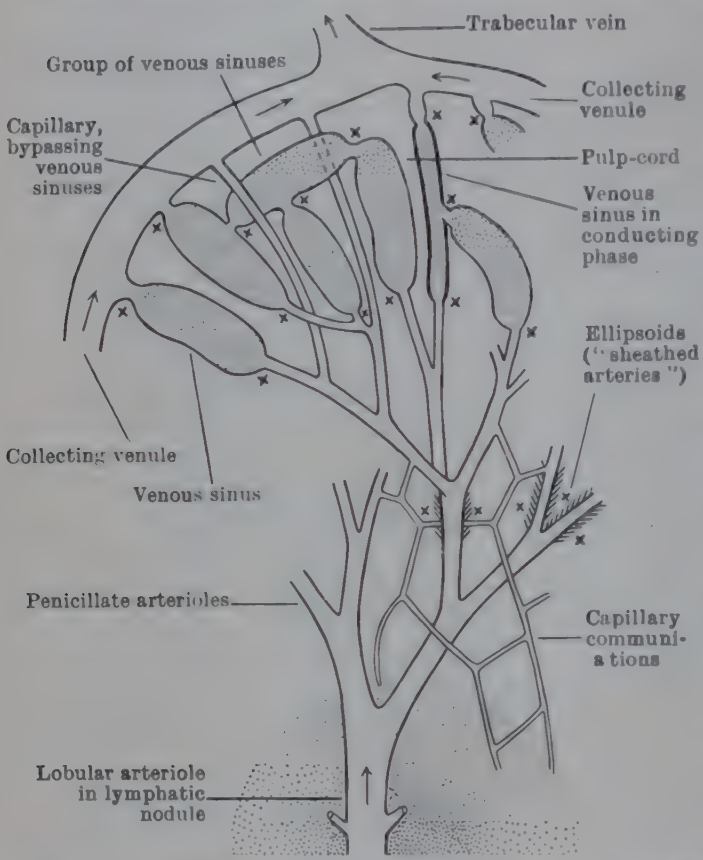

FIG. 718.—DIAGRAM OF THE TYPES OF VASCULAR CONNEXIONS THAT HAVE BEEN OBSERVED IN THE SPLEEN. × Sphincters. (After Knisely, 1936.)

Development. — The spleen is developed in the dorsal mesogastrium. The first indication is a thickening of this mesogastrium in embryos of about five weeks. In embryos of 10-12 mm. in length, there is a temporary thickening of the cœlomic epithelium over the swelling with several layers of cells, but the deeper layers are soon transformed into mesenchyme. The mesenchymal rudiment at first shows no division into lobules; a capillary network is present which forms the basis of the final vascular pattern. With the formation of the trabecular fibrous tissues along the course of the main vessels the future lobules become mapped out. Continued differentiation of the terminations of the arterial capillaries in the lobules leads eventually to the establishment of the characteristic capillary systems of the adult organ opening into wide venous capillaries. This arterio-venous capillary bed forms the rudiment of the adult splenic pulp. In it, giant cells and erythroblasts make their appearance, and blood-formation is active from about the fourth month of intra-uterine life. The lymphatic nodules arise as clumps of lymphocytic tissue in the adventitia of the arterial capillaries, during the middle and later periods of intra-uterine development, by infiltration of the walls of the vessels with lymphocytes.

Comparative Anatomy.—The spleen is found throughout the vertebrates, with the exception of the Agnatha (*e.g.*, the lamprey). Its structure is similar in fish, amphibia, reptiles, birds, and mammals; and it is in all instances developed in the dorsal mesentery of the gut. Its situation, however, relative to the alimentary canal, varies considerably; in some amphibia and reptiles, the spleen is opposite the intestines, in others opposite the stomach Certain fish normally possess several spleen-like structures.

Methods of Clinical Anatomical Examination.—The normal spleen cannot be felt by palpation of the abdominal wall. If it is enlarged or displaced, however, its lower part can be felt below the tenth costal cartilage during a movement of deep inspiration or sometimes even without such movement. Its position can be recognized by percussion; resonance is impaired over it. Anteriorly the zone of impaired resonance is limited by the area of resonance of the stomach, about the mid-axillary line; but the splenic and stomach areas may be separated by an intervening zone of resonance which is due to gas in the left flexure of the colon. Posteriorly, the upper border of the splenic zone of impaired resonance abuts on the area of lung resonance. Inferiorly, the splenic dullness merges with the zone of impaired resonance produced by the kidney, but there is a resonant angular region, below the spleen and lateral to the kidney, where resonance can be obtained from the descending colon.

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CENTRAL NERVOUS SYSTEM

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ELEMENTS OF THE CENTRAL NERVOUS SYSTEM

Every type of nervous system with which we are acquainted, from the most primitive to the most complex, is composed essentially of three categories of elements. These are (1) **sensory cells**, so situated and so specialized in structure as to be capable of being affected by changes in the animal's environment, and of transmitting the effects of such stimulation, directly or indirectly, to (2) **efferent nerve-cells**, which influence the muscles and other active tissues, so that the stimulation may find expression in some appropriate action; and (3) **intercalated nerve-cells**, which regulate such responsive behaviour by bringing it under the influence of other sensory impressions and of the state and activities of the body as a whole.

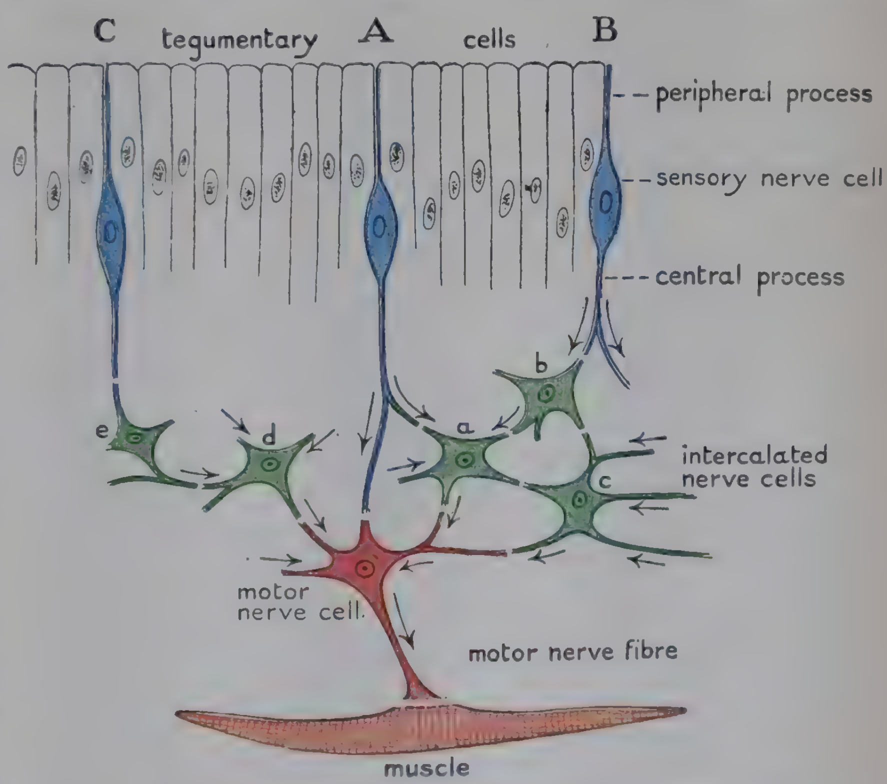


Fig. 719.—Diagram representing Essential Features in the Arrangement of the most primitive Type of Nervous System.

The study of a simple scheme representing the relationship that obtains among the three classes of elements in a primitive cœlenterate organism (Fig. 719) will make these fundamental facts plain. Changes in the animal's environment affect the extremities of the **peripheral processes** of the sensory cells (*A*, *B*, and *C*), which in such a primitive invertebrate are situated amongst the ordinary tegumentary cells: the effect is transmitted by the **central processes** of such cells (*A*, for example), either directly to the efferent cell, represented in the diagram by a **motor nerve-cell**, or more usually to an intercalated nerve-cell (*a*, *b*, or *e*). Into the cell (*a*) impulses stream from other intercalated cells (*b* and *c*), bringing the impulse from the sensory cell *A* under the influence of those coming from *B* and from more distant parts of the body through the intermediation of the intercalated cell *c*. The cells *a*, *c*, and *d* are connected with the motor nerve-cell. Thus, there is provided a mechanism whereby the conditions affecting

other regions of the body, B and C, may influence the nature of the response which the stimulation of A evokes—either increasing or diminishing its effect or perhaps altering its character.

In this way the intercalated nerve-cells form a great co-ordinating mechanism, linking together all parts of the body in such a way that the activity of any part of the organism may be influenced by the rest, and thus be enabled to act in the interest of the whole.

Throughout the whole course of its subsequent evolution the nervous system is formed of the same three kinds of elements; and the essential feature in its elaboration and increasing complexity is the multiplication of the intercalated cells, and their concentration, together with the motor nerve-cells, to form a definite organ which we call the **central nervous system.**

During the process of development of the more complex forms of nervous system, most of the sensory nerve-cells migrate from their primitive positions in or near the skin (Fig. 719); and, as the free extremity of the peripheral process retains its primitive relationship to the skin, such migration of the cell-bodies necessitates a great elongation of their peripheral processes. Although the sensory cells thus move inwards into the deeper tissues of the body, the great majority of them do not become incorporated in the central nervous system, but become collected into groups which form the **ganglia** of the sensory nerves.

In addition to its primary functions of (*a*) providing the means whereby the organism can be brought under the influence of its surroundings, and (*b*) co-ordinating the activities of the whole body, the nervous system comes also to perform other functions of wider significance.

In the course of its evolution the co-ordinating mechanism formed by the intercalated cells becomes so disposed in each animal that an appropriate stimulus applied to the sensory nerves can evoke a definite response—often of great complexity and apparent purposiveness. The nervous system thus becomes the repository of those inherited dispositions of its constituent parts which determine instinctive behaviour: and in the course of time it eventually provides also the apparatus by which individual experience and the effects of education can be brought to bear upon and modify such automatic reactions. In other words, the instrument of intelligence is formed from the nervous system; and the relatively great bulk and extreme complexity of this instrument—the brain—in Man are in a sense the physical expression of human intellectual pre-eminence.

In conformity with its primary function of affording a means of communication with the outside world, the neural elements of the whole of the nervous system in the human embryo, as in other animals, are developed from the ectoderm, as has already been explained in the chapter dealing with General Embryology. In the most primitive Metazoa the sensory nerve-cells remain in or close to the ectoderm (Fig. 719), while other ectodermal cells become converted into motor nerve-cells and intercalated nerve-cells which are found in the underlying tissues (Fig. 720). In the vertebrate embryo there is an analogous process of development, but with the important difference that the various nervous elements do not wander into the mesoderm individually. A definite patch of ectoderm is set apart to produce the greater part of the nervous tissues for the whole body; and all except the margins of that area sinks into the body *en masse.*

In one part of this ectodermal patch, many of the motor nerve-cells develop (Fig. 720, *d*), in another (*c*) only intercalated nerve-cells, in yet another (*b*) the sensory cells originate. With our knowledge of the fact (from the evolutionary point of view) that the sensory cells were originally distributed throughout the skin (Fig. 719), the idea naturally suggests itself that in man also the units of the sensory ganglia might be formed *in situ* in the ectoderm, and that the collection of sensory cells in the ganglia might possibly be brought about by the migration of such sensory cells inwards, while their peripheral processes elongate to permit such migration of the cell-bodies without disturbing their original endings in the skin. But there is no evidence to show, or even to suggest, that such a process takes place in the human embryo. The facts at our disposal show that the sensory nerve-cells are derived from sharply circumscribed patches of ectoderm,

and that the peripheral processes of these cells are distributed, by a process of outgrowth, to the outlying area of ectoderm beyond them from which the epidermis is eventually formed (Fig. 720).

At the beginning of the second week the nervous system of the human embryo is represented by a thickened plate of ectoderm lying along the median axis of the embryonic area (Fig. 721). This is the *neural plate*, and it is grooved in the median line by a shallow furrow—the *neural groove.*

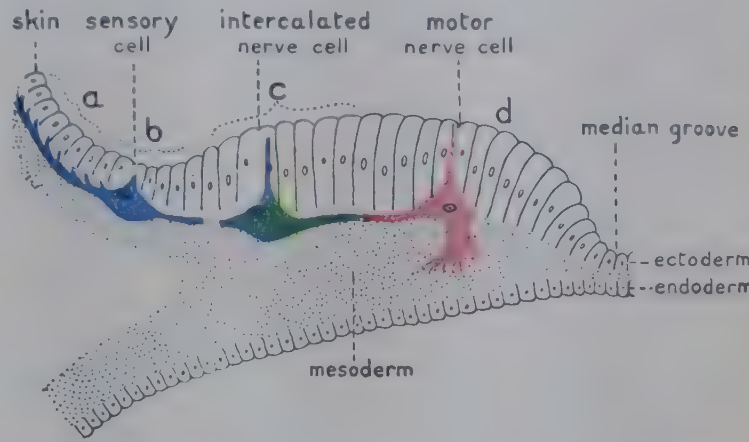


FIG. 720.—DIAGRAM REPRESENTING (IN BLACK) LEFT HALF OF TRANVERSE SECTION OF 2 MM. HUMAN EMBRYO. Superimposed upon it there is shown (in colours) the hypothetical primitive arrangement of the nervous elements derived from each part of the ectoderm.

In a diagram (Fig. 720) representing a transverse section through one-half of such an embryo (the uncoloured part), colours corresponding to those employed in Fig. 719 have been placed to indicate the nature of the elements that are known to develop in relation with each area of the ectoderm at a later period in the history of the embryo: *b* represents an area which later will form the **neural crest**, from which the sensory cells will be developed. The peripheral processes of these cells will pass into the skin (*a*) and to sensory endings elsewhere, and their central processes into the area *cd*, which will become part of the neural tube. In the area *c*, intercalated cells will develop

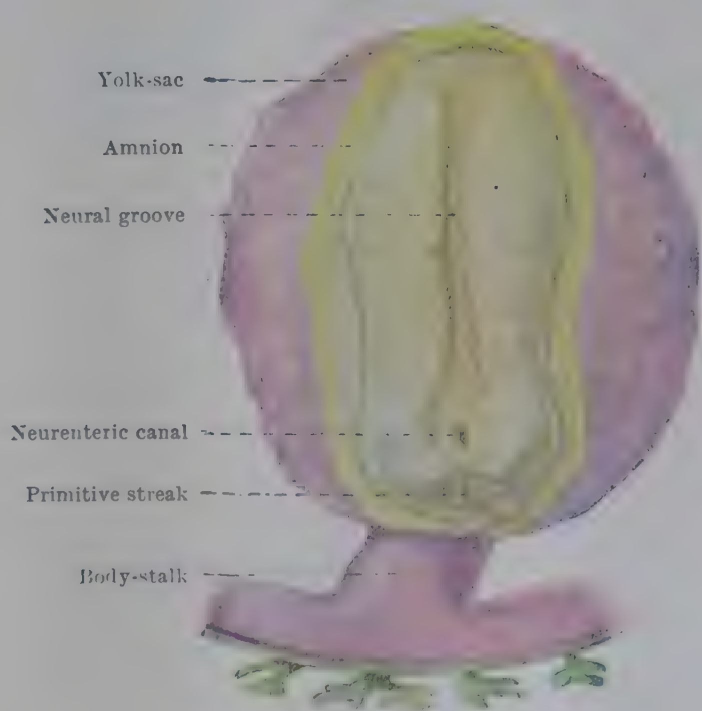


FIG. 721.—DORSAL SURFACE OF HUMAN EMBRYO 1·54 MM. LONG. (After von Spee.)

to receive the incoming sensory nerves; and in connexion with the area *d* the motor nerve-cells (as well as other intercalated cells) will be formed.

Early in the second week in the human embryo the axial groove along the median line of the neural plate becomes deepened by the tilting-up of the lateral margins of the plate. This process becomes accentuated during the next day or two until a deep cleft is formed, the walls of which consist of the thickened ectoderm and the floor of the thinner ectoderm of the neural groove

(floor-plate) joining them together. Before the end of the week the dorsal edges of the thickened plates become joined in the region which will develop into the neck; and during the third week the sealing of the lips of the neural groove extends headwards and tailwards, so that the neural tube becomes completely closed by the end of that week. The head and tail ends of the tube are the last parts to close, the latter being, as a rule, a little later than the former. When the tube is in the stage of being patent only at its two ends, the openings are known as the **anterior** and **posterior neuropores.**

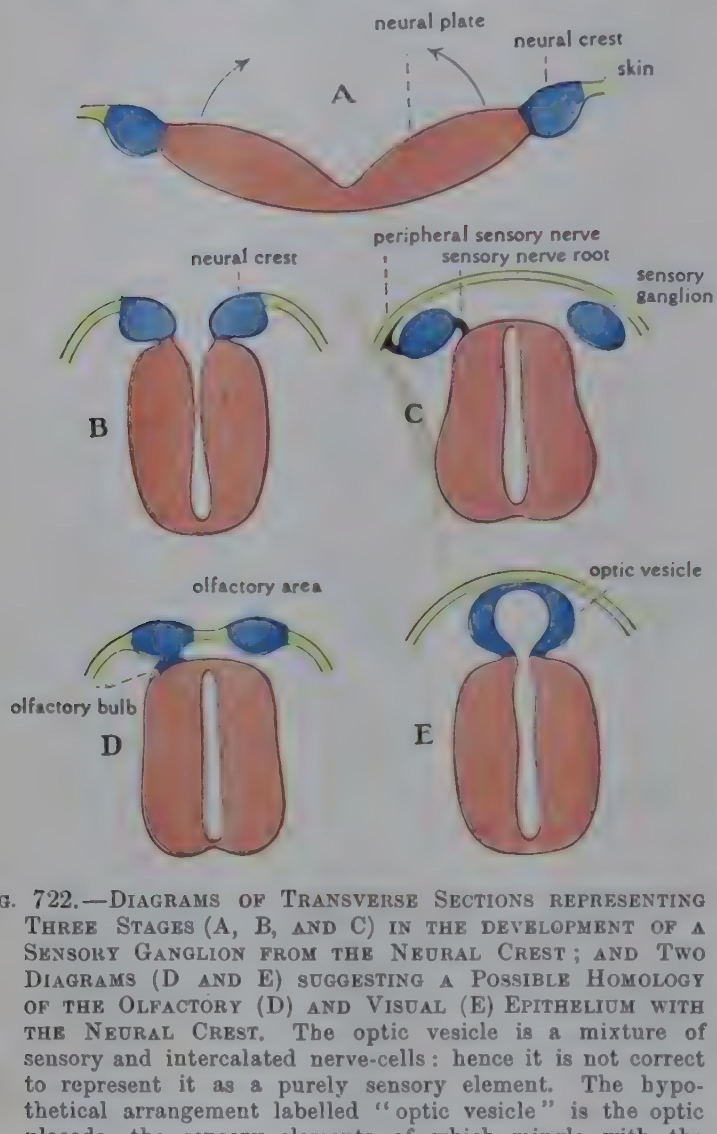


Fig. 722.—Diagrams of Transverse Sections representing Three Stages (A, B, and C) in the development of a Sensory Ganglion from the Neural Crest; and Two Diagrams (D and E) suggesting a Possible Homology of the Olfactory (D) and Visual (E) Epithelium with the Neural Crest. The optic vesicle is a mixture of sensory and intercalated nerve-cells: hence it is not correct to represent it as a purely sensory element. The hypothetical arrangement labelled "optic vesicle" is the optic placode, the sensory elements of which mingle with the neuroblasts of the neural tube; and a mixture of the two elements grows out to form the true optic vesicle.

In the process of closing, the extreme dorsal edges of the neural plate become excluded, in the greater part of its extent, from participation in the constitution either of the neural tube or of the skin, and form on each side a column of cells lying between the two. This is the **neural crest** (Fig. 722, A, B, and C).

The cells of the neural crest provide the basis for the development of the sensory ganglia of the spinal and cranial nerves, and these cells become arranged segmentally along the side of the neural tube. The neural crests, however, do not extend the whole length of the neural tube. Nevertheless, peculiar ectodermal areas, which ultimately give origin to sensory nerves, are found at the junction of the neural plate with the skin in those regions where the neural crest proper is lacking. At the extreme anterior end of the neural tube the margins of the anterior neuropore become thickened to form crest-like patches; but when the tube closes these areas do not separate from the skin (Fig. 722, D), as the rest of the neural crest does. They remain part of the skin and become the olfactory areas, in which sensory cells, very similar to those found in cœlenterate organisms (Fig. 719), develop.

A little farther on the caudal side of the olfactory region a large mass of ectoderm which appears to be homologous with neural crest tissue becomes a constituent part of the neural tube (Fig. 722, E). When the optic diverticulum grows out it carries out to the periphery these sensory cells mixed with intercalated cells of the neural tube to form the composite, sensitive membrane of the eye known as the retina.

In several other regions sensory nerves originate from cells of ectodermal areas which do not form parts of the neural crest, though they are homologous with that tissue. The nerves of hearing and taste are developed in a way that seems at first sight quite abnormal, until it is remembered that they afford examples of very primitive methods of nerve-formation.

The essential part of the organ of hearing is an ectodermal sac (otic vesicle) that develops as a diverticulum on the side of the head from a thickened patch

of ectoderm which is called the *otic placode*. Some of the cells of this area probably become transformed into nerve-cells which migrate into the space between the otic vesicle and the neural tube (Fig. 723) and join elements derived from the acoustico-facial portion of the neural crest to form the sensory neurons (p. 840) of the facial and auditory nerves.

At the upper margins of the branchial clefts a series of thickenings develop, which are known as the **epibranchial placodes**. Comparison with the process of development in fish-embryos suggests that the nerve-cells which give origin to the nerves of taste arise from these placodes as well as from cells of neural crest origin. Fibres of such origin are found in the facial, glosso-pharyngeal and (in some animals) vagus nerves (Fig. 723).

When first formed, the neural tube is compressed from side to side and presents an elliptical outline in transverse section (Fig. 722). The two side-walls are very

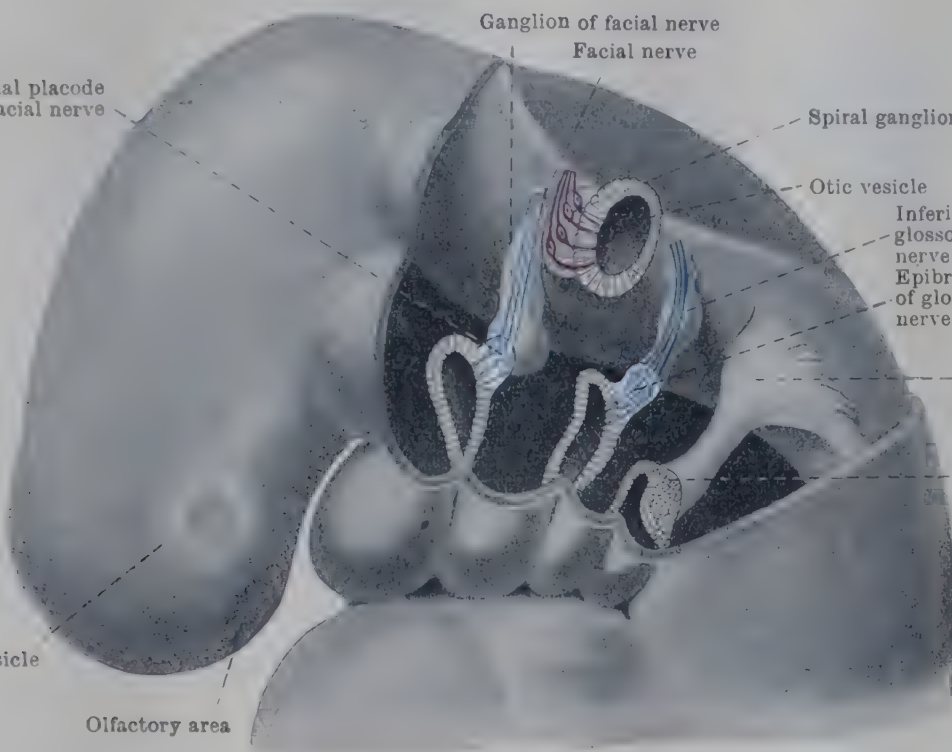


FIG. 723.—RECONSTRUCTION OF THE GANGLIA OF THE FACIAL, COCHLEAR, GLOSSO-PHARYNGEAL, AND VAGUS NERVES OF A HUMAN EMBRYO 5 MM. LONG. (Cf. Fig. 912, p. 1048.)

The epithelium of three pharyngeal grooves and the otic vesicle is represented diagrammatically; and the probable origin of the gustatory nerve-cells (and their fibres) from the epibranchial placodes is indicated in blue, and of those auditory nerve-cells contributed by the otic vesicle in purple.

thick, whilst the dorsal and ventral walls are narrow and thin, and are termed the **roof-plate** and **floor-plate** respectively (Fig. 728). The cavity of the tube in transverse section appears as a narrow slit. The wall of the neural tube consists at first of low columnar epithelium arranged in a fairly regular series, but with a certain number of large, spherical, so-called **germinal cells** scattered between the columns. But this regular disposition as a single layer of cells does not last long. For even by the second week the rapid proliferation of the cells has led to a marked increase in the thickness of the side-wall and a scattering of the more numerous nuclei, apparently irregularly, throughout its substance (Fig. 728). As growth proceeds, the innermost part of the wall of the neural tube becomes condensed to form a delicate membrane, termed the **internal limiting membrane**, which lines the lumen of the tube, whilst its outermost part presents a similar relation to an **external limiting membrane**, which invests the outer surface of the tube. Toward the end of the first month the side-walls of the tube show signs of a differentiation into three layers. Next to the central canal there is an epithelial-like arrangement of the innermost cells that forms the **ependyma.** Then there is an intermediate layer crowded with nuclei and known therefore as the nuclear or **mantle layer**. On the surface there is a layer singularly free from nuclei which is called the **marginal layer**. The

germinal cells are placed in the ependymal layer between its radially arranged cells as they pass in towards the internal limiting membrane.

From the proliferation of the germinal cells, in which mitotic figures can frequently be seen, some cells are formed which become ependymal epithelium, and others which migrate peripherally into the mantle layer. There they undergo further proliferation and some of the resulting cells develop into **spongioblasts**, which constitute the supporting framework or embryonic neuroglia; others become rudimentary nerve-cells or **neuroblasts**; and others again are known as **indifferent cells**, which are destined to undergo further division and to become the parents of more spongioblasts and neuroblasts.

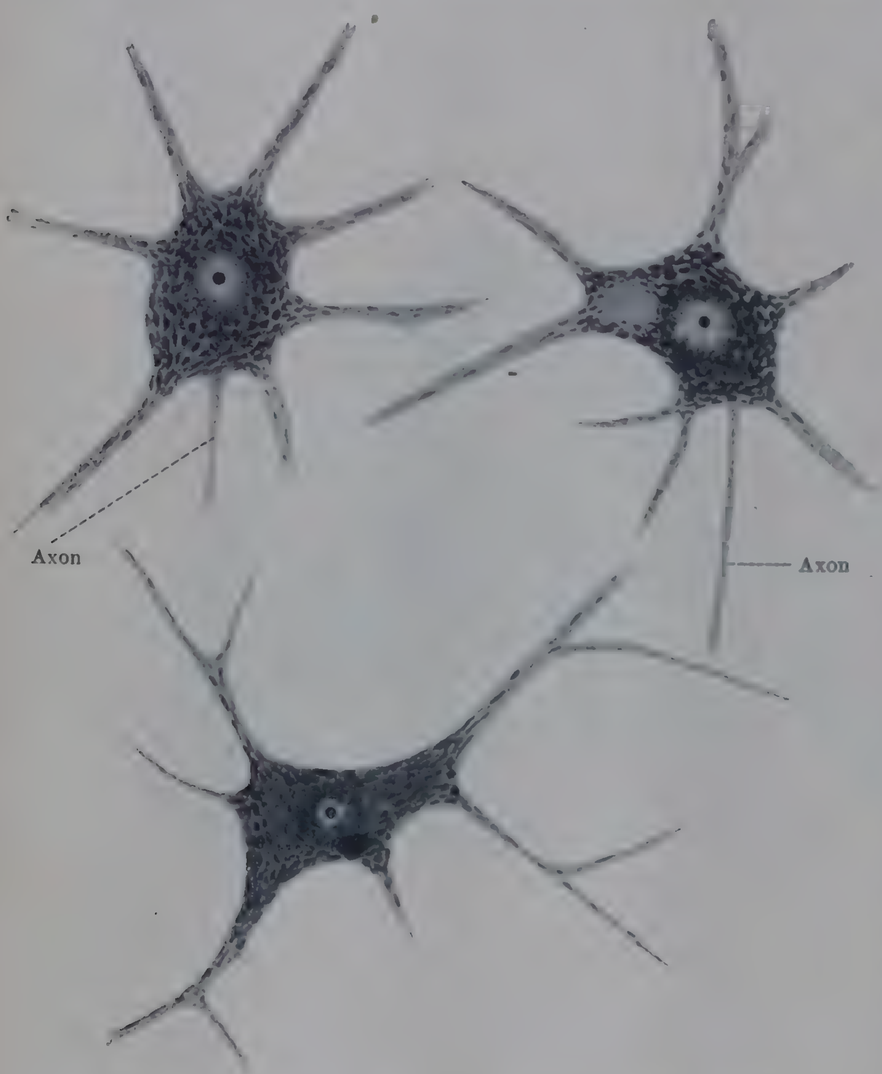


Fig. 724.—Three Nerve-Cells from Anterior Grey Column of Human Spinal Cord.

The neuroblasts are characterized by their early assumption of a piriform shape, due to the incipient outgrowth of a fibre-process. The spongioblasts, on the other hand, develop a series of branching protoplasmic processes which interlace freely to form a closely meshed network. The outermost or marginal zone of the neural tube is at first mainly composed of such a reticulum. It provides a scaffolding for the support of tracts of fibres which later grow up and down the spinal cord, linking up one part with another and connecting its whole length with the brain.

In the development of the spinal cord the three layers of the differentiating neural tube remain fairly distinct. The ependymal layer remains to form the ependymal epithelium which lines the central canal of the mature spinal cord; the mantle layer forms the grey matter of the cord, which contains receptive, motor, and intercalated neurons; and the marginal layer becomes the white matter of the cord and is occupied by tracts of ascending and descending fibres.

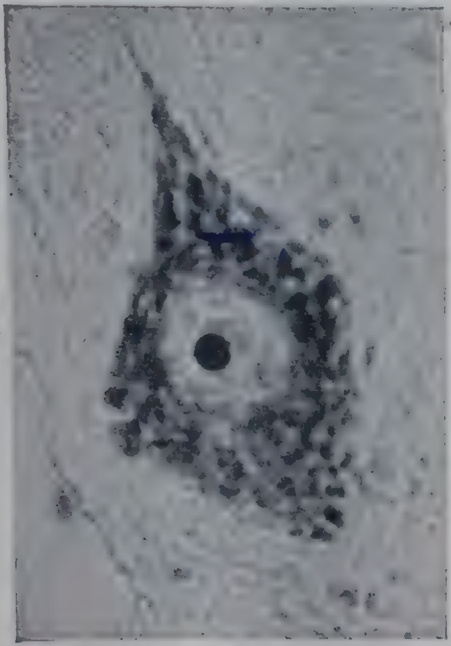
Cellular Elements of Nervous Tissue.—The anatomical unit of the nervous system is the **neuron**—that is to say, the nerve-cell with its processes. The latter are essentially conducting elements along which nervous impulses can be transmitted over considerable distances; and they form fine protoplasmic threads (or nerve-fibres) which may even reach a length of a metre or more. While there is evidence that the transmission of an impulse along a nerve-fibre can occur in the absence of its cell-body, each nerve-fibre depends on the integrity of its cell-body for the maintenance of its nutrition and vitality.

The larger nerve-cells are characterized by the presence in their cytoplasm of granules which stand out conspicuously when stained with a basic dye such as

methylene-blue. These granules are termed **Nissl bodies** or chromophil granules (Fig. 724). Their size and distribution show some variation in different types of nerve-cell; and they are absent altogether in the smallest neurons. They tend to be arranged concentrically around the nucleus and they extend also into the dendrites. They are absent, however, in the axonal process, except occasionally at its origin from the cell-body. It is of considerable importance to note that the Nissl bodies undergo characteristic changes in damaged cells. For example, if the axon is cut, they rapidly break up into a fine granular deposit and eventually disappear altogether. This reaction, which is termed *chromatolysis*, is usually accompanied by other changes such as a swelling of the cell-body and the displacement of the nucleus from a central position to the margin of the cell (Fig. 725). If regeneration occurs, the whole process is reversed and Nissl bodies once more make their appearance in the cytoplasm. The significance of the Nissl granules in the metabolism of nerve-cells remains obscure.

Another characteristic of the cytoplasm of nerve-cells is its fibrillary structure.

A



B

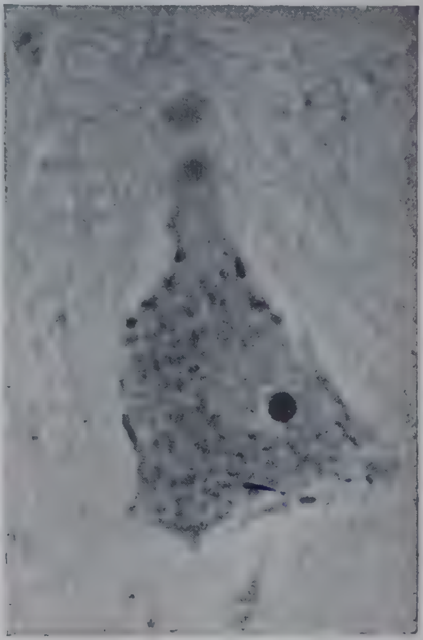


Fig. 725.—Photomicrographs showing (A) a Normal Motor Nerve-Cell of the Spinal Cord, and (B) a Motor Nerve-Cell which has undergone Chromatolysis two weeks after its Axon has been cut. (W. E. Le Gros Clark, *The Tissues of the Body.*) Note that in the degenerated cell the Nissl granules have disappeared or become dispersed in fine particles, and that the nucleus has been displaced to an excentric position. × 700.

Cells which are treated by methods of silver-impregnation show extremely fine fibrils—**neurofibrillæ**—which cross through the cell-body and extend into the axonal and dendritic processes. These neurofibrillæ were at one time regarded as the ultimate conducting elements of the neuron, but it is still disputed how far their appearance in histological preparations reflects the normal condition of the living cytoplasm. They have, however, been observed in fresh unstained nerve-cells.

Nerve-Cells of Brain and Spinal Cord.—The cells in the cerebro-spinal axis are variable both in size and form. Some are relatively large, as, for example, certain of the pyramidal cells of the cerebral cortex and the motor cells in the spinal cord, which almost come within the range of unaided vision; others are exceedingly minute, and require a high power of the microscope to bring them into view. The cell consists of a protoplasmic nucleated body, with which two kinds of processes are connected—the **axon** or emitting process and the **dendrites** or receiving processes (Figs. 726 and 727).

The **axon** presents a uniform diameter and a smooth and even outline. It may give off in its course fine collateral branches, but does not suffer thereby any marked diminution in its girth. The most important point to note in connection with the axon, however, is the fact that it forms the essential conducting element of a peripheral nerve-fibre, where it is commonly termed the *axis-cylinder*, and here it assumes one or two investing sheaths, of which more will be said later.

The axon may run its entire course within the substance of the brain or spinal cord, either for a short or a long distance (intercalated cells), or it may emerge from the brain or spinal cord in one of the cranial or spinal nerves as an efferent nerve-fibre and run a variable distance before it finally reaches the peripheral structure in relation to which it ends (efferent nerve-cells). The axon and its collaterals appear to terminate either in small button-like knobs (end-bulbs), or more frequently in terminal arborizations, the extremities of which seem to be furnished with exceedingly small terminal varicosities. When the axon or its collaterals end within the brain or the spinal cord, some of the terminal arborizations interlace with the dendrites of nerve-cells, and others are twined around the bodies of other cells. In the latter case the interlacement may be so

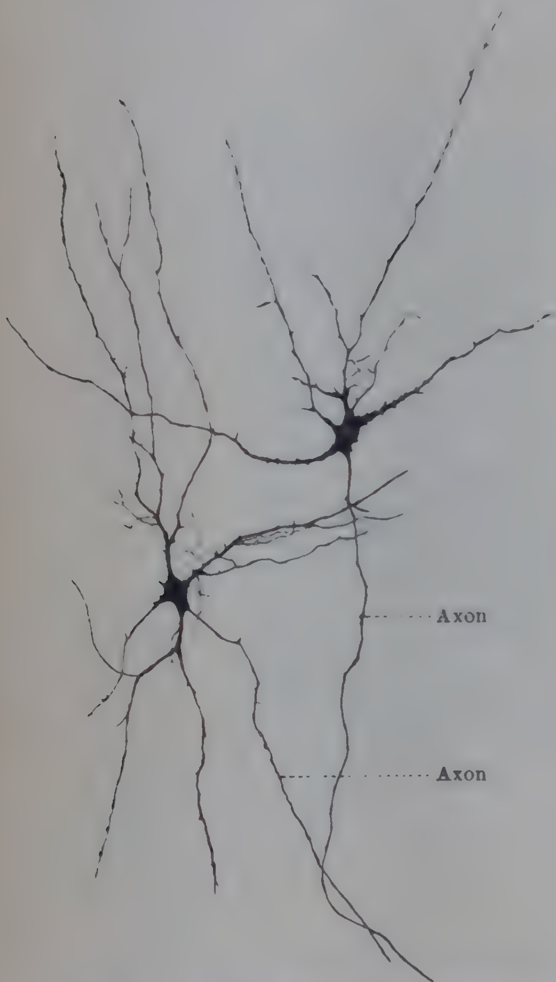


Fig. 726.—Two Multipolar Nerve-Cells. (From a specimen prepared by the Golgi method.)

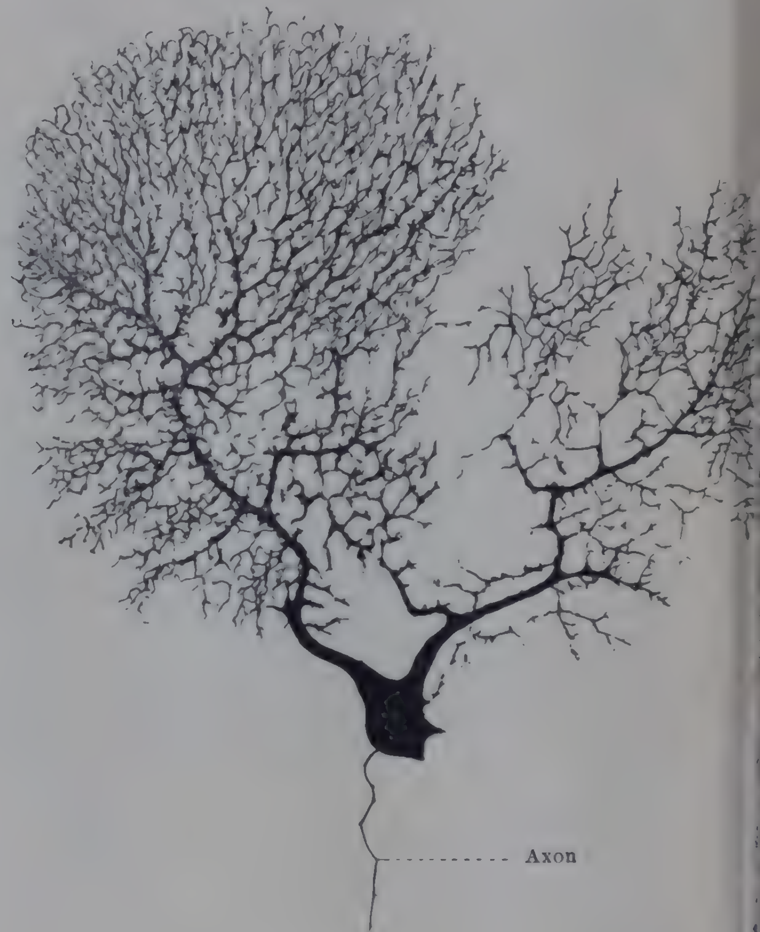


Fig. 727.—Nerve-Cell from Cerebellum (Cell of Purkinje) showing the Branching of the Dendrites. (Symington.)

close and complete that it almost presents the appearance of an enclosing basket-work. When the axon emerges from the cerebro-spinal axis its terminal arborization ends in relation to a muscle-fibre or some other tissue in the manner described below.

The **dendrites** or receiving processes of the nerve-cell are thicker than the axon, and they may present a rough-edged irregular contour. They usually divide into numerous branches, and gradually become more and more attenuated until finally they appear to end in free extremities. The branching of the dendrites sometimes attains a marvellous degree of complexity (Fig. 727), but there is no anastomosis between the dendrites of neighbouring cells, or between the dendrites of the same cell.

Most nerve-cells possess several dendritic processes and one axon, and they are therefore *multipolar* in shape. The processes are formed during development as a series of outgrowths from the cell-body, the axon usually (but not always) being the first to appear (Fig. 732). In some cases, in addition to the axonal

process, one main dendrite only may be developed, leading to the formation of a bipolar nerve-cell. Lastly, attention must be given to the *unipolar* type of cell which is really derived secondarily from a bipolar type (see p. 845). Such unipolar cells are found in the sensory ganglia of the spinal nerves and of some cranial nerves.

Efferent Nerves.—The efferent cells of the neural tube are distinguished by the fact that their axons leave the central nervous system and traverse the mesoderm for a longer or shorter distance to end in relation to a muscle-fibre or some nerve-cell outside the nervous axis. In the course of the growth of the body the various structures supplied by efferent fibres become removed progressively farther

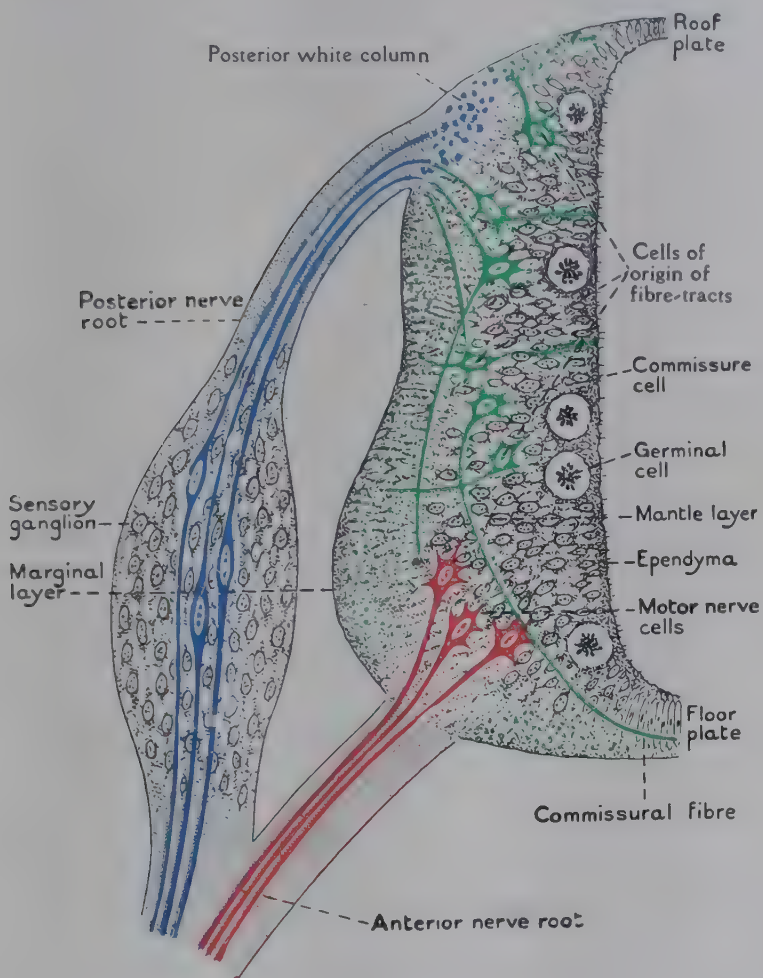


FIG. 728.—DIAGRAM OF TRANSVERSE SECTION OF EARLY NEURAL TUBE.

and farther from the central nervous system; and in that process (Fig. 729) a distinction can be detected in the behaviour of the efferent fibres (*a*) proceeding to the striated or voluntary muscles, and those (*d*) conveying impulses destined for viscera and plain muscle, respectively. The efferent cells (*a*) which innervate voluntary muscles take up their positions in the central nervous system, their axons (motor nerve-fibres) becoming elongated in the ordinary process of growth in proportion to the migration of the muscle from its original situation. But the cells (*c*) which innervate plain muscles and viscera are disposed in a different manner. They lie outside the central nervous system as constituent elements of one of the **autonomic ganglia**. Impulses from the central nervous system are transmitted to such ganglia by means of fibres arising from cells (*d*) within the central organ; and the latter elements are termed **splanchnic efferent cells**. In spite of their morphological homologies, the motor cells of the autonomic ganglia appear not to have their origin in the motor part of the neural tube but to be derived from cells of the neural crest which migrate from their original position on the dorsal aspect of the neural tube. However, this generally accepted thesis may still be regarded as not finally settled, for there is still some support for an earlier conception that the cells of the autonomic ganglia migrate out from the neural tube

along the anterior roots of the spinal nerves. Such a process would be in harmony with purely morphological expectations.

Afferent Nerves.—It has been noted that the sensory ganglia of the cranial and spinal nerves are derived from the neural crest or from ectodermal tissue homologous with it. In the process of development each of the cells of these ganglia sends out (1) a process to the periphery which ultimately forms a sensory receptor ending, and (2) a process which enters the dorsal part of the neural tube. This central process may penetrate directly to the mantle layer to terminate in relation to the neurons in this layer, or it may ascend or descend through the neural tube in the marginal layer for a variable distance before its termination.

Nerve Components.—From the statements in the preceding paragraphs it must be evident that there are several varieties of afferent and efferent nerves that respectively enter and leave the central nervous system. The cells of origin of the efferent nerves collect in the ventral part of the side-wall of the neural tube; and for this reason that part of the wall becomes swollen at an early stage of development (Figs. 729 and 730). It is called the **basal lamina**. Most of the cells that emit afferent fibres are situated in the sensory ganglia outside the central nervous system, and their growth can therefore have no direct influence upon the form of the neural tube; but their central processes become inserted into the dorsal part of the side-wall of the tube, which is called the **alar lamina**; and groups of intercalated cells collect around the entering fibres to form **receptive** or **terminal nuclei**. The growth of the terminal nuclei leads to an expansion of the alar lamina which is analogous to that seen in the basal lamina but is much less extensive. The unequal swelling of the dorsal and ventral parts of each side-wall of the neural tube leads to the development of a longitudinal groove—**sulcus limitans** (Fig. 730)—as a demarcation between the alar and basal laminæ.

The **nuclei of origin** of the efferent fibres, which are found in the basal laminæ, may be divided into two main groups (and, in some regions of the nervous axis, three). There is first the group of large multipolar nerve-cells which emit fibres to innervate the ordinary striated voluntary muscles. This is commonly called the **somatic efferent nucleus**. Then there is a group of small multipolar cells, the axons of which pass out into autonomic ganglia and indirectly control the involuntary plain muscles and other active parts of viscera. Those cells form the **splanchnic efferent nucleus**.

In the upper cervical region of the spinal cord and in the brain-stem a portion of the somatic efferent nucleus is set apart to innervate the striated muscles developed in the pharyngeal arches (Fig. 812). This is termed a *branchial nucleus*, for, although the muscles which it supplies are not distinguishable from ordinary skeletal musculature in their minute structure, they have a different developmental origin, being derived from the mesoderm of the "branchial" arches formed in the wall of the pharynx. It may be noted, too, that the cells of the branchial nuclei are similar to those of the somatic efferent nuclei (see *Nucleus ambiguus*, p. 929).

The alar lamina also can be subdivided into a series of functional areas (Fig. 730). In the dorsal part there is the **somatic afferent terminal nucleus**, which receives impulses coming from somatic structures such as the skin, subcutaneous tissues, muscles, and joints. In the brain-stem a *special somatic afferent nucleus* is developed for the reception of impulses from the cochlea and semicircular canals (Fig. 812). Then there is a group of cells collected around the incoming visceral sensory nerves—the **splanchnic afferent terminal nucleus.** A part of this, again, is specialized in the brain-stem to form a *special splanchnic afferent nucleus* (the gustatory nucleus) which receives impulses from the sense-organs of the tongue (Fig. 812, p. 924).

This analysis of the various functional elements that may enter into the constitution of the various cranial and spinal nerves is made use of in elaborating the **theory of nerve components**, which will help us to understand many features of the structure of the nervous system that otherwise would be unintelligible. It will be noted that primarily the arrangement of nerve-cells in the lateral wall of the neural tube from dorsal to ventral aspect is as follows: somatic sensory, splanchnic sensory, splanchnic motor, and somatic motor (Fig. 730).

This simple arrangement persists in the spinal cord and to some extent also in the brain-stem. Elsewhere it becomes modified and obscured during the process of development of the more specialized parts of the brain.

Ganglia of Sensory Nerves.—The cells found in the ganglia of the cranial nerves and on the posterior roots of the spinal nerves differ in origin from neurons in the grey matter of the brain and spinal cord. As already indicated, the ganglia in question are derived from the neural crest. The cells in these ganglionic masses are at first oval in form, and each extremity or pole becomes drawn out into a process, so that the neurons become bipolar. The processes are distinguished as central and peripheral according to the direction which they take. The central processes penetrate the wall of the neural tube. In the region of the spinal cord they form the fibres of the posterior roots of the spinal nerves. In the substance of the cerebro-spinal axis they give off numerous collaterals, and after a course of varying extent they end, after the manner of an axon, in terminal arborizations which enter into relationships with certain nerve-cells in the cerebro-spinal axis. The peripheral processes extend distally until they finally reach the skin or other sensory surface; for example, many of the fibres which go to the skin break up into fine terminal filaments which end freely between the epithelial cells of the epidermis. The two processes of a ganglion-cell, therefore, form the afferent fibres, and constitute the path along which a nervous impulse initiated by a peripheral

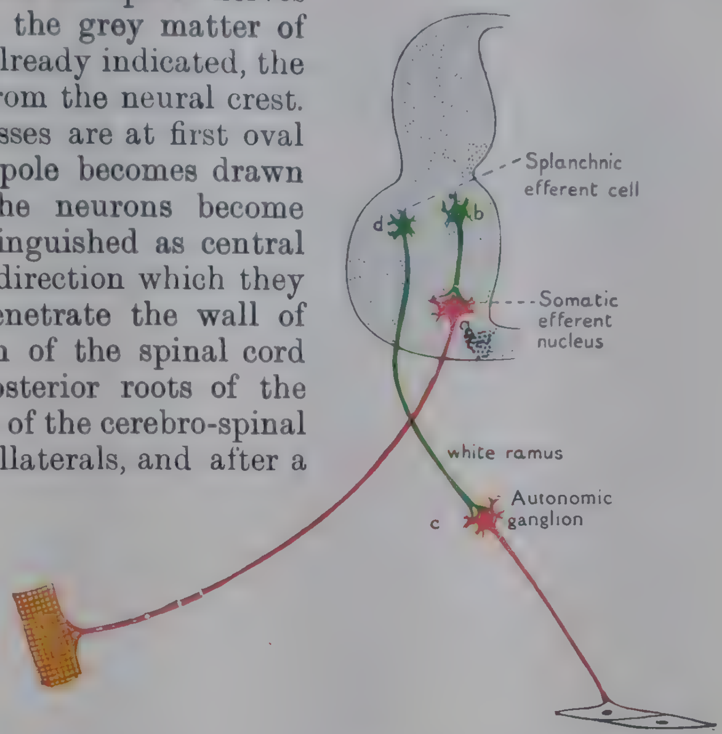


Fig. 729.—Diagram of Transverse Section of Left Half of Neural Tube representing the Arrangement of the Autonomic Nerves, to suggest the Possible Homology of a Sympathetic Ganglion Cell with a Central Motor Cell and of a White Ramus with the Axons of Intercalated Cells.

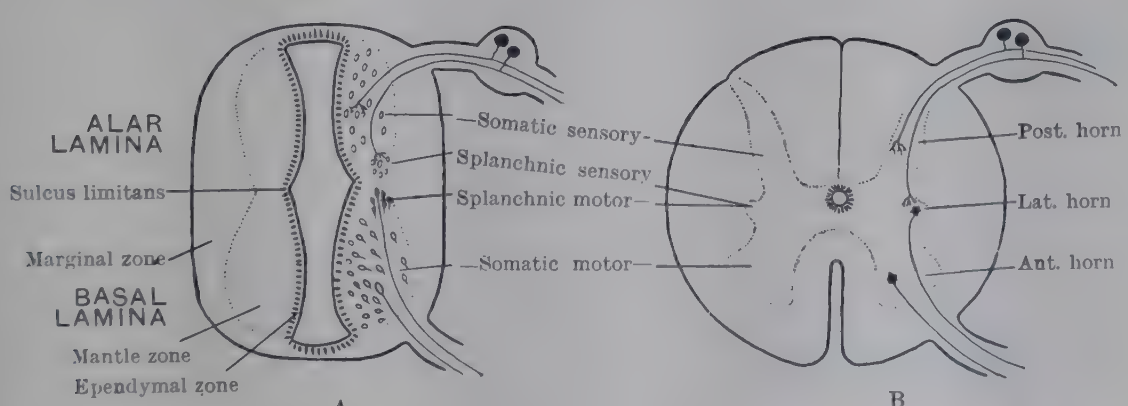


Fig. 730.—Diagrams of Transverse Sections of (A) Embryonic Neural Tube and (B) Spinal Cord showing the Main Categories of Afferent and Efferent Nerve-Components and their Central Nuclei. (W. E. Le Gros Clark, *The Tissues of the Body.*)

stimulus is conducted towards the brain and spinal cord. The body of the cell is, as it were, interposed in the path of such impulses.

But the original bipolar character of these cells, with very few exceptions (ganglia in connexion with the auditory nerve and the bipolar nerve-cells in the olfactory mucous membrane), gradually undergoes a change which ultimately leads to their transformation into unipolar cells. Asymmetrical growth leads to a gradual approximation of the attached ends of the processes, and finally to a condition in which they appear to arise from the extremity of a short common stalk in a

T-shaped manner (Fig. 734). It is interesting to note that in some types of fish the original bipolar condition of the spinal ganglion-cells is retained without change throughout life.

A comparison with more typical nerve-cells suggests that the peripheral process of a unipolar ganglion-cell is really a much elongated dendrite (in spite of its enclosure in a medullary sheath), for it conducts impulses towards the cell-body. In this case the central process is to be regarded as the axon.

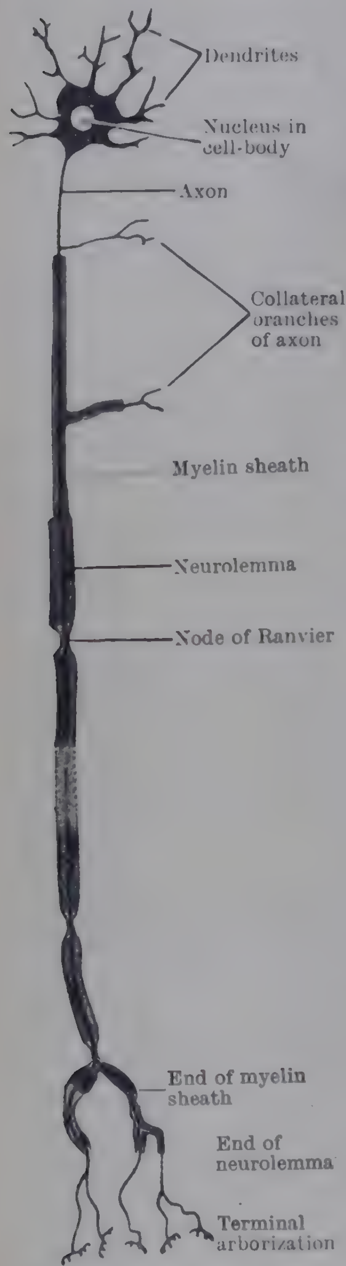


FIG. 731.—DIAGRAM OF A PERIPHERAL MOTOR NEURON SHOWING STRUCTURE OF MEDULLATED NERVE-FIBRE. (Maximow and Bloom, *Text-Book of Histology*.)

The interruption of the fibre by broken lines indicates that it may be relatively very much longer.

The Synapse.—It has been noted that dendrites are the receiving processes of a nerve-cell and that the axon is the emitting process, In other words, the neuron shows a dynamic polarity with respect to its processes, nerve-impulses being directed towards the cell-body by the dendrites and away from the cell-body by the axon. Within the central nervous system, and also in the peripheral course of the autonomic nervous system, nervous impulses may be conducted along relays of neurons, the terminal arborizations of the axon of one neuron effecting a contact with the dendrites or the cell-body of another. Such a connexion is termed a **synapse**, and this part of a nervous circuit is of extreme importance on physiological and pharmacological grounds.

In spite of prolonged controversy in the past, it is now almost universally admitted that at the synapse there is no protoplasmic continuity between one neuron and another—the relation between the processes of the two neurons being one of contact only. Similarly, the connexions of a peripheral nerve-fibre with a muscle-cell or a sensory cell are effected by contiguity and not by protoplasmic continuity. These dispositions, indeed, are implicit in what has been termed the *neuron theory*. This theory (which is now commonly accepted) states that each nerve-cell with its processes is a separate and independent anatomical unit, and that each nerve-fibre is ultimately the protoplasmic process of a nerve-cell. It is not opportune to enter here into a discussion of the neuron theory or to quote the questionable evidence which has been adduced by those who hold that the nervous system is really a syncytium of cellular elements. We may observe, however, that apart from direct histological observations there seems to be overwhelming evidence that each complete neuron is indeed a separate cellular element. Embryological studies, tissue-culture experiments, physiological data on the transmission of the nervous impulses, the degenerative processes which occur after injury to a nerve-cell or section of the axon, and the effects of certain pharmacological agents, all point to this conclusion (Le Gros Clark, 1945).

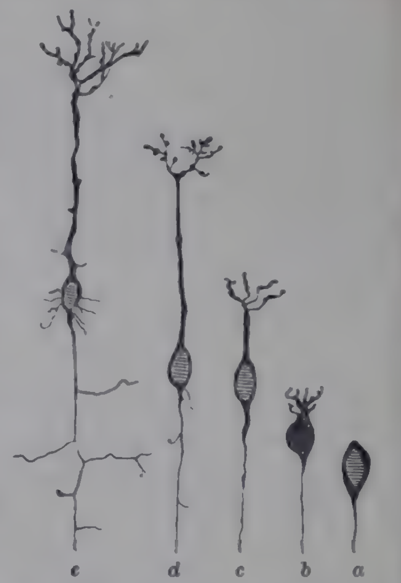


FIG. 732.—RAMÓN Y CAJAL'S INTERPRETATION OF THE DEVELOPMENTAL STAGES EXHIBITED BY A PYRAMIDAL CELL OF THE BRAIN.

a, Neuroblast with rudimentary axon, but no dendrites; *b* and *c*, the dendrites beginning to sprout out; *d* and *e*, further development of the dendrites and appearance of collateral branches on the axon.

Nerve-Fibres.—Nerve-fibres, arranged in bundles of greater or less bulk,

form the nerves which pervade every part of the body. They also constitute the greater part of the brain and spinal cord. As already noted, nerve-fibres are the conducting elements of the nervous system; they serve to bring the nerve-cells into relation both with one another and with the various tissues of the body.

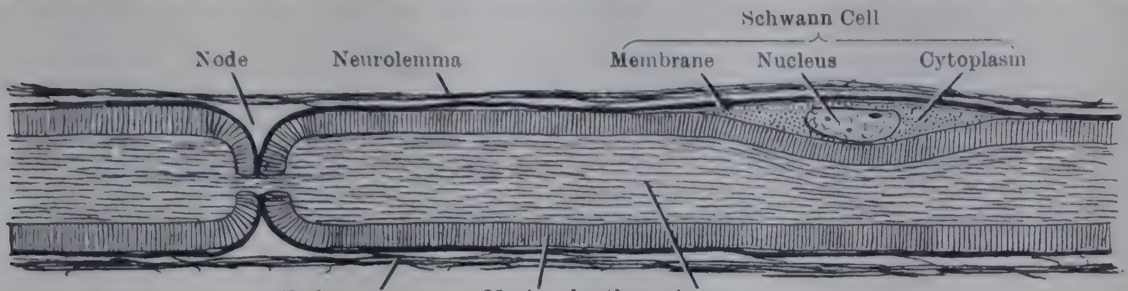


Fig. 733.—Diagram of a Normal Medullated Nerve-Fibre.

The Schwann nucleus lies nearer to the node than it would usually do, but otherwise the proportions are correct. (Holmes & Young, 1942.)

There are different varieties of nerve-fibres, but in all of them the essential constituent is the delicate, thread-like axon. The most obvious difference between individual fibres depends upon the nature of the covering of the axon. When it is coated on the outside by a more or less thick sheath of a fatty substance termed **myelin**, which can be demonstrated by reagents such as osmic acid, it is said to be a myelinated or *medullated fibre* (Fig. 733). When the visible coating of myelin is absent the fibre is termed a non-myelinated or a non-medullated fibre. A second sheath—thin, delicate and membranous, and placed externally—also may be present in each case. It is termed the **neurolemma** (or primitive sheath) and is intimately related to cellular elements called *Schwann cells* which partially invest the axon (or the myelin sheath when this is present). From a structural point of view, therefore, four different forms of nerve-fibre may be recognized :—

Non-medullated—
1. Naked axons.
2. Axons with Schwann cells

Medullated—
3. Schwann cells absent.
4. ,, ,, present.

Fig. 734.—Three Stages in the Development of a Cell in a Spinal Ganglion.

The significance of the medullary sheath and the investing Schwann cells remains obscure. The medullary sheath is commonly believed to subserve insulating functions and it is possible that it is concerned with the nutrition of the axon. It is known also that the thickness of the sheath has some relation to the rate of conduction in a nerve-fibre. The Schwann cells play an important but not an essential part in the regeneration of cut nerve-fibres. The observation that nerve-fibres within the central nervous system do not (in mammals) undergo repair after they have degenerated was at one time attributed to the fact that they have no investment of Schwann cells. This assumption, however, has received no support from recent experimental studies.

Every nerve-fibre near its origin and as it approaches its termination is unprovided with sheaths of any kind, and is simply represented by a non-medullated, naked axon (Fig. 731). The fibres of the olfactory nerves afford us an example of non-medullated fibres furnished with Schwann cells. Similar fibres are abundant in the peripheral distribution of the sympathetic nervous system, and they are found in small numbers also in peripheral nerves of the somatic type.

It is important to note that the distinction between the medullated and non-

medullated fibres is not one which exists throughout all stages of development. As already pointed out, every fibre is the prolongation of a cell, and in the first instance it is not provided with a medullary sheath. Indeed, it is not until about the fifth month of intra-uterine life that those fibres which are to form the white substance of the cerebro-spinal axis begin to acquire their coating of myelin. Further, this coating appears in the fibres of different fasciculi or tracts at different periods, and knowledge of the fact has helped anatomists to follow out the connexions of the tracts of fibres which compose the white matter of the brain and spinal cord.

It has already been explained that fibres which form the nerves may be classified into two sets—afferent and efferent. **Afferent nerve-fibres** conduct impressions from the peripheral organs into the central nervous system; and, as this frequently leads to a conscious awareness of the original stimulus, or, in other words, a sensation, they are often called *sensory fibres*. **Efferent nerve-fibres** carry impulses out from the brain and spinal cord to peripheral organs. The majority of them go to muscles to induce contraction and are termed *motor fibres*; others go to glands to promote secretion and are called *secretory fibres*. (For a discussion on the structure of nerve-fibres, see Young, 1942.)

Neuroglia.—The neuroglia is the supporting tissue of the central nervous system. It may be considered to include two different forms of tissue, viz., the lining ependymal cells and the neuroglia proper. We place these under the one heading, seeing that they have a common developmental origin.

The **ependymal cells** are the columnar epithelial cells which line the central canal of the spinal cord and the cavities of the brain. In the embryonic condition a process from the deep extremity of each cell traverses the entire thickness of the neural wall and reaches the surface. It is not known for certain whether or not this is the case in the adult, but it appears that in most parts of the brain and spinal cord this connexion becomes broken. The ependymal epithelium is characteristically ciliated, but the functional significance of the cilia is obscure, for they have not been observed to show any movement. In the ventricles of the brain a part of the ependymal lining covers invaginated tufts of vascular pial tissue (choroid plexuses) and here it plays the part of a secretory epithelium, for it is concerned in the production of cerebro-spinal fluid (p. 1003).

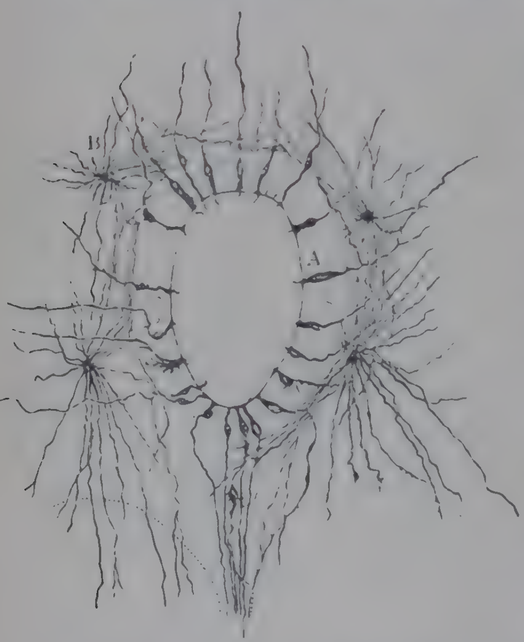


Fig. 735.—Section through Central Canal of Spinal Cord of Human Embryo, showing Ependymal and Neuroglial Cells. (After v. Lenhossek.)

A, Ependymal cell. B, Neuroglial cell.

Note that the dorsal (posterior) aspect is *below*.

The **neuroglia proper** is present in both the white and the grey matter of the cerebro-spinal axis. It constitutes an all-pervading matrix in which the various nerve-elements are embedded in such a way that they are all bound together into a consistent mass and are yet all severally isolated from one another.

Neuroglia is composed of cells in which the cell-body is relatively small and is provided with fine, filamentous processes. The latter may attain to a considerable complexity, and by their interlacements they constitute a feltwork which can be demonstrated microscopically by special methods of silver-impregnation. Whilst the neuroglia is for the most part intimately intermixed with the neuronal elements, there are certain localities, in both the brain and spinal cord, where it is spread out in more or less pure layers. Thus, upon the surface of the brain there is such a layer; likewise beneath the ependymal lining there is a thin stratum of neuroglia. Various types of neuroglial cell are recognized and, although the functional significance of each type is not in every case apparent, their recognition is of considerable practical importance, since they are responsible for forming different kinds of tumours which are met with clinically. Neuroglial tissue in general, like the ependymal epithelium, is

formed embryologically from ectoderm, being derived from the neuro-epithelium of the neural tube. There is one exception, however, in a type of neuroglia called *microglia* (or mesoglia). Microglial cells are mesodermal derivatives and they are distinguished by their high motility and their phagocytic properties. They play the part of macrophage cells in the central nervous system and have important protective functions.

GENERAL PLAN OF CENTRAL NERVOUS SYSTEM

In the foregoing account it has been explained that the nervous system is composed of a series of afferent nerves which bring information from every part of the body into the central nervous system, from which efferent nerves pass out to the muscular and other active parts of the body, providing the means for translating such information into appropriate action. But it has been seen that the essential parts of the central nervous system are the intercalated cells, which provide the means whereby the information brought in by any sensory nerve may be placed at the service of the whole body, and the response which it excites may be controlled and regulated by the condition of the rest of the body. The system of intercalated cells links together into one co-ordinated mechanism the whole nervous system and, through it, every part of the body itself.

In some very primitive and remote ancestor of Man (and in fact of the vast majority of animals) one end of the nervous system became enhanced in importance to form a brain, which assumed a dominant influence over the rest. This was brought about, in the first place, by the fact that in an elongated prone animal moving forwards the front end would naturally come first into relationship with any change in environment, and that earlier acquisition of information concerning the outside world would necessarily give the head-end of the nervous system exceptional opportunities for influencing the rest of the nervous system. This predominance is further accentuated by the development in the head-region of the organs of special sense, which provide mechanisms specially adapted to be influenced by light, sound, and such delicate chemical forms of stimulation as excite in ourselves sensations of smell and taste. As the information conveyed by the special senses, such as the scent of food or the visual impression of some enemy, must be able immediately to influence the movements of the whole body, it follows that a specially abundant system of intercalated elements link the central ends of the nerves of the special senses with the rest of the central nervous system. Moreover, the predominant influence of the head-end of the central nervous system implies that it must be provided with a specially large series of nervous connexions (in the form of fibre-tracts), not only for the purpose of bringing influence to bear upon the rest of the nervous system, but also of being itself brought into intimate relationship with the nervous system as a whole, seeing that sensory impulses are constantly pouring into every part of it.

Thus the head-end of the central nervous system becomes the brain, which is characterized by a series of large irregular swellings, due to (*a*) the development around the termination of each special sensory nerve of a mass, or group of masses, of intercalated cells which will enable the effects of the visual, auditory, olfactory, gustatory, or other sensations to influence the whole nervous system, and (*b*) the evolution of complicated systems of intercalated cells which receive, and in a sense blend, impressions from all parts of the nervous system, and emit fibres which pass, directly or indirectly, to the various groups of motor nerve-cells to control their activities and, through them, the behaviour of the animal.

Development of Brain.—In the development of the human embryo the distinction between the head-end and the rest of the central nervous system is indicated even before the medullary plate is completely folded up to form the neural tube. The widened part represents the rudiment of the brain; and the rest of the tube will become converted into the spinal cord.

If the attempt is made to analyse the meaning of the early broadening of the brain rudiment it will be found to be due in great measure to the fact that there is added to the margins of the medullary plate (see Fig. 722 E, p. 838) the material from which the sensitive part of the eye and the optic nerve are developed; but

soon after the neural tube is closed, irregular swellings make their appearance around the attachments of the nerves of smell, vision, hearing, and taste (Fig. 736), and also of the vagus nerve, which is widely distributed to the viscera of the neck, thorax, and abdomen.

But there are other factors besides the irregularities of growth of its walls which add complexity to the form of the brain in the embryo. In the course of their growth both parts (brain and spinal cord) of the neural tube undergo great extensions in length, breadth, and thickness; but in the case

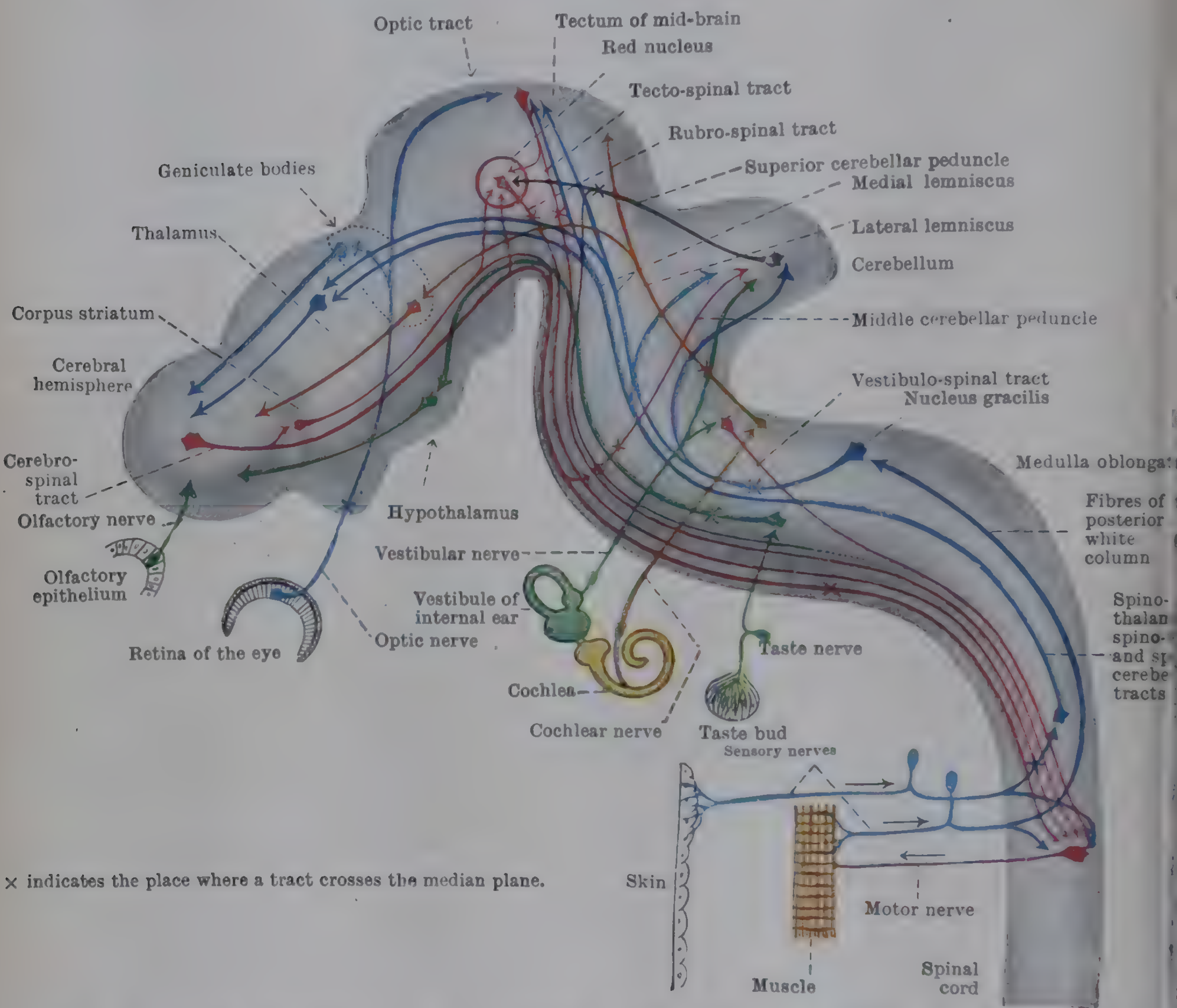


FIG. 736.—DIAGRAM REPRESENTING THE CONNEXIONS OF SOME IMPORTANT SENSORY AND MOTOR TRACTS IN THE BRAIN. Motor paths in red; sensory in other colours. The tracts are represented as projected on to the outline of an embryonic brain which shows the main divisions of the brain in a simplified plan. See also Figs. 758-762.

of the cord it is the increase in length that is most distinctive, whereas in the brain the irregular expansion in breadth and thickness is more striking. Nevertheless, the brain elongates more rapidly than that part of its mesodermal capsule which ultimately becomes the brain-case; hence it becomes bent, apparently to permit of its being packed in the limited length of the cranial cavity. But if it is admitted that these mechanical considerations are in a measure responsible for the three bends which develop in the embryonic brain, their situation and the forms they assume are determined by the irregularities of growth inherent in the brain itself (p. 61).

Even at a time, about the end of the third week, when the anterior (head) end of the neural tube is still open (anterior neuropore), a right-angled bend has already developed in the rudiment of the brain (**cerebral vesicle**). Slightly less than half of the length of the vesicle has projected beyond the headward end of the notochord and become flexed ventrally round it (Fig. 737).

This bend is known as the **cephalic flexure**. The region of the brain vesicle in which it develops will later on become the **mid-brain** or **mesencephalon**; and even at the early stage of development now under consideration (Fig. 737) there is a slight narrowing of the tube (**isthmus**) that marks the boundary between the mid-brain and the **hind-brain** or **rhombencephalon**. Immediately beyond the end of the notochord there is an even fainter trace of a constriction that indicates the line of demarcation between the mid-brain and the **fore-brain** or **prosencephalon**.

Shortly after the appearance of the cephalic flexure a similar bending occurs in the region where the brain becomes continuous with the spinal cord (Fig. 738 A). It is called the **cervical flexure**.

But at that stage, or even earlier (Fig. 737), there has been developing a third bend which produces effects that differ from those just mentioned. At the end of the fourth week a slight bulging can be detected on the ventral side of the hind-brain (Fig. 738): during the next four weeks it steadily becomes accentuated and forms the **pontine flexure**. The convexity of the bend is directed ventrally, differing in this respect from both of the other flexures. The difference in direction has a profound influence upon the form which the hind-brain assumes. If a plastic tube is bent, a strain is thrown upon the wall in the concavity of the flexure. If the wall is strong and resisting, like the floor-plate of the neural tube (in the cases of the cephalic and cervical flexures), the bending does not affect the outline of the tube (in section) very materially. But when the strain is thrown upon the thin roof-plate during the development of the pontine flexure it is not strong enough to resist; it becomes stretched and allows the side-walls of the neural tube to splay laterally in precisely the same manner as occurs when a rubber tube is bent towards a side which has been split (or weakened) longitudinally (Fig. 738). This mechanical factor seems to determine the form assumed by the hind-brain at the end of the first month; and gives its cavity—the fourth ventricle—a lozenge or rhomboid form when seen from its dorsal aspect through the thin translucent roof. For this reason the hind-brain is known as the **rhombencephalon**.

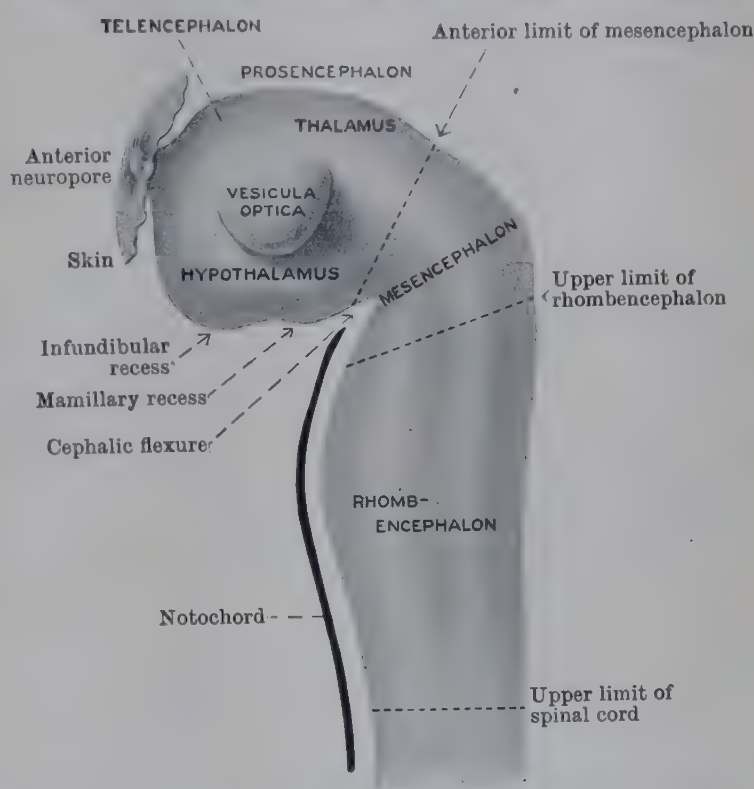


FIG. 737.—LEFT SIDE OF BRAIN OF HUMAN EMBRYO ABOUT THREE WEEKS OLD. (After a model by His, 1904.)

The rhombencephalon forms at first more than half of the brain, and, as it expands, it appears to become marked off from the rest by a constriction called the **isthmus rhombencephali**.

The development of the pontine flexure subdivides the rhombencephalon into two parts—the **myelencephalon**, joined to the spinal cord, and the **metencephalon**, joined to the rest of the brain.

The myelencephalon is known as the **medulla oblongata**, and important nuclei develop in it. These include the nuclei of the nerves which are concerned in the regulation of the activities of the heart, lungs, and a considerable part of the alimentary canal, and also the receptive nuclei of the nerves of taste.

The insertion of the auditory nerve in the neighbourhood of the outsplayed, lateral angle of the rhombencephalon leads to the profound transformation of the metencephalon. The auditory nerve conveys into the hind-brain impulses which

are stimulated by movements of fluid in the closed sac developed from the otic vesicle (Fig. 812, p. 924). The truly auditory function of the apparatus is called

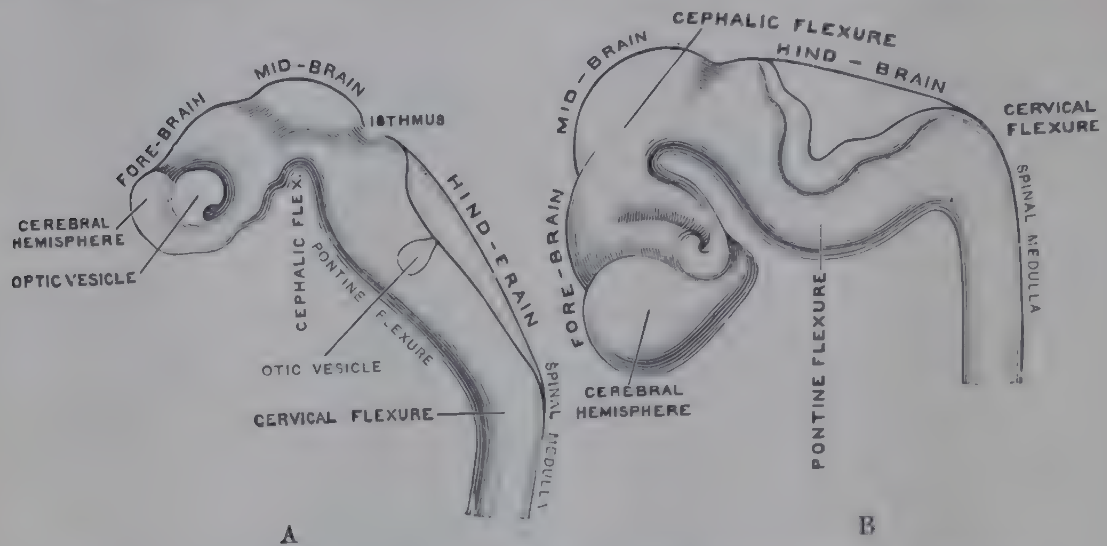


FIG. 738.—TWO STAGES IN THE DEVELOPMENT OF THE HUMAN BRAIN. (After His.)
A, Brain of embryo of the fifth week. B, Brain of embryo of six weeks.

into activity when the movements of the fluid are caused by waves of sound transmitted to it from the outside world. But it is obvious that motion may also be set up in the fluid by changes in position of the body itself; in other words, movements in the fluid of the otic vesicle may stimulate nerves to convey to the brain information concerning the position and movements of the body itself. There are separate fibre-bundles in the auditory nerve to serve each of these functions, and they are referred to as the cochlear and vestibular divisions of the nerve. A great mass of nerve-cells develops around the termination of that part of the auditory nerve which is called vestibular to make use of the information for the regulation of the movements of the body in balancing or equilibration. To enable the terminal vestibular nucleus the better to perform its function of equilibration, depending as it does upon the co-operation and adjustment of the movements of vast numbers of widely separated muscles, nerve-tracts coming from muscles

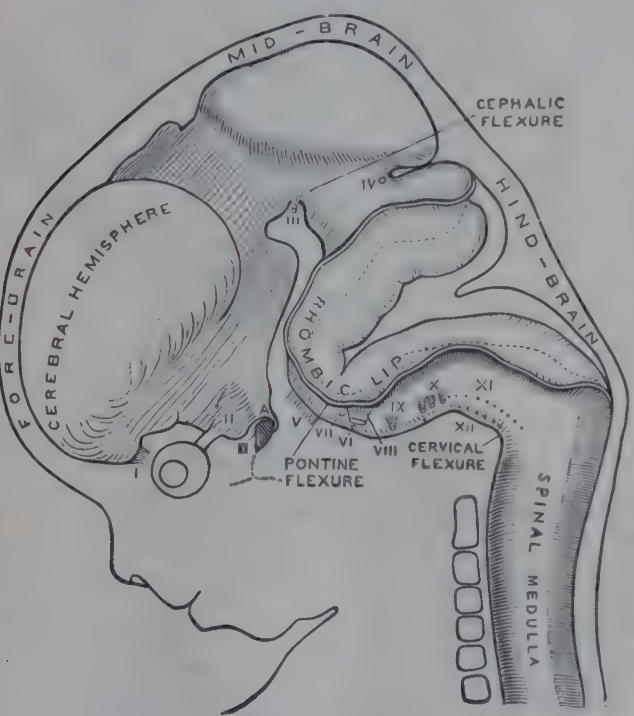


FIG. 739.—PROFILE VIEW OF BRAIN OF HUMAN FŒTUS OF TEN WEEKS. (After His.)
The Cranial Nerves are indicated by numerals.
A, Cerebral diverticulum (post. lobe) of hypophysis cerebri.
B, Oral diverticulum (ant. lobe) of hypophysis cerebri.

and skin-areas of all parts of the body make their way into the vestibular nucleus; and it expands and forms a great excrescence known as the **cerebellum**. As the cerebellum has to adjust the activities of all the muscles of the body it necessarily becomes the great organ of muscular co-ordination, and as such it is made use of by those parts of the brain which have to initiate and control complex actions such as skilled movements. It will be shown in the subsequent account how the cerebellum becomes linked to the mid-brain to co-ordinate the movements of the body which are excited by this part of the brain; and, later, how it becomes associated with the fore-brain, when the latter becomes responsible for the initiation and control of the most highly

skilled actions. For the latter purpose the cerebellum emits a system of fibres that convey impulses which are eventually relayed to the cerebral hemispheres. Moreover, a great pathway of efferent nerve-fibres is laid down to connect the fore-brain with the cerebellum: the terminal pathway of this connexion is situated on the ventral (anterior) aspect of the metencephalon in the form of a great mass of transverse fibres. At one time these strands of nerve-fibres were looked upon as a bridge between the two hemispheres of the cerebellum: hence the name **pons** was applied to them. This term is now applied not only to the fibres themselves, but also to the upward prolongation of the medulla oblongata, to the surface of which they are related.

The division of the rest of the brain into **mesencephalon** and **prosencephalon** develops later and is less fundamental than the primary demarcation of the rhombencephalon.

The visual apparatus is connected with both the mid-brain and the fore-brain, to both of which also nerve-pathways are established to convey sensory impressions of touch and sound from the spinal cord and medulla oblongata. From the alar laminæ of the mesencephalon the **tectum** or dorsal part of the mid-brain is formed, and in it there are developed four little hillocks—**corpora quadrigemina**—to receive these varied impressions and to enable them to influence the actions of the whole body. Special nerve-paths, called the **tecto-spinal tracts**, are laid down from the corpora quadrigemina (Fig. 736) to the spinal cord to enable the mid-brain to control the motor nuclei of the muscles of the trunk and limbs. A group of intercalated cells known as the **red nucleus** develops in each half of the mid-brain for the purpose of establishing connexions between the cerebellum and the mid-brain. When an impulse passes out of the mid-brain by the tecto-spinal tract to excite some movement of the body, the red nucleus provides the link by which the cerebellum can co-ordinate the actions of the muscles involved. By means of a **rubro-spinal tract** it can bring its influence to bear directly upon the nuclei of motor nerves in the brain and spinal cord (Fig. 736). While, however, the rubro-spinal tract is an important tract in lower mammals, it becomes relatively insignificant in the human brain, where the motor functions of the central nervous system are dominated by the elaborately developed fore-brain.

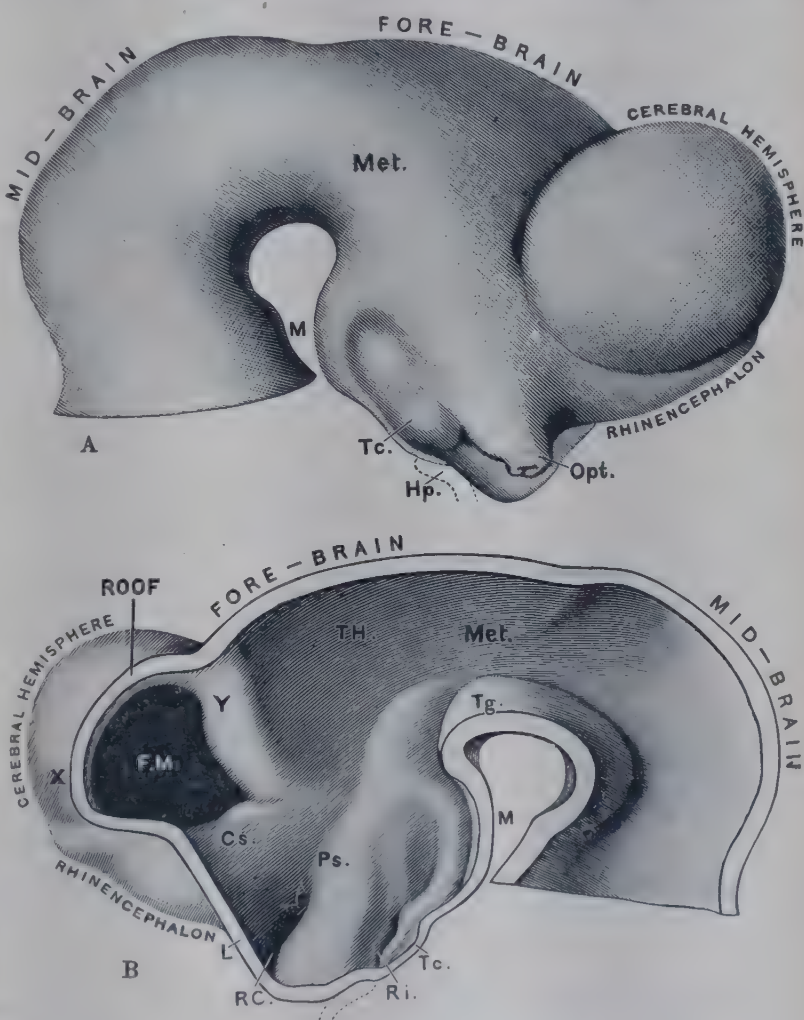


FIG. 740.—BRAIN OF HUMAN EMBRYO IN SEVENTH WEEK. (His, 1904.)

A, Brain from right side. B, Median section of same brain.
M, Mamillary eminence; Tc., Tuber cinereum; Hp., Hypophysis (hypophysial diverticulum from oral cavity); Opt., Optic stalk; TH., Thalamus; Tg., Tegmentum of mid-brain; Ps., Hypothalamus; Cs., Corpus striatum; F.M., Interventricular foramen; L, Lamina terminalis; RO., Optic recess; Ri., Infundibular recess; Met., Region of geniculate bodies.

The prosencephalon is at first, and in some of the lower fishes remains, the most insignificant of the three brain vesicles, but in the human brain (as also in

that of most other vertebrates, though in varying degrees) a pair of enormous excrescences—the **cerebral hemispheres**—are budded off from it; and they become the dominant part of the nervous system (Fig. 740). The median, unpaired part of the prosencephalon contains the cavity of the third ventricle, and this part of the brain is termed the *diencephalon*. The cerebral diverticula are hollowed out by the lateral ventricles, and together they comprise the *telencephalon* or "end-brain".

Each hemisphere is formed, however, from a relatively small part of the side-wall of the prosencephalon, the rest of which goes to form the optic diverticula, the thalamus, and the hypothalamus, among other structures. The cerebral hemisphere is at first pre-eminently olfactory in function, the nerves of smell being inserted directly into it. But impressions of the associated sense of taste make their way into the cerebral hemisphere in the most primitive vertebrates: the gustatory nerves are inserted into the medulla oblongata, but fibre-paths are laid down to establish connexions which (by paths not yet definitely established) reach the cerebral hemisphere (Fig. 736). Other types of sensory impulse reach the cerebral hemispheres by passing through a mass of nervous tissue which is developed in the wall of the third ventricle—the **thalamus**. The thalamus is developed as a greatly swollen part of the prosencephalic wall adjoining the mesencephalon. Its main part receives sensory impressions brought up from the spinal cord and the terminal nuclei of the sensory cranial nerves and transmits them to the corresponding cerebral hemisphere. Its caudal portion becomes specialized as special receptive nuclei for visual and auditory impressions for transmission to the cerebral hemisphere. These terminal nuclei are called the **geniculate bodies**. Thus, the cerebral hemisphere, from being essentially a receptive organ for smell impressions, ultimately becomes the terminus of all the sensory paths, and the structure that is concerned with the consciousness of all kinds of sensations. It also controls the voluntary movements of the opposite half of the body and emits a great strand of fibres—the **cerebral peduncle**—to establish relations with the cerebellum and all the motor nuclei on the other side of the brain and spinal cord (Fig. 736).

The most primitive part of the prosencephalon (but of extreme functional importance for the very reason that it *is* a primitive and fundamental component of the fore-brain) is the **hypothalamus**. This is a mass of nervous tissue which forms the floor of the third ventricle and is intimately related to the attachment of the hypophysis cerebri. It is to be regarded as a central mechanism for the regulation of the visceral activities of the body, and, as such, it plays an important part in metabolic functions and emotional reactions.

SPINAL CORD

The **spinal cord** is the part of the central nervous system which occupies the upper two-thirds of the vertebral canal. It is an elongated cylindrical structure, slightly flattened in front and behind, and extends from the foramen magnum to the lower border of the body of the first lumbar vertebra or to the upper border of the second. Its average length is 45 cm. in men and 43 cm. in women.

The level of the lower end of the cord varies from the middle of the last thoracic vertebra to the upper border of the third lumbar and is said to be slightly lower in women than in men. It varies also in the fœtus and infant at different periods of development. Up to the third month of intra-uterine life the spinal cord occupies the entire length of the vertebral canal. But from that time onwards, the vertebral column lengthens at a more rapid rate than the cord. The spinal cord, therefore, has the appearance of shrinking in an upward direction within its canal, and at birth the lower end usually is opposite the body of the third lumbar vertebra. The attitude of the body affects to a small degree the position of the lower end of the cord. When the trunk is bent well forwards, the terminal part of the cord rises slightly.

At the foramen magnum the spinal cord becomes continuous with the medulla oblongata, whilst its lower end tapers rapidly to a point and forms a conical extremity termed the **conus medullaris**. From the end of the conus medullaris a slender glistening thread is prolonged downwards within the vertebral

canal, and finally anchors the cord to the back of the coccyx. The prolongation receives the name of the **filum terminale**.

The diameter of the cord is very much smaller than that of the vertebral canal The wide interval left between it and the walls of its canal is clearly a provision for allowing free movement of the vertebral column without producing any jarring contact between the cord and the surrounding bones.

Three protective membranes invest the cord. From within outwards they are termed (1) the pia mater, (2) the arachnoid mater, and (3) the dura mater. The **pia mater** is a vascular membrane of trabecular tissue which forms the immediate investment. It is closely applied to the cord, and from its deep surface numerous fine septa penetrate into the substance of the cord. The **arachnoid mater** is an exceedingly delicate, transparent membrane which is loosely wrapped around the cord so as to leave a considerable interval between itself and the pia mater, termed the subarachnoid space, in which there is always a varying amount of cerebro-spinal fluid. Outside the arachnoid mater the **dura mater** forms a wide, dense, fibrous sheath which extends downwards for a considerable distance beyond the cord. The cord is suspended within its sheath of dura mater by a pair of wing-like ligaments, termed the **ligamenta denticulata**, which extend from the sides of the spinal cord, and each of them is attached by a series of pointed tooth-like processes to the inner surface of the dura mater (Fig. 880). Between the wall of the vertebral canal and the dura mater there is a narrow interval, called the *extradural space*, which is filled up by soft areolo-fatty tissue and numerous thin-walled veins arranged in a plexiform manner. The existence of this space allows for a considerable variation in the volume of cerebro-spinal fluid which surrounds the spinal cord. For further details, see p. 999.

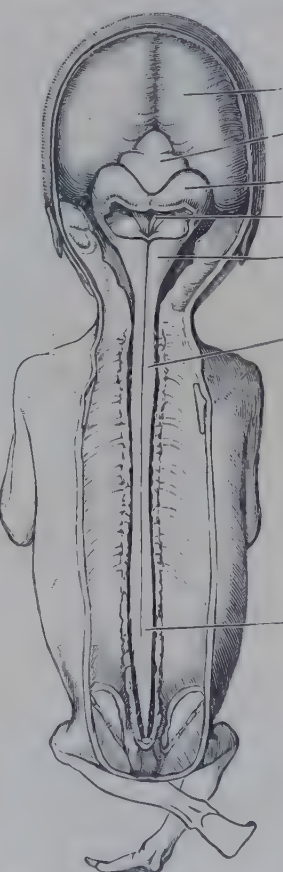


Fig. 741.—Human Fœtus in Third Month of Development, with Brain and Spinal Cord exposed from behind.

Thirty-one pairs of spinal nerves arise from the spinal cord. They are classified into eight cervical, twelve thoracic, five lumbar, five sacral, and one coccygeal; and, according to the attachments of these groups of nerves, the cord is divided into cervical, thoracic, lumbar, and sacral *regions*. It must be understood that these regions are determined by the nerve-attachments and not by any direct relationship between the parts of the spinal cord and the sections of the vertebral column which bear the same names. The differential growth between the spinal cord and the vertebral canal (to which reference has already been made) necessarily alters the primitive relations between the segmental levels of the spinal cord and the corresponding vertebral segments. Thus, in the adult, the first thoracic segment of the cord lies opposite the sixth cervical vertebra, and the first lumbar segment opposite the ninth thoracic vertebra.

Each spinal nerve is attached to the cord by an anterior and a posterior root, and as the roots are traced to their central attachments they are seen to break up into a number of separate bundles which spread out (in some cases very widely) as they approach the cord (Fig. 743). Each pair of nerves is therefore attached to a portion of cord of some length, and such a portion receives the name of a *segment* of the spinal cord. There is, however, no means of marking off one segment from another except by the attachments of the nerve-roots.

In the cervical and lumbar regions the nerve-roots are crowded together, so that little or no interval is left between the roots of neighbouring nerves. In the thoracic region, however, distinct intervals may be observed, and the root-bundles are more loosely arranged. From this it will be evident that the segments are not of equal length. In the cervical region they

measure about 12 mm. in length, in the thoracic region from 20 to 24 mm., and in the lumbar region about 10 mm.

Owing to the great difference between the lengths of spinal cord and vertebral column, the farther we pass down the greater is the distance between the attachment of the nerve-roots and the intervertebral foramina through which the corresponding nerves leave the vertebral canal. As the nerve-roots do not unite to form a spinal nerve-trunk till they reach the intervertebral foramen, it thus happens that the nerve-roots which spring from the lumbar and sacral regions attain a very great length and descend vertically in the lower part of the vertebral canal in a bunch or leash, in the midst of which lie the conus medullaris and the filum terminale. This great bundle of nerve-roots receives the appropriate name of the **cauda equina**.

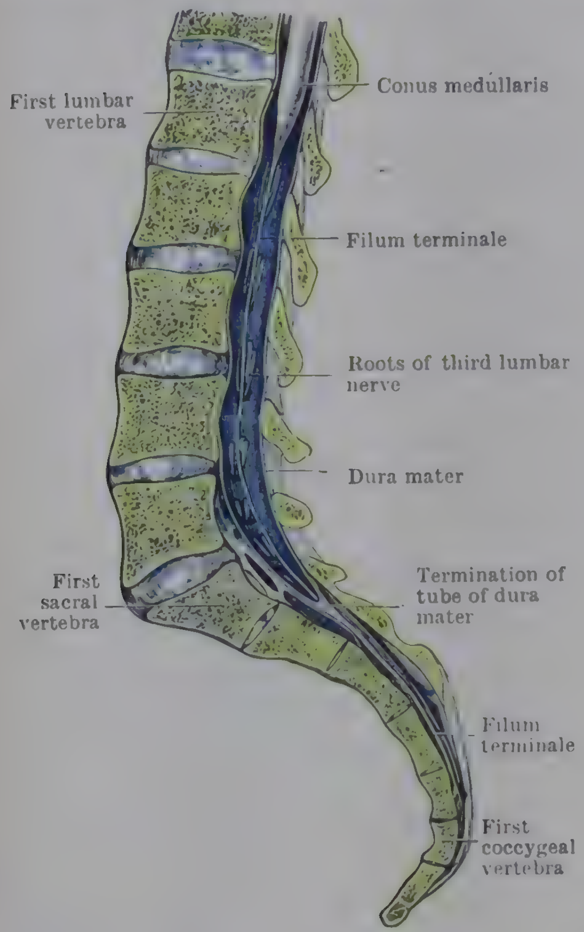


Fig. 742.—Conus Medullaris and the Filum Terminale.

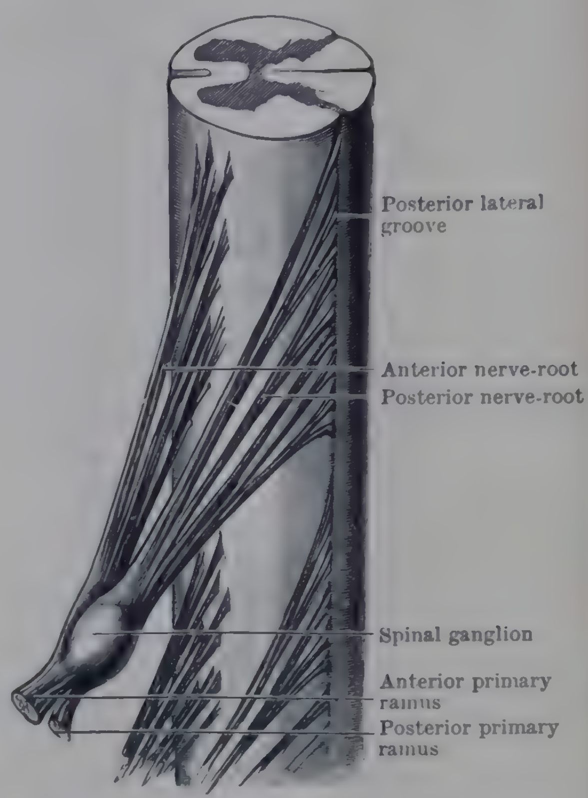


Fig. 743.—Roots of the Seventh Thoracic Nerve (semi-diagrammatic).

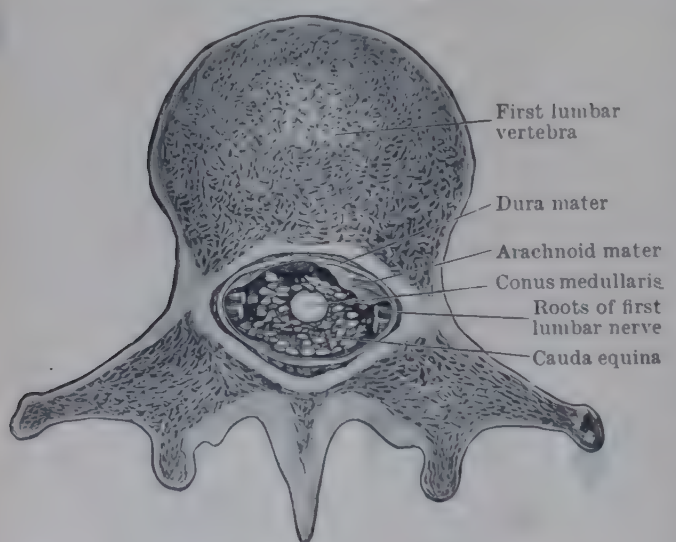


Fig. 744.—Section through Conus Medullaris and Cauda Equina as they lie in the Vertebral Canal.

Enlargements of Spinal Cord.—Throughout the greater part of the thoracic region, the cord presents a uniform girth, and a very nearly circular outline in transverse section. In the cervical and lumbar regions, however, it shows marked swellings. The **cervical enlargement** is the more evident of the two. It begins very gradually at the upper end of the cord, attains its greatest breadth (12 to 14 mm.) opposite the fifth or sixth cervical vertebra, and finally subsides opposite the second thoracic vertebra. This portion of the cord gives attachment to the great nerves which supply the upper limbs. The **lumbar enlargement** begins at the level of the tenth thoracic vertebra, and

acquires its maximum transverse diameter (11 to 13 mm.) opposite the last thoracic vertebra. Below, it rapidly tapers away into the conus medullaris. To the lumbar enlargement are attached the great nerves of the lower limbs.

The enlargements of the cord are associated with the outgrowth of the limbs. In the earlier developmental stages they are not present, and they take form only as the limbs become developed. In different animals their size corresponds to some extent with the size of the limbs. Thus, in the long-armed orang and gibbon the cervical swelling is very pronounced.

Development of Spinal Cord.—The early stages of the process by which the originally simple epithelial neural tube becomes converted into the central

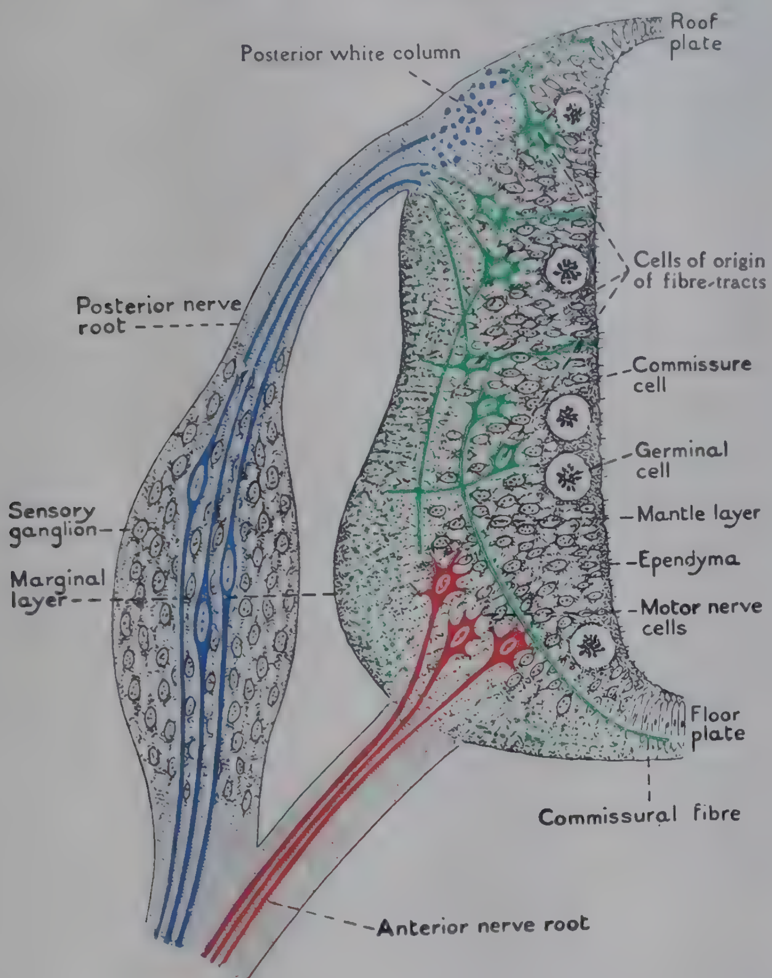


FIG. 745.—DIAGRAM OF TRANSVERSE SECTION OF EARLY NEURAL TUBE.

nervous system have already been considered. It remains to be explained how the features specially distinctive of the spinal cord are produced.

In the early stages (Fig. 745), the neuroblasts are scattered in the intermediate one of the three zones of which the thick side-wall of the neural tube is composed—the mantle layer. The motor nerve-cells soon congregate in large numbers in the ventral part of the basal lamina (Fig. 746), so that the mantle layer expands there into a broad excrescence, which is the rudiment of the **anterior grey column**. The anterior grey column contains the efferent or motor nerve-cells, the axons of which emerge as the **anterior root** of a spinal nerve. At this stage the rest of the mantle layer consists of a thin stratum of neuroblasts (Fig. 746)—mainly intercalated cells—which receive the sensory impressions that enter the cord through the **posterior root** and transmit impulses into axons passing (*a*) to the motor nuclei of the same side, (*b*) to the other side of the cord through the floor-plate (Fig. 745), or (*c*) into the superficial stratum (peripheral layer) of the cord, where they bend upwards or downwards as constituent elements of the **white columns**. As development proceeds (Fig. 745) the **grey substance** formed of these intercalated cells becomes much more abundant and forms a broad blunt boss (Fig. 746 B and C) which is the rudiment of the **posterior grey column**.

The surfaces of the grey columns become coated with a layer of white matter,

composed at first mainly of the medullated axons of cells in the root-ganglia and intercalated cells in the cord; and as the white columns increase in thickness they help to mould the form of the grey columns. This is displayed best in the case of the posterior grey column. The major portion of the white substance which accumulates behind (and afterwards lies on the medial side of) the posterior grey column—the **posterior white column**—does not consist of fibres springing from intercalated cells, either of the cord or any other part of the central nervous system, but of the direct continuations of the central processes of the cells in the spinal ganglia (Figs. 745 and 746). A large proportion of the fibres of the posterior root do not enter the grey columns immediately after their insertion into the alar lamina, but bifurcate to form two vertical nerve-fibres, one passing upwards and the other downwards, in the posterior white column before they end in the grey column some distance above or below the the place where they gained admission to the cord. As the cord grows, the originally blunt posterior grey column becomes drawn backwards into an increasingly attenuated edge and the posterior white column, which was placed originally upon its lateral surface (Fig. 746 A), and then upon its posterior surface (Fig. 746 B), gradually assumes a wedge-shaped form (Figs. 746 C and 748), on the medial side of the grey matter.

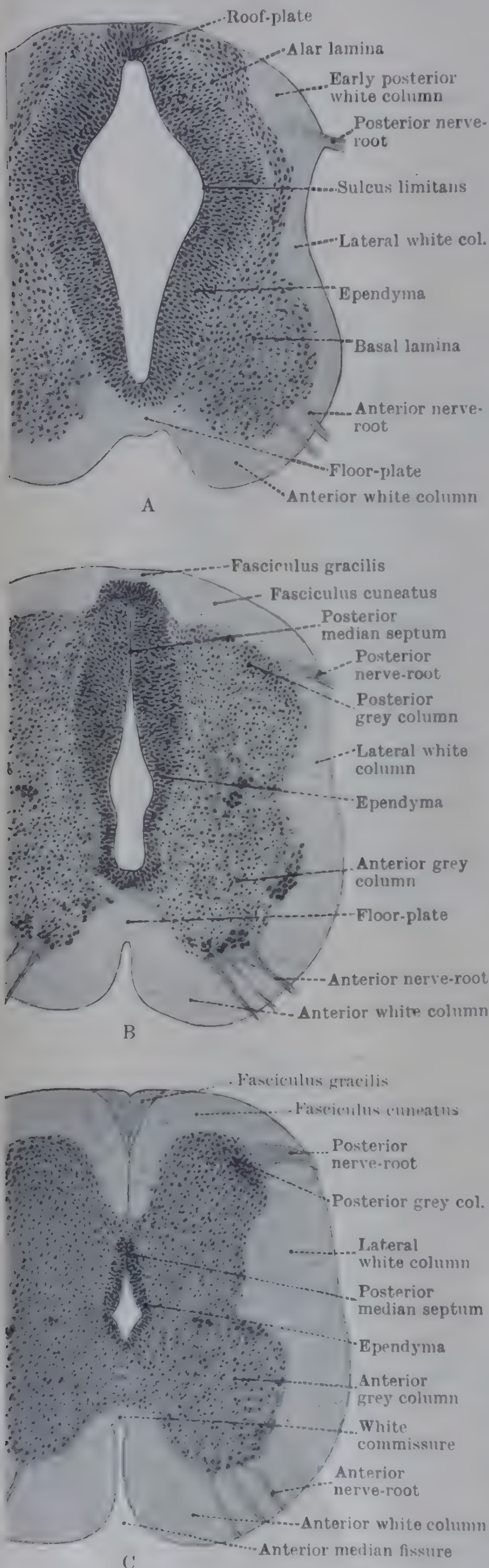


Fig. 746.—Three Stages in the Development of Spinal Cord. (After His.)

Development of Anterior Median Fissure, Posterior Median Septum, and Central Canal.—As the anterior columns of grey matter and white matter increase in size, the anterior surface of the cord, on each side of the median plane, bulges forwards, and the **anterior median fissure** (Fig. 746 A, B, and C) is produced as the natural result.

There has been considerable discussion as to the mode of formation of the **posterior median septum**; but there is no doubt as to the essential facts. Early in the third month the walls of the posterior three-fourths (of the sagittal extent) of the **central canal** become approximated (Fig. 746), and later they fuse to obliterate that part of the canal. But the part of the septum thus formed is only an insignificant portion of the whole. For most of the septum is produced by the gradual elongation of the epithelial cells that line the remnant of the central canal as the fibre-masses of the posterior white columns expand and separate the posterior surface of the cord farther and farther from the canal (see Fig. 735).

Furrows of Spinal Cord.—When cross-sections of the adult cord are made it is seen to be a bilateral structure partially divided into a right and a left half by the anterior median fissure in front and the posterior median septum behind. The anterior median fissure penetrates for rather less than a third of the antero-posterior diameter of the cord. The pia mater dips into it and forms a fold within it. The posterior median septum in the cervical and thoracic regions penetrates into the cord until it reaches a point slightly beyond its centre. It is extremely thin, and consists of ependymal and neuroglial elements, and is intimately connected with the adjacent sides of the two halves of the cord. The pia mater passes over the posterior median septum and sends no prolongation into it. In the lumbar region the septum becomes shallower, whilst the anterior median fissure deepens, and ultimately in the lower part of the cord the fissure and septum are very nearly equal in depth.

The two halves of the cord may show slight differences in the arrangement of parts; but they are virtually symmetrical. They are joined together by a fairly broad commissure which intervenes between the median fissure and the septum.

An inspection of the surface of each half of the cord brings into view a longitudinal groove or furrow at some little distance from the posterior median septum, along its whole length. Through the bottom of this groove the bundles of the posterior nerve-roots enter the spinal cord in accurate linear order. There is no corresponding furrow on the anterior part of each half of the cord in connexion with the emergence of the bundles of the anterior nerve-roots. They emerge irregularly over a broad strip of the anterior surface of the cord which corresponds in its width to that of the subjacent anterior grey column.

The grey columns and the nerve-roots divide the white matter into three white columns—anterior, lateral and posterior—the most lateral of the bundles of the anterior roots being taken as the line of demarcation between the anterior and lateral columns.

In the cervical region a distinct longitudinal groove (sulcus intermedius posterior) marks on the surface the position of a septum of pia mater which dips into the cord and divides the posterior white column into a lateral part termed the **fasciculus cuneatus** and a medial portion named the **fasciculus gracilis**.

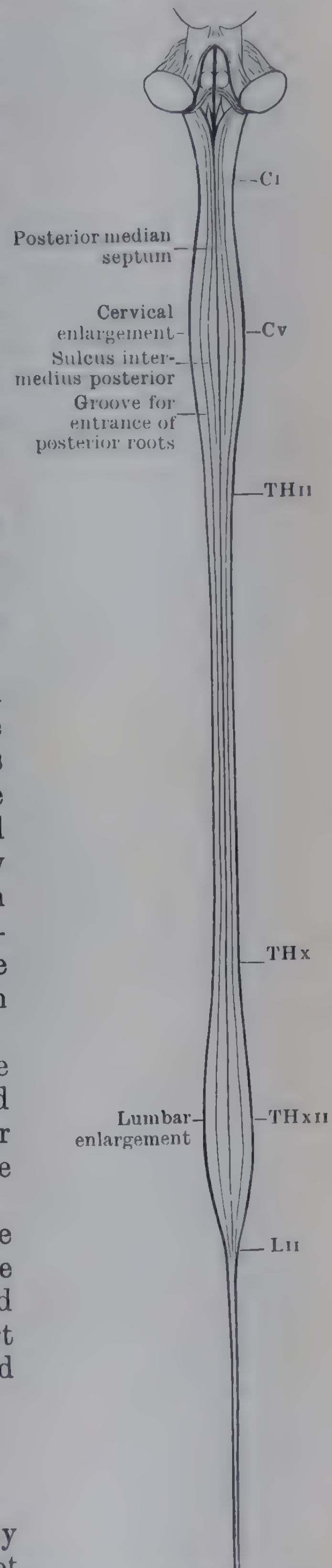


Fig. 747.—Diagram of the Spinal Cord as seen from behind.

Ci, Cv, etc., indicate levels in relation to the vertebræ.

Internal Structure of Spinal Cord

The spinal cord is composed of a central core of grey matter thickly coated with white matter. At only one spot does the grey matter come close to the surface, viz., at the entrance of the posterior nerve-roots.

Grey Matter of Spinal Cord.—The grey matter of the cord has the form of a fluted column, but it is customary to describe it as it appears in transverse sections. It then presents the appearance of the capital letter H. In each half of the cord there is a crescentic mass, the concavity of which is directed laterally. The crescents of opposite sides are connected across the median plane by a transverse band named the **grey commissure**. The posterior median septum extends forwards until it reaches the grey commissure. The bottom of the anterior median fissure, however,

is separated from it by a strip of white matter termed the **white commissure** (Fig. 749 A). In the grey commissure may be seen the **central canal**, which tunnels the entire length of the cord and is just visible to the naked eye as a minute speck.

Each crescentic mass of grey matter presents certain well-defined parts. The portions behind and in front of the grey commissure are termed respectively the **posterior** and the **anterior horns** and are the corresponding grey columns as seen in cross-section. They stand out in marked contrast to each other. The **anterior horn** is short, thick, and very blunt at its extremity. Further, its extremity is separated from the surface of the cord by a moderately thick layer of white matter. Through this layer the bundles of the anterior nerve-roots pass on their way to the surface. Throughout the greater part of the cord the **posterior horn** is elongated and narrow, and is drawn out to a fine point which almost reaches the surface (Fig. 748).

The apical part of the posterior horn differs a little in appearance from the general mass of the grey matter. It has a lighter and more translucent look and is called the **substantia gelatinosa**; it is V-shaped in outline and fits on the posterior horn like a cap.

In the thoracic region of the spinal cord, a pointed projection juts out from the lateral side of the grey matter nearly opposite the grey commissure. This is **the lateral horn** (Fig. 749 B). Traced upwards it becomes absorbed in the greatly expanded anterior grey column of the cervical enlargement. Followed in a downward direction it blends with the anterior column in the lumbar enlargement and contributes to the thickening of that column.

The grey matter is for the most part fairly sharply mapped off from the surrounding white matter; but in the cervical region, on the lateral side of the crescentic mass, fine bands of grey matter penetrate the white matter, and, joining with one another, form a network, the meshes of which enclose small islands of white matter. This constitutes what is called the **formatio reticularis** (Fig. 748). Although best marked in the cervical region, traces of the same reticular formation may be detected in the lower segments.

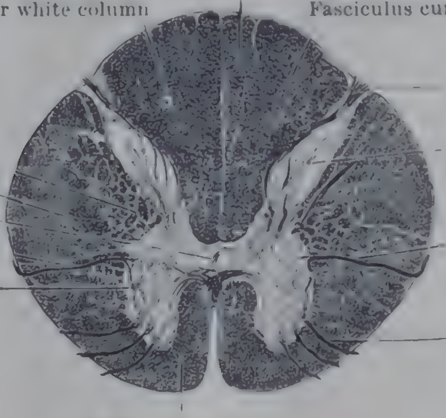


FIG. 748.—TRANSVERSE SECTION OF UPPER PART OF CERVICAL REGION OF SPINAL CORD. (From a specimen prepared by the Weigert-Pal method, by which the white matter is made dark and the grey matter bleached.)

Characters presented by Grey Matter in Different Regions of Spinal Cord.—The grey matter is not present in equal quantity nor does it exhibit the same form in all regions of the cord. Indeed, each segment presents its own special characters in both respects; but it will be sufficient if the broad distinctions which are evident in the different regions are pointed out.

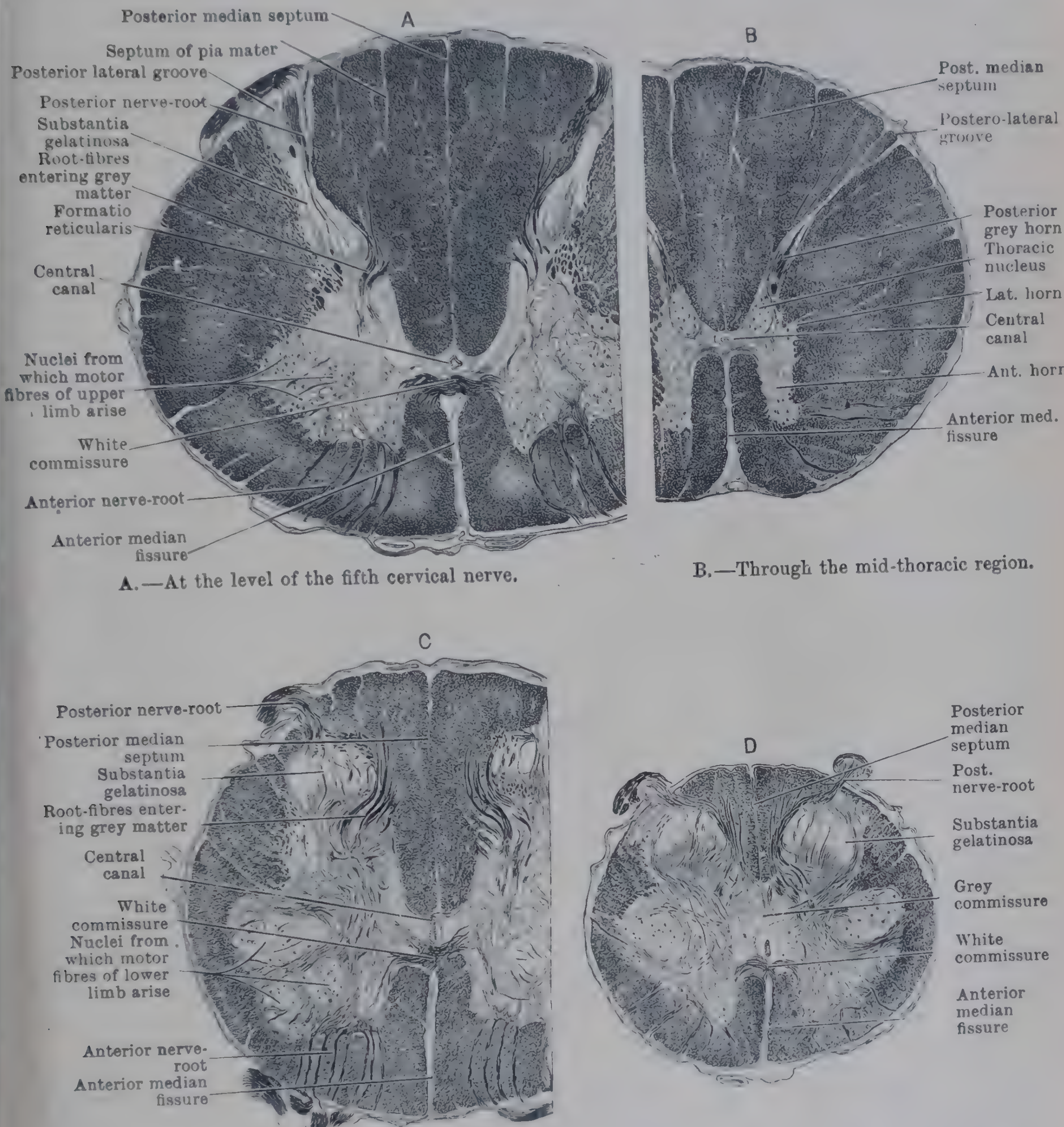
Wherever there is an increase in the size of the nerves attached to a particular part of the cord, a corresponding increase in the amount of grey matter will be observed. The regions where the grey matter bulks most largely are therefore the lumbar and cervical enlargements, for the great nerve-roots which go to form the nerves of the large limb-plexuses enter and pass out from these portions of the cord. In the thoracic region there is a reduction in the quantity of grey matter, in correspondence with the smaller size of the thoracic nerves.

In the *thoracic region* (Fig. 749 B) both horns of grey matter are narrow, but the posterior horn is the more attenuated. In this region the lateral horn also is characteristic, and the substantia gelatinosa in transverse section is pointed and attenuated.

In the upper three segments of the *cervical region* the anterior horns are not

large, and here they resemble the corresponding horns in the thoracic region. But in these segments (and more especially in the first and second) there is a marked attenuation of the neck of the posterior horn, and the grey commissure is very broad.

In the cervical enlargement the contrast between the two horns is most striking; the anterior horn is of great size and presents a very broad surface towards the front of the cord, whilst the posterior horn remains narrow. The great increase



A.—At the level of the fifth cervical nerve. B.—Through the mid-thoracic region.

C.—At the level of the fourth lumbar nerve. D.—At the level of the third sacral nerve.

FIG. 719.—SECTIONS THROUGH EACH OF THE FOUR REGIONS OF SPINAL CORD. (From specimens prepared by the Weigert-Pal method: the white matter is dark; the grey matter is bleached.)

in the bulk of the anterior horn is due to a marked addition of grey matter on its lateral side, and, seeing that this additional matter is traversed by a greater number of fibres, it stands out, in well-prepared specimens, more or less distinctly from the part of the horn that lies to the medial side and represents the entire anterior horn in the thoracic and upper cervical segments. This lateral addition contains the nuclei of origin of the motor nerves of the upper limb. The characteristic thickening of the anterior horn is evident, therefore, in those segments of the spinal cord which supply fibres to the brachial plexus, viz., the lower five cervical segments and the first thoracic segment.

In the *lumbar region* the anterior horns again broaden out for the lumbar enlargement, and for the same reason as in the cervical enlargement. The nuclear masses from which the motor fibres of the lower limbs take origin are added to the lateral part of the columns and give them a very characteristic appearance. In this region, however, the posterior horns also are broad and are capped by substantia gelatinosa which has a semilunar outline. There is consequently no difficulty in distinguishing, from an inspection of the grey matter alone, between transverse sections of the spinal cord taken from the cervical and lumbar enlargements.

In the lower part of the **conus medullaris** the grey matter in each half is an oval mass joined to its fellow of the opposite side by a thick grey commissure. Here, almost the entire bulk of the cord consists of grey matter, the white matter being reduced to a thin coating on the surface.

White Matter of Spinal Cord.—In transverse sections of the cord, the three columns into which the white matter is divided become very apparent. The **posterior white column** is wedge-shaped, and it lies between the posterior median septum and the posterior grey column. The **lateral white column** occupies the concavity of the grey crescent. Behind, it is bounded by the posterior grey column, whilst in front it extends as far as the most lateral fasciculi of the anterior nerve-roots. The **anterior white column** includes the white matter between the anterior median fissure and the anterior grey column, and also the white matter in front of the anterior grey column. The latter portion is traversed by the emerging fibres of the anterior nerve-roots.

In cross-sections the partition of pia mater which divides the posterior white column into the **fasciculus gracilis** and the **fasciculus cuneatus** is very strongly marked in the cervical region, but as it is traced downwards it becomes shorter and fainter, and finally disappears altogether at the level of the eighth thoracic segment.

The white matter is not present in equal quantity throughout the entire length of the spinal cord. It increases steadily from below upwards, and this increase is most noticeable in the lateral and posterior columns. The increase is simply related to the fact that the ascending sensory tracts of the cord become gradually more bulky as they receive accessions from succeeding posterior nerve-roots, while, in a reverse direction, the motor tracts become more attenuated as their component fibres end at successive levels in the anterior grey column. In the lower part of the conus medullaris the amount of grey matter is actually greater than that of the white matter; but in the lumbar region the proportion of grey to white matter is approximately 1 : 2, and in the thoracic and cervical regions 1 : 5.

Central Canal.—The central canal is a very minute tunnel situated in the grey commissure and is barely visible to the naked eye in transverse section. It traverses the entire length of the spinal cord; above, it passes into the medulla oblongata, where it opens into the fourth ventricle of the brain; below, it is continued for about 5 mm. into the filum terminale, and there it ends blindly. Only in the lumbar region does the central canal occupy the centre of the cord. In the thoracic and cervical regions, it lies much nearer the front than the back of the cord; but, as it is traced down into the conus medullaris, it inclines backwards. The width of the canal also varies in different parts of the cord. It is narrowest in the thoracic region; and in the lower part of the conus medullaris it expands into a fusiform dilatation very nearly 1 mm. in diameter.

The central canal is at first lined with a layer of ciliated columnar cells whose outer ends taper into slender processes which penetrate into the substance of the cord; but their cilia are very early lost, and it is not uncommon to find the canal blocked up by epithelial debris.

Filum Terminale.—The delicate thread to which this name is applied is continuous with the pia mater at the end of the conus medullaris. It is easily distinguished, by its silvery and glistening appearance, from the nerve-roots (**cauda equina**) amidst which it lies. It is about 18 cm. in length; and down to the level of the second sacral vertebra it is enclosed with the nerve-roots within the arachnoid and dura mater; as it pierces them at that point it derives a sheath from the dura mater. It then proceeds downwards in the sacral canal, and finally gains attachment to the periosteum on the back of the coccyx

(Fig. 742, p. 856). It encloses the lowest part of the central canal surrounded by a variable amount of grey matter. Clinging to the outer surface of the grey matter there are some bundles of nerve-fibres associated with some nerve-cells identical with those in the spinal ganglia. These nerve-fibres are believed to represent vestigial caudal nerves.

Component Parts of Grey Matter of Spinal Cord

As elsewhere in the central nervous system, **neuroglia** enters largely into the constitution of the grey matter of the cord. The **nervous elements** are (1) nerve-cells and (2) nerve-fibres—both medullated and non-medullated.

In two situations the grey matter presents peculiar features, viz., the apex of the posterior grey column and the tissue around the central canal. In both situations the grey matter stains more deeply with carmine and is more translucent; in other respects the central grey matter and the substantia gelatinosa are very different. The **central grey matter** forms a thick ring around the central canal. It is composed almost entirely of neuroglia, and is traversed by the fine processes from the outer ends of the ependymal cells which line the canal. In transverse sections, the **substantia gelatinosa**, in the cervical and thoracic regions, is V-shaped in outline, and embraces the tip of the posterior grey horn; in the lumbar region this cap has a semilunar outline. In the substantia gelatinosa the neuroglia is present in small quantity, and it is composed mainly of small nerve-cells in considerable numbers.

Nerve-Cells.—The nerve-cells are scattered plentifully throughout the grey matter, but perhaps not in such great numbers as might be expected when we note the enormous number of nerve-fibres with which they stand in relation. They are mostly multipolar, and send off several branching dendrites and one axon. In size they vary considerably, and as a rule (to which, however, there are many exceptions) the bulk of a nerve-cell has a relation to the length of the axon which proceeds from it.

When the nerve-cells are studied in a series of transverse sections of the spinal cord, it will be noticed that a large proportion of them are grouped in clusters in certain districts of the grey matter; and as these groups are seen in very much the same position in successive sections, it is clear that the cells are arranged in longitudinal columns of greater or less length. Thus, we recognize: (1) a ventral column of cells in the anterior grey column; (2) an intermedio-lateral column in the lateral grey column, where that exists; and (3) a postero-medial column of cells (thoracic nucleus), forming a most conspicuous group in the medial part of the neck of the posterior grey column in the thoracic region.

Other cells, besides those forming these columns, are scattered irregularly throughout the posterior grey column and the part of the grey crescent which lies between the two columns.

Ventral Cell-Columns and the Origin of Fibres of Anterior Nerve-Roots.—The ventral cell-groups occupy the anterior grey column, and in them are found the largest and most conspicuous cells in the spinal cord. They extend from one end of the cord to the other. These ventral nerve-cells have numerous wide-spreading dendritic processes, and it is to be noticed that certain of the dendrites do not confine their ramifications to the grey matter. Thus, some of the cells along the medial border of the anterior grey column send dendrites across the median plane in the commissure to end in the anterior grey column of the opposite side; whilst others, lying along the lateral margin of the anterior grey column, send dendrites in amongst the nerve-fibres of the adjoining white matter.

The axons of a large proportion of the ventral cells converge together, and, becoming medullated, they form bundles which pass out from the grey matter and through the white matter in front of the anterior grey column to emerge finally as the fibres of the anterior nerve-roots. These cells, then, are the sources from which the nerve-fibres of the anterior nerve-roots proceed, and in consequence they are frequently spoken of as the "motor cells" of the spinal cord. Whilst this is the arrangement of the axons of the great majority of the motor cells, it should be

noted that a few cross the median plane in the white commissure and emerge among the fibres of origin of the opposite anterior nerve-root.

The ventral cells are not scattered uniformly throughout the anterior grey column. They are aggregated more closely together in certain parts, and thus form sub-columns more or less perfectly marked off from each other.

Thus, one sub-column of ventral cells occupies the medial part of the anterior grey column throughout almost its whole length. In only two segments of the cord is it

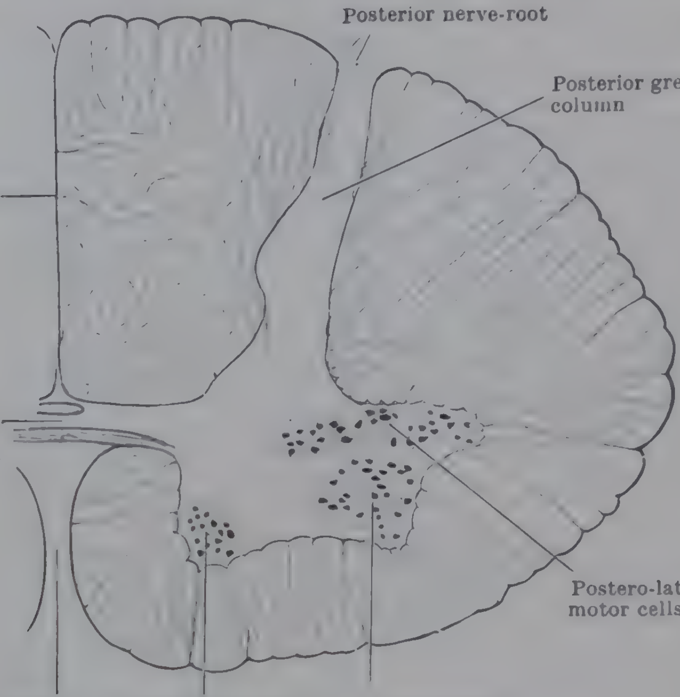


FIG. 750.—SECTION THROUGH FIFTH CERVICAL SEGMENT OF SPINAL CORD.
This and the following three figures are founded on Plates in Bruce's *Atlas of the Spinal Cord.*

absent, viz., the fifth lumbar and the first sacral; at that level alone is its continuity broken. It is termed the *antero-medial column* or group of ventral cells. Behind that cell-column there is another classed with it to which the name of *postero-medial column* is given, but this column of cells is not continuous throughout the entire length of the spinal cord. It is present in the thoracic region, where the motor nuclei for the muscles of the limbs are absent; and it is seen also in two or three of the segments of the cervical region and in the first lumbar segment; elsewhere it is not represented.

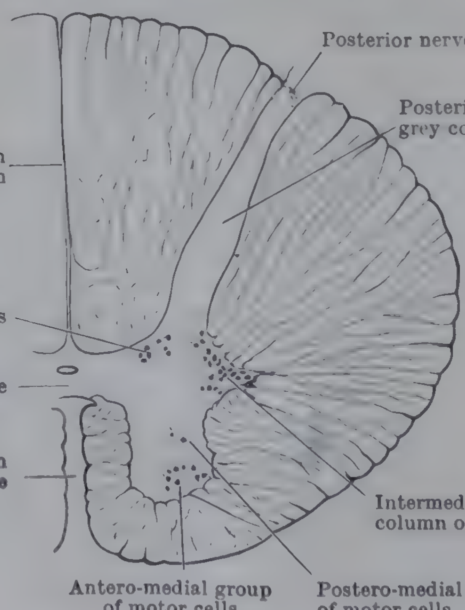


FIG. 751.—SECTION THROUGH EIGHTH THORACIC SEGMENT.

In the cervical and lumbar enlargements, where the marked lateral out-growth is added to the lateral side of the anterior grey column, certain groups of large multipolar cells are visible. They are the nuclei of origin of the motor fibres of the limbs, and consequently they are not represented in the upper three cervical segments, nor in any of the thoracic segments (with the exception of the first) nor in the lowest two sacral segments.

These *lateral cells* are arranged in several columns which extend for varying distances in the superadded lateral parts of the anterior grey column.

The two main columns are an *antero-lateral* and a *postero-lateral column*; in certain segments there is also a *retro-postero-lateral column*, and in a number of segments in the lumbar and sacral regions a *central column* of cells (Bruce, 1901; Romanes, 1941).

There can be no doubt that the grouping of the motor cells in the anterior grey column stands in relation to the muscle-groups to which their axons are distributed; but from what has been said it will be apparent that sharply defined cell-clusters associated with particular muscles do not exist. Still, much can be learned regarding the localization of the motor nuclei in the anterior grey column from the study of the changes which occur in the cell-columns after atrophy of isolated muscles or groups of muscles, and after complete or partial amputation of limbs. It has been pointed out that the long muscles of the trunk (as, for example, the different parts of the sacro-spinalis muscle) receive nerve-fibres from all the segments of the cord. Now, it has been noted that there is only one cell-column—the antero-medial column—which pursues an almost uninterrupted course throughout the entire length of the cord. It may be assumed, therefore, that the nerve-fibres which go to the long trunk-muscles take origin in those medial cells.

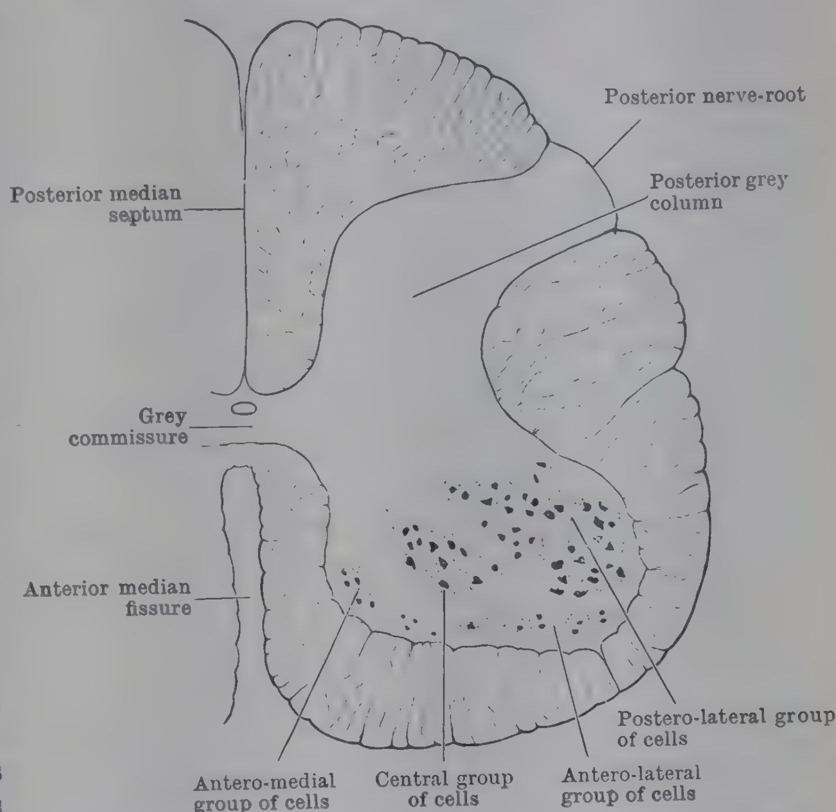


Fig. 752.—Section through Third Lumbar Segment of Cord.

Intermedio-Lateral Cell-Column.—The intermedio-lateral cells form a long slender column which extends throughout the entire thoracic region in the lateral grey column and is prolonged into the first and second lumbar segments. In transverse sections through the cord, this column presents a very characteristic appearance, because its cells are small and are closely packed together. Although these cells, as a continuous column, are restricted to the region indicated, it should be noted that part of the same group reappears in the third and fourth sacral segments. From these cells very fine fibres arise and leave the spinal cord, intermingled with the motor fibres of the anterior nerve-roots; they pass into the sympathetic ganglia, of which they constitute the white rami communicantes. They are the splanchnic efferent fibres of the cord.

Thoracic Nucleus.—This occupies the posterior grey column and is the most conspicuous of all the cell-groups in the cord. It does not, however, extend along its whole length; indeed, it is almost entirely confined to the thoracic segments of the cord, which is the reason for the designation "thoracic nucleus". It begins opposite the seventh or eighth cervical nerve, and it ends at the level of the second lumbar nerve. In transverse section it presents an oval outline and is seen in the medial part of the neck of the posterior grey column immediately behind the grey commissure (Fig. 751). On the lateral side it is circumscribed by numerous curved fibres from the entering posterior nerve-root, and in the lower thoracic region (opposite the eleventh and twelfth thoracic nerves) it becomes so marked that it forms a bulging on the medial side of the posterior grey column.

The cells of the thoracic nucleus are large, and have several dendrites. The axons enter the lateral white column to form a strand of fibres described later as the posterior spino-cerebellar tract.

Nerve-Fibres in Grey Matter of Spinal Cord.—Nerve-fibres, both medullated and non-medullated, pervade every part of the grey matter. They are of three kinds, viz., (1) main axons of the cells, (2) collaterals, (3) terminations of nerve-fibres. Many of the nerve-fibres which compose the white columns give off numerous fine collateral branches which pass into the grey matter from all sides and finally end in relation with the nerve-cells. The majority of the nerve-fibres themselves, which thus give off collaterals, finally enter the grey matter and end similarly. The axons of the majority of the cells in the grey matter leave it and enter either a peripheral nerve or a tract in the white matter.

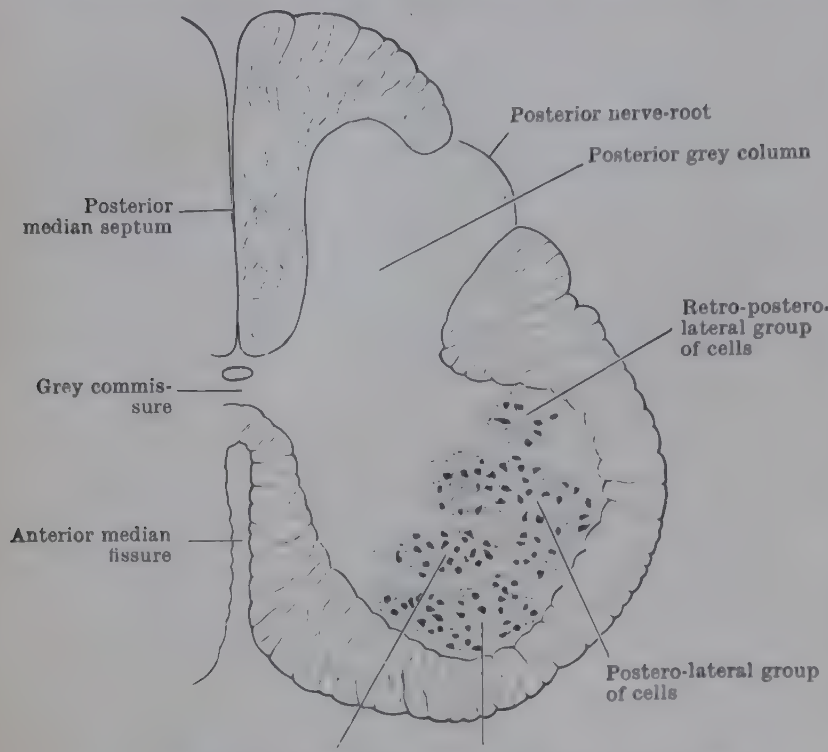


FIG. 753.—SECTION THROUGH FIRST SACRAL SEGMENT.

The nerve-fibres thus derived are interwoven together in the grey matter in a dense and seemingly inextricable interlacement.

COMPONENT PARTS OF WHITE MATTER OF SPINAL CORD

The white matter is composed of nerve-fibres embedded in neuroglia. The fibres, for the most part, pursue a longitudinal course; and, from the deep surface of the pia mater, fibrous septa are carried in along vertical planes between the fibres so as to form an irregular and very imperfect fibrous framework of support. The neuroglia is disposed in a layer of varying thickness subjacent to the pia mater, and it is carried into the cord so as to give a coating to both sides of the various pial septa. The neuroglia is disposed also around the various nerve-fibres, so that each of them may be said to lie in a sheath of that substance. The nerve-fibres are mostly medullated, but have no investment of Schwann cells. It is the medullary substance of the nerve-fibres which gives to the white matter its opaque, milky-white appearance. When a thin transverse section is stained in carmine and examined under the microscope the white matter presents the appearance of a series of closely applied circles, each with a dot in the centre (Fig. 754). The dot is the cut axon, and the dark ring which forms the circumference of the circle is the wall of the neuroglial canal occupied by the fibre. The medullary substance is very faintly seen. It presents a filmy or cloudy appearance between the axon and the neuroglial ring.

Arrangement of Nerve-Fibres of White Matter in Tracts.—When the white matter of a healthy adult spinal cord is examined, the fibres are seen to vary considerably in size; and although there are special places where larger or smaller nerve-fibres are present in greater numbers than elsewhere, yet, as a rule, both large and small fibres are mixed together. From normal preparations no definite indication can be obtained of the fact that the longitudinally arranged fibres are grouped together in more or less discrete tracts, the fibres of which run a definite course and present definite connexions. Yet this is known to be the case, and the existence of the separate tracts has been proved both by embryological

investigation and by the examination of the effects of injuries produced in the nervous system experimentally in living animals or accidentally in Man.

By the **experimental method** it has been shown that when a nerve-fibre is severed the part which is detached from the nerve-cell degenerates, whilst the part which remains connected with the nerve-cell undergoes little or no change. This is called "Wallerian" degeneration. Thus, if in a living animal one-half of the spinal cord is cut across, and after a few weeks the animal is killed and the cord examined, it will be seen that there are degenerated tracts of fibres in the white matter both above and below the plane of division; but, still further, it will be manifest also that the tracts which are degenerated above the plane of division are not the same as those which are degenerated below that level. The interpretation is obvious. The nerve-tracts which have degenerated above the plane of section are the offshoots of nerve-cells which lie in lower segments of the cord or in spinal ganglia below the plane of section. Severed from their nerve-cells, they undergo what is called *ascending degeneration.* On the other hand, the nerve-tracts which have degenerated in the portion below the plane of division are the axons of cells which lie at a higher level than the plane of section—either in higher segments of the spinal cord or in the brain itself. Cut off from the nerve-cells from which they proceed, they provide an example of *descending degeneration.*

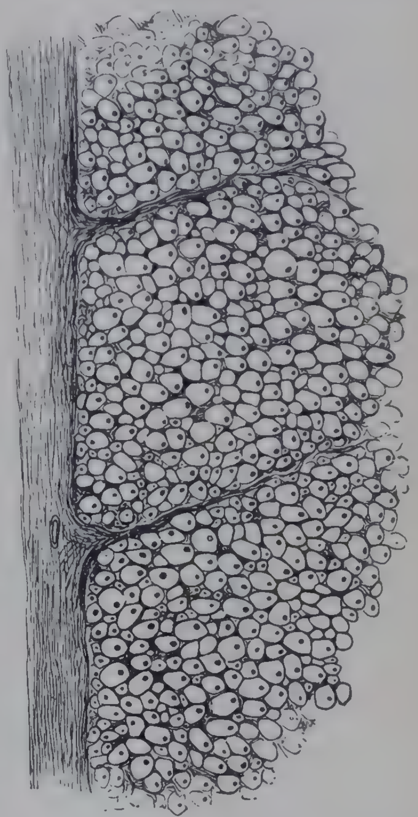


Fig. 754.—Transverse Section through White Matter of Spinal Cord. (Highly magnified.)

The **embryological method** was first employed by Flechsig, and it is often referred to as Flechsig's method. It is based upon the fact that nerve-fibres in the earliest stages of their development are naked axons, unprovided with medullary sheaths. Further, the nerve-fibres of different strands assume their medullary sheaths at different periods. If the fœtal central nervous system is examined at different stages of its development, it is in some cases possible to locate the different tracts of fibres by evidence of this kind. Speaking broadly, the fibres which myelinate first are those which bring the central nervous system into relation with the peripheral parts (skin, muscles, etc.); then, those fibres which bind the various segments of the central nervous system together; next, those which connect the spinal cord with the cerebellum; and, lastly, the tracts which connect the cerebral hemispheres with the spinal cord. The fibre-tracts concerned in the performance of automatic movements therefore become mature before those which provide for the controlling influence of the higher centres. It by no means follows that in all the higher animals corresponding strands myelinate at relatively corresponding periods. Take a young animal which from the time of its birth is able to move about and perform voluntary movements of various kinds in a more or less perfect manner, and compare it with the helpless new-born infant, which is capable of automatic movements only. In the lower animal, the motor tracts which descend from the cerebrum into the spinal cord myelinate at an early period; in the infant, the corresponding fibres do not obtain their medullary sheaths until after birth. The study of the dates at which the various strands of nerve-fibres myelinate therefore not only gives the anatomist a means of locating their position in the white matter of the central nervous system, but also provides some indication of their functions and the periods at which these functions become fully operative (Langworthy, 1923; Lucas Keene & Hewer, 1931; Romanes, 1947).

It is a matter of interest to note that influences which either accelerate or retard the periods at which nerve-fibres are brought into functional activity have also an effect in determining the dates at which the fibres assume their sheaths of myelin. Thus, when a child is prematurely born the whole process of myelination is, as it were, hurried up; and further, when in new-born animals light is freely admitted to one eye and carefully excluded from the other, the fibres of the optic nerve of the former myelinate more rapidly than those of the other.

Study of the minute structure of the central nervous system in normal or experimental material, especially of tissues that have been stained by the methods of Golgi and Ramón y Cajal or by the use of methylene blue, completes the results attained by the other methods, by demonstrating the precise mode of origin and termination of the various tracts.

Posterior White Column and Posterior Roots of Spinal Nerves.—In the cervical and upper thoracic regions of the spinal cord the posterior white column is divided by a septum of pia mater into the **fasciculus cuneatus**, which lies laterally and next to the posterior grey column, and the **fasciculus gracilis**, which lies medially and next to the posterior median septum. The nerve-fibres of the fasciculus cuneatus are for the most part larger than those of the

fasciculus gracilis; and both tracts have a very intimate relation to the posterior nerve-roots; indeed, they are both composed almost entirely of fibres which enter the cord by those roots and then pursue a longitudinal course.

The nerve-fibres of the posterior nerve-roots enter opposite the apex of the posterior horn and divide within the fasciculus cuneatus into ascending and descending branches which diverge abruptly as they pass upwards and downwards.

The **descending fibres** are, as a rule, short, and soon end in the grey matter. They form a bundle, called the **semilunar tract**, which lies between the fasciculus gracilis and fasciculus cuneatus, and undergoes descending degeneration when the cord is divided (Fig. 755).

The **ascending fibres** vary greatly in length, and, at differing distances from the point where the parent fibres enter the cord, they end in the grey matter. A small contribution, however, of ascending fibres, from each posterior nerve-root, extends upwards to end in the medulla oblongata (Figs. 736 and 757).

As each posterior nerve-root enters, its fibres range themselves in the lateral part of the posterior white column close up against the posterior grey column. The nerve-

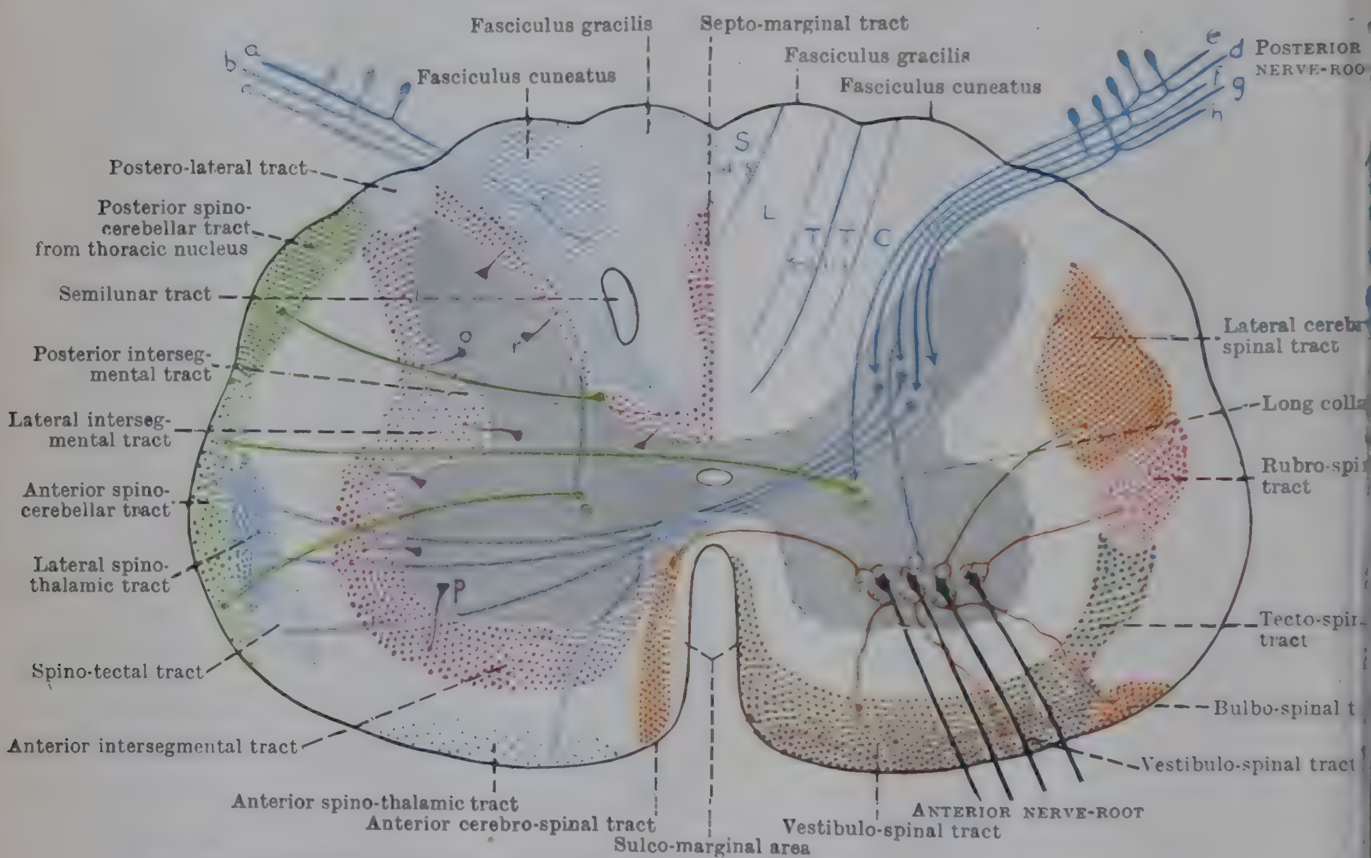


FIG. 755.—DIAGRAM TO ILLUSTRATE THE POSITION OF THE VARIOUS TRACTS IN THE SPINAL CORD.

fibres of the nerve-root next above take the same position, and consequently those which entered from the nerve immediately below are displaced medially, and come to lie in the posterior white column nearer to the median plane. This process goes on as each nerve-root enters, and the result is that the fibres of the lower nerves are gradually pushed nearer and nearer to the posterior median septum in a successive series of lamellar bundles. The greater number of the fibres which are thus carried upwards from the posterior nerve-roots sooner or later leave the posterior white column and enter the grey matter, to end there in relation to some of its cells; but every posterior nerve-root sends a few fibres up the whole length of that portion of the spinal cord which lies above, and thus the posterior white column gradually increases in bulk as it is traced upwards, and, in all except the lowest part of the cord, the posterior white column is separable into a fasciculus gracilis and a fasciculus cuneatus. The fasciculus gracilis is composed of the long ascending fibres of the posterior nerve-roots which have entered the lower segments. To put the matter differently: the fibres of the sacral roots are displaced medially by the entering lumbar fibres, these are, in their turn, pushed medially by the entering thoracic fibres, and, lastly, the fibres of the cervical roots displace the thoracic fibres.

The difference between the fasciculi simply is this, that the fasciculus gracilis is composed of the fibres of posterior nerve-roots which have entered the cord at a lower level than those that form the fasciculus cuneatus. The fibres of the fasciculus gracilis, taking them as a whole, run therefore a very much longer course.

Our knowledge of the constitution of the posterior white columns is derived largely from the study of the course of degeneration in monkeys after the cord has been cut across—either partially or completely. But we have also a direct knowledge of the lamination of the posterior columns of the human spinal cord (Fig. 756) acquired from the examination of cases in which the cord or its nerve-roots had been injured during life. We have some information of the lamination of crossed ascending fibres also in the anterior and lateral white columns of the human cord. That information is given diagrammatically in Fig. 756. It will be noted that of the fibres which cross before they ascend in this column, those from the lower segments are superficial, and the latest arrivals from the opposite side (*i.e.*, those from the upper segments) travel deep in the white matter.

Experimental and clinical evidence has established that the long fibres of the tracts of the posterior column convey impulses which have their origin in sensory nerve-endings in the skin, and also in muscles, joints, and related structures (proprioceptive impulses). Hence, an interruption of these fibres leads to a defect of motor co-ordination and to an inability to recognize passive movements. It also interferes with finer tactile sensibility and with those aspects of tactile sensation into which a spatial element enters, *e.g.*, the localization of a tactile stimulus and the discrimination of compass-points. It is useful to anticipate at this point by noting that the fibres of the ascending tracts of the posterior column finally end in two collections of nerve-cells in the medulla—the nucleus gracilis and nucleus cuneatus. From here the proprioceptive impulses are relayed by a great sensory tract—the medial lemniscus—which after decussation ascends to the thalamus of the opposite side. Lastly, a third relay of neurons projects the impulses from the thalamus to the sensory areas of the cerebral cortex.

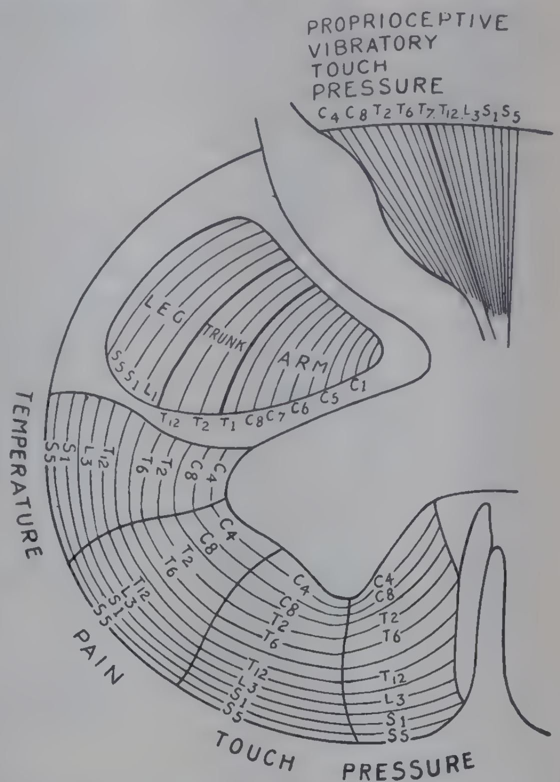


FIG. 756.—DIAGRAM (after Foerster, 1936) to show: (i) the peripheral position in the antero-lateral white column of ascending fibres from the lowest segments of the cord and the position progressively nearer the grey matter of those from higher segments ; (ii) the medial position in the posterior white column of fibres ascending from the lowest segments and the progressively lateral position of those from higher segments ; (iii) lamination of fibres within the lateral cerebro-spinal tract.

Numerous collateral fibres stream into the posterior grey column both from the ascending and descending branches of the entering fibres of the posterior nerve-roots. They are classified into long and short collaterals. The **long collaterals** extend forwards into the anterior grey column and end in relation to the anterior nerve-cells. The **short collaterals** end in relation to the nerve-cells in the substantia gelatinosa and other nerve-cells of the posterior grey column.

The majority of the fibres of each posterior nerve-root enter the cord on the medial side of the apex of the posterior horn. The manner in which they are related to the fasciculus cuneatus and the fasciculus gracilis has been noticed ; but a certain number of those fibres which lie most laterally take a curved course forwards on the medial side of the posterior horn and then pass into it. In the thoracic region these curved fibres end in connexion with the cells of the thoracic nucleus (Fig. 749 B, p. 861, and Fig. 751).

Postero-Lateral Tract.—This is a small tract of nerve-fibres of minute calibre which assume their medullary sheaths at a comparatively late period and, indeed, many of them are non-medullated. It is placed at the surface of the cord close in front of the entering posterior nerve-roots. It is formed by some of the lateral fibres of the posterior nerve-roots which do not enter the fasciculus cuneatus, but pass upwards close to the substantia gelatinosa, in which most of them ultimately end. There is evidence to show

that these fibres are largely concerned with the transmission of impulses that underlie the sensation of pain.

It is evident that the fibres which enter the cord through each posterior nerve-root have three main modes of distribution: (1) the majority take part in the formation of the posterior white column, and pass upwards or downwards to end in the grey matter at some other level in the central nervous system; (2) some fibres, and many collaterals of fibres in the fasciculus cuneatus, lie close to the posterior grey column and describe a series of graceful curves as they pass forwards, before turning laterally into all regions of the grey matter to end at the same level as they enter the cord; (3) a third series form the postero-lateral tract and end in connexion with the cells of the substantia gelatinosa and other cells in the posterior and anterior grey columns.

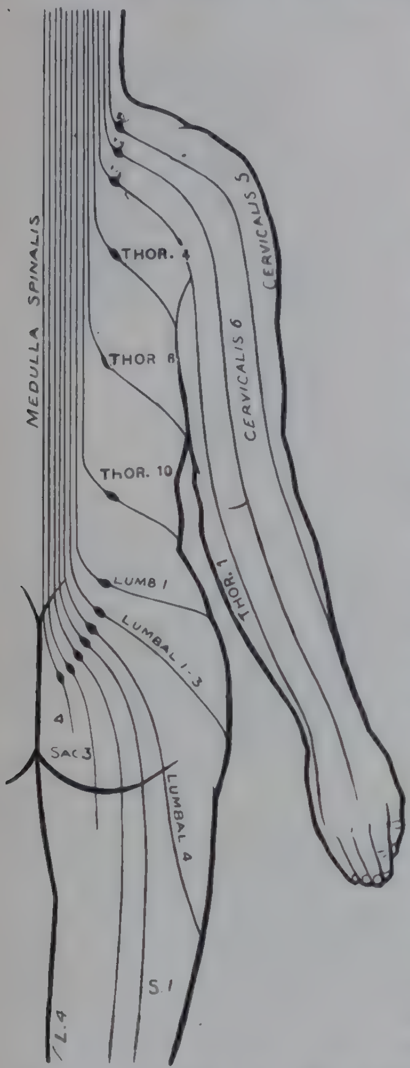


Fig. 757.—Diagram to show the Manner in which Fibres of Posterior Nerve-Roots enter and ascend in the Posterior White Column.

The fibres derived from the posterior nerve-roots which ascend in the posterior white columns to the medulla oblongata of the brain constitute a direct sensory tract; there are other fibres which form crossed sensory tracts termed the **spino-thalamic tracts.** The latter fibres arise as the axons of certain of the cells in the posterior grey column in relation to which fibres from the posterior nerve-roots have ended, and, after crossing to the opposite side of the cord through the white commissure, they ascend in the cord to the brain, where they ultimately reach the thalamus. As the spino-thalamic fibres ascend in the cord they are gathered into two loose and not very sharply defined strands, called the **anterior** and **lateral spino-thalamic tracts**, which pass upwards in the corresponding white columns.

The lateral spino-thalamic tracts are mainly concerned with the transmission of impulses related to the sensations of temperature and pain, while crude tactile and pressure impulses are carried up the cord by the fibres of the anterior spino-thalamic tract. It is of some importance to recognize that the fibres which form these tracts cross over from the opposite side of the spinal cord close in front of the central canal. Hence pathological conditions affecting this part of the spinal cord (*e.g.*, syringomyelia) are liable to involve these decussating fibres and to lead to defects of cutaneous sensations at lower levels of the body.

Association Fibres in the Posterior White Column.—The whole of the fibres of the posterior white column are not derived from the posterior nerve-roots. A few fibres have a different origin. They are derived from certain of the cells of the grey matter, and, having entered the posterior white column, they divide into branches which pass upwards and downwards in the column for a varying distance before they finally turn in to end in the grey matter at higher and lower levels. These fibres, therefore, are links of connexion between different segments of the cord, and they constitute the **posterior intersegmental tract**. Our information regarding these fibres is at present defective; but it is believed that the deepest part of the column, *i.e.*, the part next the grey commissure, and the **septo-marginal tract**, placed in apposition with the posterior median septum and in the adjoining part of the surface, belong mainly to this category.

Lateral and Anterior White Columns.—It is convenient to consider the anterior along with the lateral column and to call the whole mass of white substance left after elimination of the posterior white column the **antero-lateral white column.** In contact with the surface of the grey columns there is a broad band of white matter, the parts of which are known respectively as **anterior** and **lateral intersegmental tracts.** They are composed mainly of fibres which spring

from nerve-cells in the grey columns, and, after passing for varying distances upwards or downwards, end in the grey matter of the cord. They constitute an intrinsic system of fibres linking together different levels of the spinal cord. They become medullated before any other fibres, except the root-fibres and their continuations in the posterior white column. When cut across, some of the fibres degenerate above the injury and others below it.

The best-known long or extrinsic systems of fibres in the antero-lateral white column are the **cerebro-spinal** and **spino-cerebellar tracts**.

There are, however, many other tracts at least as important as these, but there is as yet no close agreement as to their precise limits or connexions. One reason for this is that some of the elements of one tract may become intermingled with those of another; moreover, the position and relations of certain of them vary considerably at different levels of the cord. In Fig. 755 an attempt has been made to indicate the present state of our knowledge of these great strands of white fibres. The diagram is not intended to represent any definite level of the cord, though certain features are shown which occur only in the cervical region; and in respect of other features, the arrangement found in lower regions of the cord has been introduced to make the diagram more serviceable.

Much of the apparent complexity of this chart will disappear if the reader recalls some general statements (p. 849) made with regard to the main features of the brain. It was then explained that when afferent nerves which come from the skin and muscles enter the cord, they not only establish relations with the motor nuclei and other spinal structures in the neighbourhood of their insertion, but also give rise, directly or indirectly (see Fig. 736), to many tracts which pass upwards to reach the medulla oblongata, the cerebellum, the mid-brain, the thalamus, and the cerebral hemisphere. In the neighbourhood of each level where these ascending sensory tracts end, such as, for example, the region of the vestibular nucleus and cerebellum, the tectum of the mid-brain, the corpus striatum, and the cerebral hemisphere, great descending tracts originate and pass downwards in the spinal cord (Fig. 736—the red lines). Thus we have cerebro-spinal, rubro-spinal, tecto-spinal, vestibulo-spinal, and bulbo-spinal tracts passing down the spinal cord; and each system eventually ends in relation to the series of motor nuclei—many of them in the spinal cord.

In the antero-lateral white column the various fasciculi will be found to be grouped roughly into three bands: next to the grey matter there are the intersegmental tracts; then comes a band of descending (motor) fasciculi; and then, on the surface, a series of ascending (sensory) fasciculi. This arrangement, however, is not maintained with any degree of exactitude in the anterior column, where the sharp demarcation between ascending and descending fasciculi is in great part destroyed by the intermingling of fibres passing in opposite directions.

It has already been explained that of the fibres which enter the spinal cord in the posterior root the great majority enter the posterior white column, where they bifurcate (Fig. 755 *a*); one branch of each fibre passes upwards either in the fasciculus gracilis or in the fasciculus cuneatus, or it may pass from the latter into the former; the other descends in the semilunar tract. Other fibres enter the postero-lateral tract. But all the remaining fibres of the posterior root, together with the majority of the fibres of the fasciculus cuneatus, sooner or later enter the grey matter (Fig. 755 *b* to *h*) of the cord.

Some of them (*b*) pass directly to end in the **thoracic nucleus** of their own side; and from its cells fresh fibres arise which pass laterally through the posterior grey column and lateral white column to reach the surface, where they bend upwards as constituent fibres of the **posterior spino-cerebellar tract**. These fibres pass upwards through the whole length of the cord (above their place of origin), into the medulla oblongata, and thence into the cerebellum through its inferior peduncle. Other fibres on the same side (*c*), and perhaps also on the other side (*d*), end amidst cells scattered in the base of the posterior grey column, the axons of which pass into the **anterior spino-cerebellar tract**. In this tract they ascend through the spinal cord, medulla oblongata, and pons, to enter the cerebellum by the superior peduncle. The two spino-cerebellar tracts convey to the cerebellum the afferent

impulses from the muscles and associated structures that underlie the unconscious control of muscular co-ordination and the regulation of muscular tonus.

Among the descending tracts that connect various parts of the brain (see Fig. 736) with the motor nerve-cells in the anterior grey column may be mentioned the **cerebro-spinal**, the **rubro-spinal** (from the red nucleus), the **tecto-spinal** (from the superior corpus quadrigeminum), the **vestibulo-spinal** (from the terminal nucleus of the vestibular nerve), and the **bulbo-spinal tracts**.

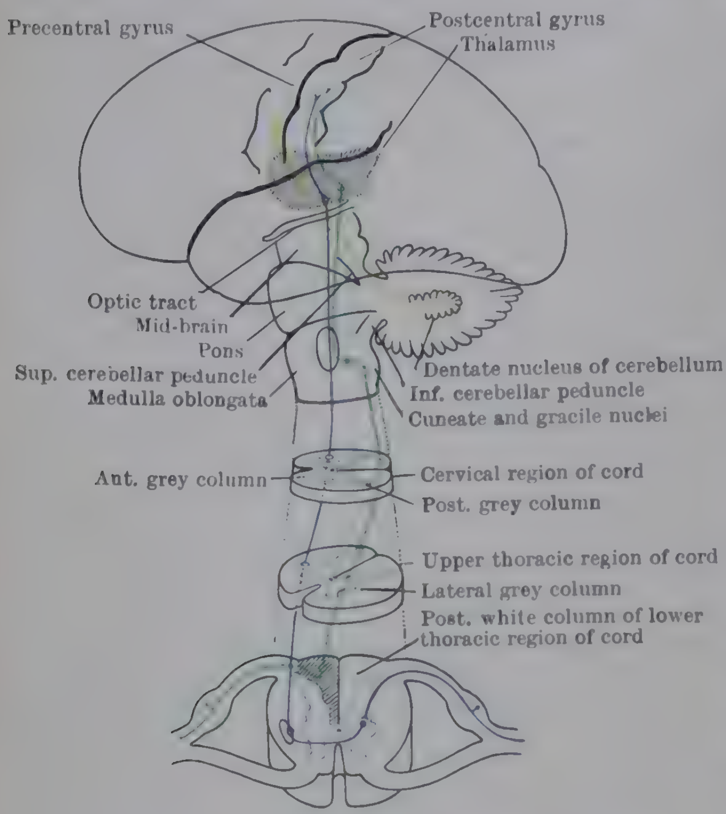


FIG. 758.—DIAGRAM OF TRACTS ASCENDING IN SPINAL CORD AND BRAIN TO THALAMUS AND CEREBRAL CORTEX.

Blue: Spino-thalamic fibres cross in the cord and ascend to the thalamus in the anterior (not shown) and lateral spino-thalamic tracts.
Green: Fibres which run up in the posterior white column and convey proprioceptive impulses to the cuneate and gracile nuclei, whence the medial lemniscus carries them across the median plane and then upwards to the ventral nucleus of the thalamus. From the thalamus, the sensory impulses (blue and green) are relayed to the postcentral gyrus of the cerebral cortex.
Yellow: Dentato-thalamic fibres carry impulses from the dentate nucleus of the cerebellum to the anterior part of the ventral nucleus of the opposite thalamus, whence the impulses are relayed to the precentral gyrus.

There are two cerebro-spinal tracts, crossed and uncrossed. They are composed of fibres of diverse origin in the cerebral hemisphere but, from the functional point of view, the most important are those which arise from conspicuous large pyramidal cells in the motor area of the cerebral cortex and pass downwards through the brain-stem to gain the spinal cord. On the front of the medulla (as we shall see later) they form a prominent column on each side of the median plane, and these columns are termed the *pyramids*. Hence the cerebro-spinal tracts are often referred to as the "pyramidal tracts". As they enter the cord, most of the fibres cross the median plane to the opposite side to form the crossed cerebro-spinal tract. This tract, therefore, conveys impulses to the motor cells of the spinal cord from the opposite cerebral hemisphere. The few fibres which continue down into the anterior white column of the spinal cord without undergoing a decussation constitute the uncrossed or direct cerebro-spinal tract. Not only is the crossed cerebro-spinal tract much larger than the uncrossed, it is also by far the more important clinically.

The crossed cerebro-spinal tract is situated in the lateral white column of the cord and is commonly termed the **lateral cerebro-spinal tract**. It occupies a position immediately antero-lateral to the posterior grey column, and subjacent to the posterior spino-cerebellar tract, which separates it from the surface of the cord. Below the point where the posterior spino-cerebellar tract begins, the lateral cerebro-spinal tract becomes superficial, and in this position it can be traced as low as the fourth sacral segment. As it descends in the cord it gradually diminishes in size, because as it traverses each spinal segment numerous fibres leave it to enter the anterior column of grey matter and end in connexion with the motor cells from which the fibres of the anterior nerve-roots arise. The entire strand is ultimately exhausted in this way. Numerous collateral fibres spring from the fibres of the cerebro-spinal tracts; they enter the grey matter and end in a similar manner. Thus, a single fibre may be connected with several segments of the spinal cord before it finally ends. The lateral cerebro-spinal tract must be regarded as a great motor pathway which brings the spinal motor apparatus under voluntary control, for it is known that the initiation and control of voluntary move-

ments depend on its integrity. The fibres of the cerebro-spinal tracts are sometimes referred to as *upper motor neurons*, in contradistinction to the motor cells of the spinal cord and the efferent fibres of the peripheral nerves to which they give rise, which are the *lower motor neurons*.

In many marsupials, rodents, and ungulates the crossed cerebro-spinal tract lies in the posterior white column of the spinal cord.

The uncrossed cerebro-spinal tract, as already mentioned, lies in the anterior white column of the cord and is named the **anterior cerebro-spinal tract.** It is usually of small size and lies near the anterior median fissure. As a rule it

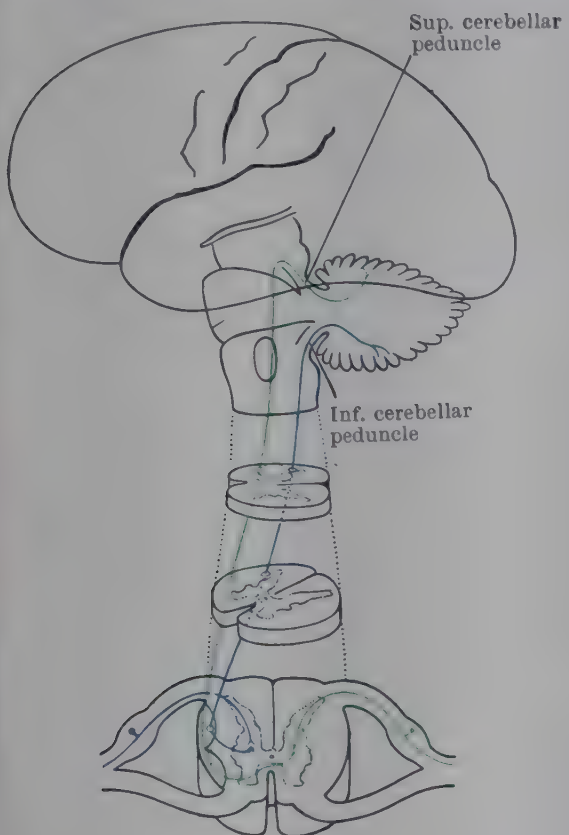


Fig. 759.—Diagram of Spino-Cerebellar Tracts.

Blue: Path of proprioceptive impulses conveyed by posterior spino-cerebellar tract (arising in thoracic nucleus of same side) through inferior cerebellar peduncle to vermis of cerebellum.
Green: Path of proprioceptive impulses conveyed by anterior spino-cerebellar tract (arising in the base of the posterior grey column of both sides, but chiefly opposite side) to vermis of cerebellum through superior peduncle.

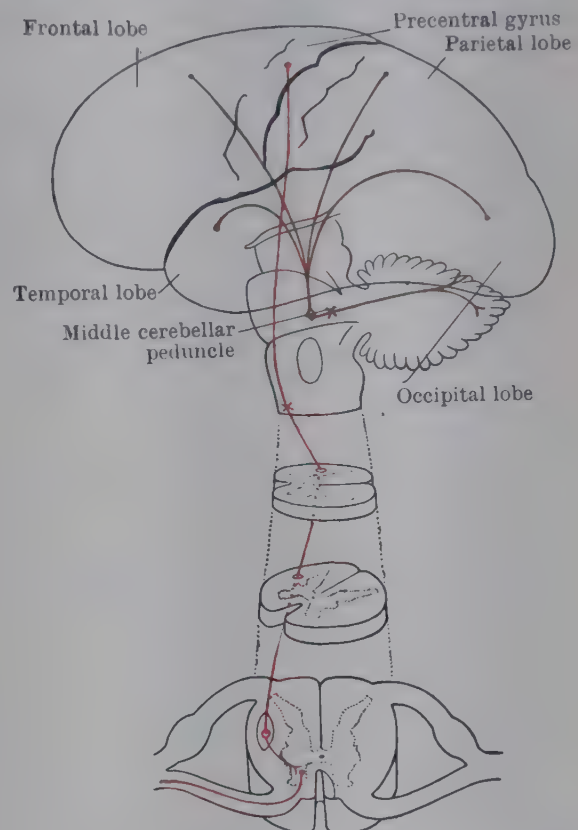


Fig. 760.—Diagram of Cortico-Spinal and Cortico-Ponto-Cerebellar Fibres.

Red: Path of efferent impulses conveyed by pyramidal fibres from motor area of cerebral cortex through lateral (crossed) cerebro-spinal tract to motor cells in anterior grey column of spinal cord, and thence by fibres of anterior nerve-root.
Brown: Cortico-ponto-cerebellar system, conveying impulses from cerebral cortex to nuclei pontis and thence to opposite half of cerebellum.

cannot be traced lower than the middle of the thoracic region, and its relative size varies greatly in different individuals. Although the fibres of this tract do not to any significant extent cross the median plane as they enter the cord, they do not actually end on the same side of the cord; at successive levels along the path of the tract they make use of the white commissure and cross to the opposite side to terminate in relation to motor cells in the same manner as the fibres of the lateral cerebro-spinal tract.

From the decussation of the cerebro-spinal tracts it follows that their destruction in any part of their course through one side of the brain must result in paralysis of the muscles supplied by the efferent fibres of the opposite side of the spinal cord. This paralysis, it should be noted, affects only the *voluntary* movement of these muscles.

In cases of old brain-lesions it is sometimes possible to detect some degenerated fibres in the lateral cerebro-spinal tract of the sound side, and from that it is supposed that the tract contains a few uncrossed fibres. If this is the case, each side of the spinal cord actually stands in connexion with the motor area of both cerebral hemispheres. Experimental evidence has shown that, strictly speaking, this is true, but the homolateral connexions are too few to have any practical significance from the clinical point of view.

It may be noted that the fibres of the cerebro-spinal tracts are not medullated until the time of birth. Indeed, they are the latest of all the tracts of the spinal cord to undergo myelination (p. 867).

The rubro-spinal tract is situated in the lateral white column immediately anterior to the lateral cerebro-spinal tract. It is composed of fibres which have their origin in the red nucleus of the opposite side of the mid-brain and undergo decussation immediately after leaving the red nucleus. The rubro-spinal fibres

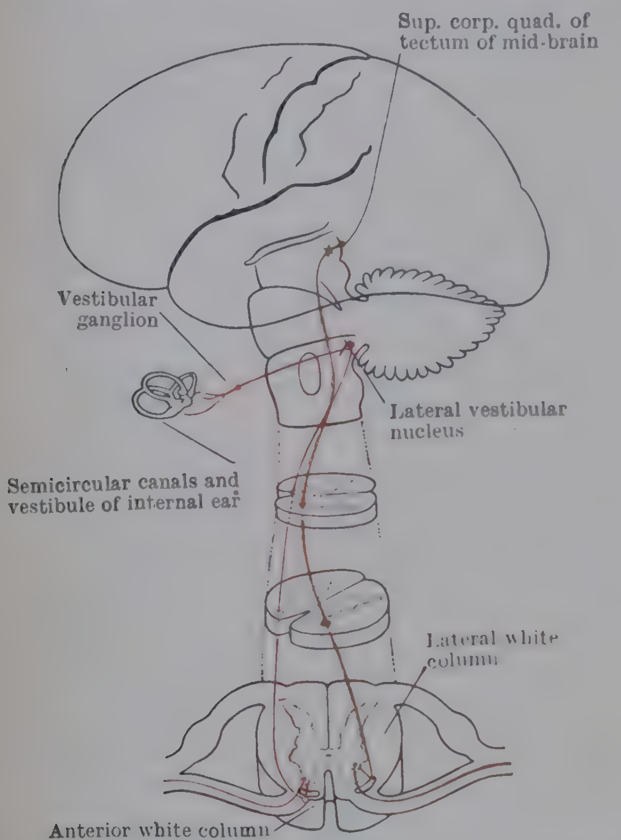


FIG. 761.—DIAGRAM OF VESTIBULO-SPINAL AND TECTO-SPINAL TRACTS.

Red : Fibres of the vestibular nerve send their peripheral branches to the semicircular canals and their central branches to vestibular nuclei in medulla oblongata and pons. The vestibulo-spinal tract arises from the lateral vestibular nucleus and descends in the anterior white column of the cord (mainly on the same side). At successive levels, fibres leave the tract and make synaptic contact with motor cells in the anterior grey column.

Brown : The tecto-spinal tract arises in the mid-brain from the superior corpus quadrigeminum and descends through the brain-stem into the antero-lateral white column of the cord on a deeper plane than the vestibulo-spinal tract. At successive levels, fibres make synaptic connexion with the motor cells.

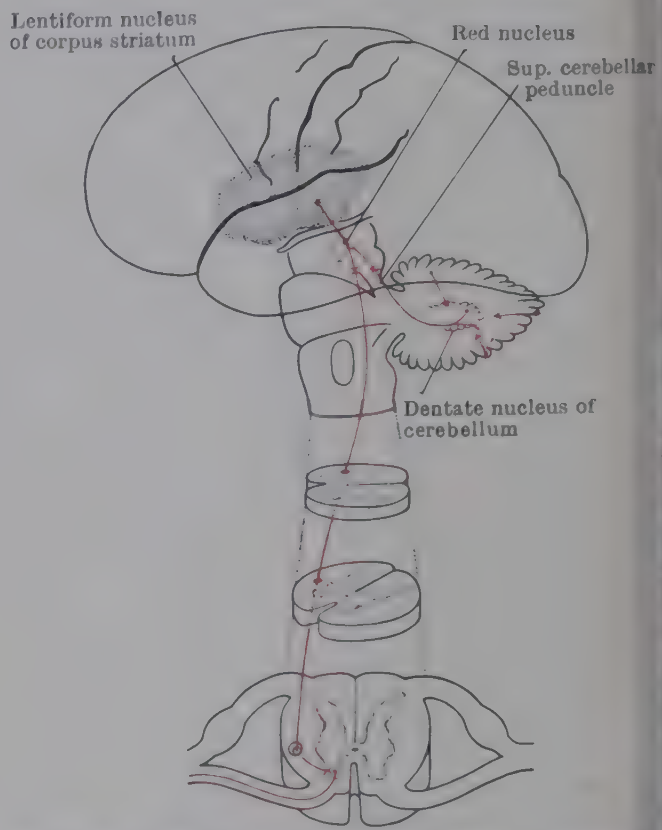


FIG. 762.—DIAGRAM OF THE RUBRO-SPINAL SYSTEM OF FIBRES.

Red : The rubro-spinal tract arises in the mid-brain from the red nucleus, crosses the median plane at once and descends through the brain-stem into the lateral white column of the spinal cord. At successive levels, its fibres leave the tract to make synaptic connexion with motor cells. The tract is relatively much bigger in lower mammals than in Man.

The red nucleus receives afferent fibres from the corpus striatum of the cerebrum and from the cerebellum. Fibres from all parts of the cerebellar cortex run to the dentate nucleus in the centre of the same cerebellar hemisphere. Fibres from the dentate nucleus are carried by the superior cerebellar peduncle into the mid-brain, where they cross the median plane and end in the red nucleus.

terminate in connexion with the motor cells of the spinal cord in the same manner as the fibres of the cerebro-spinal tracts. Since the red nucleus itself receives efferent fibres from the opposite side of the cerebellum, it follows that the rubro-spinal tract provides a pathway through which one-half of the cerebellum can exert an influence over the lower motor neurons of the *same* side of the spinal cord. It has already been mentioned, and it is well to emphasize again, that in the human brain the rubro-spinal tract is poorly developed; it probably extends into only the upper part of the spinal cord.

The **tecto-spinal tract** is a rather diffuse collection of fibres spread out through the superficial part of the anterior white column and extending laterally into the lateral column. They arise from the superior corpus quadrigeminum of the mid-brain and decussate before descending into the spinal cord. Like the rubro-spinal tract, the tecto-spinal tract is an important motor system in many lower mammals in which the mid-brain is a relatively larger and more important element of the central nervous system. In the human brain, however, in which

functional centres of control are relegated to the more elaborate organization of the cerebral hemispheres, the tecto-spinal tract becomes correspondingly reduced. The fibres of the tecto-spinal tract convey impulses by which the reflex centres of the tectum of the mid-brain (particularly the visual centres) influence the activity of the lower motor neurons of the spinal cord.

The **vestibulo-spinal tract** occupies the surface layer of white matter in the anterior white column. Its fibres are derived from the lateral vestibular nucleus (Deiters' nucleus), and, while most of them remain uncrossed, an appreciable number cross to reach the opposite side of the spinal cord. They terminate at successive levels in connexion with the motor cells of the anterior horn, and they provide a pathway by which impulses from the semicircular canals (concerned with equilibratory reflexes) can modify the activity of the lower motor neurons.

The **bulbo-spinal tract** forms a small triangular area at the surface immediately to the lateral side of the anterior nerve-roots, but there is great uncertainty as to its mode of origin; it has been called the *fasciculus olivo-spinalis*, because its discoverer, Helweg, believed it to originate from the olivary nucleus in the medulla. However, there are good reasons for supposing that this cannot be the case, and that it must arise elsewhere in the hind-brain.

Besides the descending tracts and the spino-cerebellar tracts, the anterior and lateral white columns of the spinal cord also contain the anterior and lateral spino-thalamic tracts, which have already been mentioned. The relative positions occupied by these tracts are shown in the diagram in Fig. 755. Closely intermingled with the lateral spino-thalamic tract are ascending fibres which also take their origin from cells in the posterior grey column of the opposite side but end in the superior corpus quadrigeminum of the mid-brain. These fibres comprise the **spino-tectal tract**. They contribute to the reflex activities of the mid-brain by transmitting somatic sensory impressions to the superior corpus quadrigeminum.

The student will find it convenient at this stage to gain a general idea of the course of the main ascending and descending tracts of the spinal cord, and their connexions, even though he may be as yet unacquainted with the regions of the brain where they terminate or have their origin. The five schematic diagrams in Figs. 758 to 762 have been contrived with this end in view. They should be studied at this juncture, and reference made to them later when the various tracts come under further consideration.

White Commissure.—The white commissure is composed of medullated nerve-fibres that pass from one side of the spinal cord to the other and enter the anterior grey column and the anterior white column. It is to be regarded more as a decussation than as a commissure, and its width, which varies slightly in different regions, fluctuates in correspondence with the diameter of the spinal cord.

Amongst the fibres which cross in the white commissure may be mentioned: (1) the fibres of the anterior cerebro-spinal tract; (2) the fibres of the spino-thalamic and spino-tectal tracts; (3) collaterals from both the anterior and lateral white columns; (4) axons of many of the cells of the grey matter; (5) the dendrites of some of the medial anterior cells.

Grey Commissure.—Although this is composed of grey matter with a large admixture of neuroglia, numerous nerve-fibres pass transversely through it to establish relations between the cells of the two sides of the spinal cord.

ENCEPHALON OR BRAIN

The **brain** is the enlarged and greatly elaborated upper part of the cerebro-spinal nervous axis. A brief reference has already been made (p. 836) to the embryological and evolutionary factors which have contributed to its development. In this section we are concerned with its adult structure and connexions.

The brain is surrounded by the same membranes that envelop the cord (the

dura mater, arachnoid mater, and pia mater), and it almost completely fills the cavity of the cranium. So closely, indeed, is the skull moulded on the brain that the impress of the brain is in many places evident upon the inner surface of the cranial wall. The relations of cranium to brain are therefore very different from those presented by the vertebral canal to the spinal cord, for the cord, as we have noted, occupies only a small part of the cavity of its bony case.

General Appearance and Connexions of Brain.—On first inspection, the human brain, deprived of its membranous coverings, appears to consist mainly of a pair of large, symmetrical, ovate masses of richly convoluted nervous tissue, closely pressed together but separated in the median plane by a deep longitudinal fissure. These are the **cerebral hemispheres**, the surface layer of which is composed of grey matter—the *cerebral cortex*. In its intrinsic structure the cerebral cortex is the most highly organized part of the whole brain and it reaches its acme of development in Man. Its great surface expansion in the human brain is reflected in its elaborate convolutions as well as in the relatively large size of the cerebral hemispheres. The hemispheres, indeed, cover the whole of the rest of the brain so that, when viewed from above, they are the only parts of the brain which are visible. If the longitudinal fissure is opened up, the cerebral hemispheres can be seen to be connected across the median plane by a massive bridge of white matter. This is the **corpus callosum**, and it is composed of commissural fibres through which the cortex of one hemisphere is linked up with that of the opposite hemisphere.

If the corpus callosum is split along the median plane, it will be seen to be some distance above the roof of the *third ventricle* (Fig. 764). This is the cavity of that part of the fore-brain which is called the diencephalon, and its lateral wall is formed on each side by an ovate mass of grey matter—the thalamus.

The **thalamus** (which is not visible in the intact brain) is to be regarded primarily as a sensory relay-station through which a variety of sensory impulses are projected on to the cerebral cortex. For this purpose it receives a number of ascending tracts from the spinal cord and hind-brain, as well as a considerable proportion of retinal fibres by way of the optic tract, while abundant fibre-connexions (the thalamic radiations) run from it to extensive areas of the cerebral cortex.

The third ventricle communicates with the *fourth ventricle* (in the hind-brain) by a narrow channel which tunnels the mid-brain and is called the *aqueduct of the mid-brain*. Anteriorly the third ventricle communicates by the interventricular foramina with the *lateral ventricles*, which lie within the cerebral hemispheres.

If the brain is viewed from its basal aspect, many parts of the mid-brain and hind-brain come to view (Fig. 763). The base of the brain presents a very uneven surface which is more or less accurately adapted to the inequalities of the floor of the cranial cavity. Posteriorly is seen the **medulla oblongata**—a short cylindrical structure which is the upward continuation of the spinal cord through the foramen magnum. The medulla lies in front of the cerebellum, fitting into a depression—the vallecula cerebelli—which intervenes between the ventral surfaces of the two cerebellar hemispheres. On each side of the medulla, the rounded surface of each cerebellar hemisphere is apparent.

The **cerebellum** as a whole is a relatively large structure whose surface layer of grey matter—the *cerebellar cortex*—is crossed from side to side by closely set, parallel fissures. Above, the cerebellum is covered over by the posterior or occipital lobes of the cerebral hemispheres. It is connected with the mid-brain, pons, and medulla (which, together, are referred to as the brain-stem) by three pairs of peduncles. These can be seen in some part of their extent in the intact brain without further dissection. If the medulla is gently displaced downwards from the under surface of the cerebellum, a large bundle of nervous tissue is seen to extend on each side from its posterior part into the substance of the cerebellum. These bundles are the **inferior cerebellar peduncles**. As they pass up they diverge from each other, leaving a triangular space which marks the position of the lower part of the fourth ventricle.

Turning again to the base of the brain, the medulla is found to terminate abruptly at the lower margin of a prominent white elevation called the **pons**. This is formed superficially of closely-packed transverse fibres which on each side are compressed into a rope-like strand that plunges into the corresponding cerebellar hemisphere. This is the **middle cerebellar peduncle**, and its fibres have their origin in grey matter which lies within the substance of the pons—*nuclei pontis*.

Immediately in front of the pons there is an irregular recess. It is bounded behind by the pons, on each side by the temporal lobe of the cerebral hemisphere, and in front by the orbital portions of the frontal lobes. Passing laterally from each side of the anterior part of the recess is the deep cleft—the *lateral sulcus* of

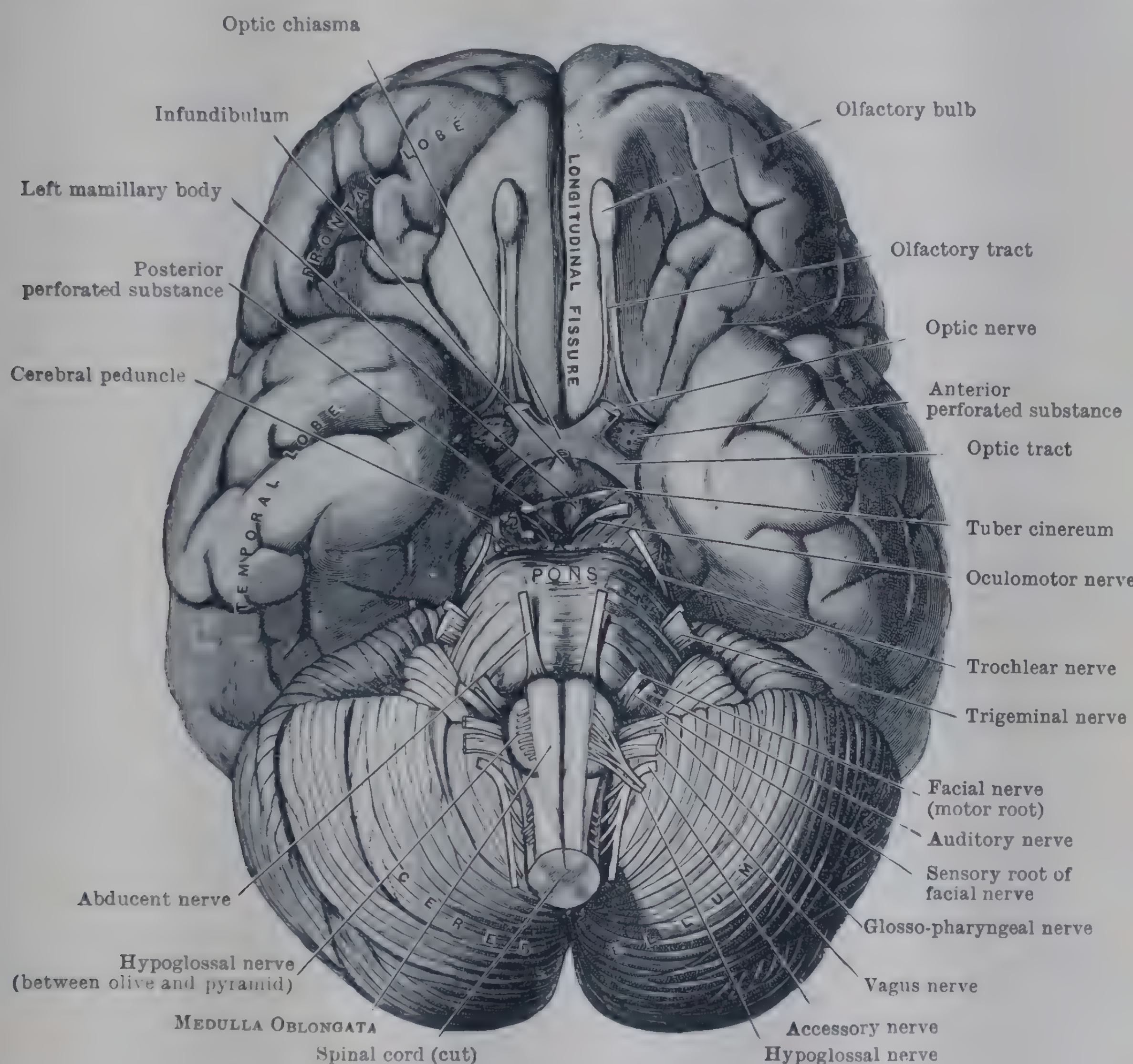


FIG. 763.—BASE OF THE BRAIN WITH THE CRANIAL NERVES ATTACHED.

the cerebrum—which intervenes between the projecting extremity of the temporal lobe and the frontal lobe of the cerebrum.

Within the deep hollow on the base of the brain two large rope-like strands—the **cerebral peduncles**—may be seen issuing from the inferior surface of the cerebral hemispheres. The importance of these peduncles is emphasized by the fact that, among other fibre-systems, they contain the fibres of the cerebro-spinal tracts which are passing from their origin in the cerebrum to the spinal cord. As they extend downwards the peduncles converge so that when they disappear into the substance of the pons they are in close apposition to each other. The cerebral peduncles form the front of the mid-brain, and if the cerebellum and cerebral hemispheres are carefully separated it is possible to catch a glimpse of the back or "roof" of the mid-brain (tectum) which is marked by four hemispherical eminences —the **corpora quadrigemina**.

It is convenient at this stage to note that the inferior corpora quadrigemina are auditory centres in which ascending auditory tracts terminate, while the superior corpora quadrigemina are predominantly visual centres, and are connected to the spinal cord also by spino-tectal and tecto-spinal tracts.

Extending to the posterior surface of the mid-brain just below the inferior corpora quadrigemina, the **superior cerebellar peduncles** can be detected passing upwards from the cerebellum.

Referring again to the base of the brain, we see a deep triangular depression between the cerebral peduncles—the *interpeduncular fossa.* In the floor of the fossa the following structures are visible from behind forwards: (1) the posterior perforated substance; (2) the mamillary bodies; and (3) the tuber cinereum. All these structures are incorporated in the floor of the third ventricle and form component parts of the **hypothalamus.**

The **posterior perforated substance** is a layer of grey matter in which there are numerous small apertures. These transmit a series of small arteries—the central branches of the posterior cerebral arteries.

The **mamillary bodies** are two small, white, hemispherical eminences placed side by side immediately in front of the posterior perforated substance.

The **tuber cinereum** is a slightly raised area of grey matter occupying a position between the mamillary bodies behind and the optic chiasma in front. Attached to the anterior part of the tuber cinereum can usually be seen a process called the **infundibulum**—the stalk which connects the *hypophysis cerebri* (pituitary body) with the base of the brain. The hypophysis itself is usually torn away in the removal of the brain from the cranial cavity.

In front of the tuber cinereum the **optic chiasma** is evident as a broad white transverse band, formed by the union of the two optic nerves. In the substance of the optic chiasma the fibres from the retina undergo a partial decussation. They then continue backwards as the optic tracts, and, if the temporal lobe is slightly displaced, each of these can be traced round the lateral aspect of the cerebral peduncle.

On the under surface of the frontal lobe of each cerebral hemisphere is the **olfactory bulb** which, in the skull, lies in contact with the cribriform plate of the ethmoid and here receives the olfactory nerve-fibres which come up from the nasal cavity. From the olfactory bulb a slender *olfactory tract* runs backwards. Immediately behind its attachment to the brain is an area of grey matter—the **anterior perforated substance**—marked by a cluster of small foramina. These transmit important blood-vessels into the substance of the brain—the central branches of the anterior and middle cerebral arteries.

In the preceding paragraph we have enumerated the main features of the brain which are to be seen on its basal aspect. All the cranial nerves also are evident on the base of the brain, but these will be treated in detail in later sections. Their position and appearance are shown in Fig. 763.

Weight of the Brain.—The average weight of a man's brain is about 1350 grammes. A woman's brain weighs rather less, but this difference is simply related to the smaller bulk of the body. If the body-weight is discounted, it appears that the difference in the relative weights of the brain in the two sexes is insignificant. The variations met with in brain-weight are very considerable, but only in rare cases has a brain weighing less than 1000 grams been found to be associated with apparently normal intellectual functions. In microcephalic idiocy the brain, owing to arrested development, is sometimes very small.

MEDULLA OBLONGATA

The **medulla oblongata** is the continuation upwards of the spinal cord. It is a little more than 1 inch (25 mm.) in length, and it may be regarded as beginning about the level of the foramen magnum. From there it proceeds upwards in a very nearly vertical direction, and ends at the lower border of the pons. At first its girth is similar to that of the spinal cord, but it rapidly expands

as it approaches the pons, and consequently it presents a more or less conical form. Its anterior surface lies behind the grooved surface of the basilar portion of the occipital bone, and its posterior surface is related to the vallecula of the cerebellum. The medulla oblongata is divided into bilaterally symmetrical halves by the **anterior and posterior median fissures.**

The **anterior median fissure**, as it passes from the spinal cord on to the medulla oblongata, is interrupted at the level of the foramen magnum by several strands of fibres which cross the median plane from one side to the other. This intercrossing is termed the *decussation of the pyramids*. Above the decussation it is continued upwards to the lower border of the pons, but is often made very

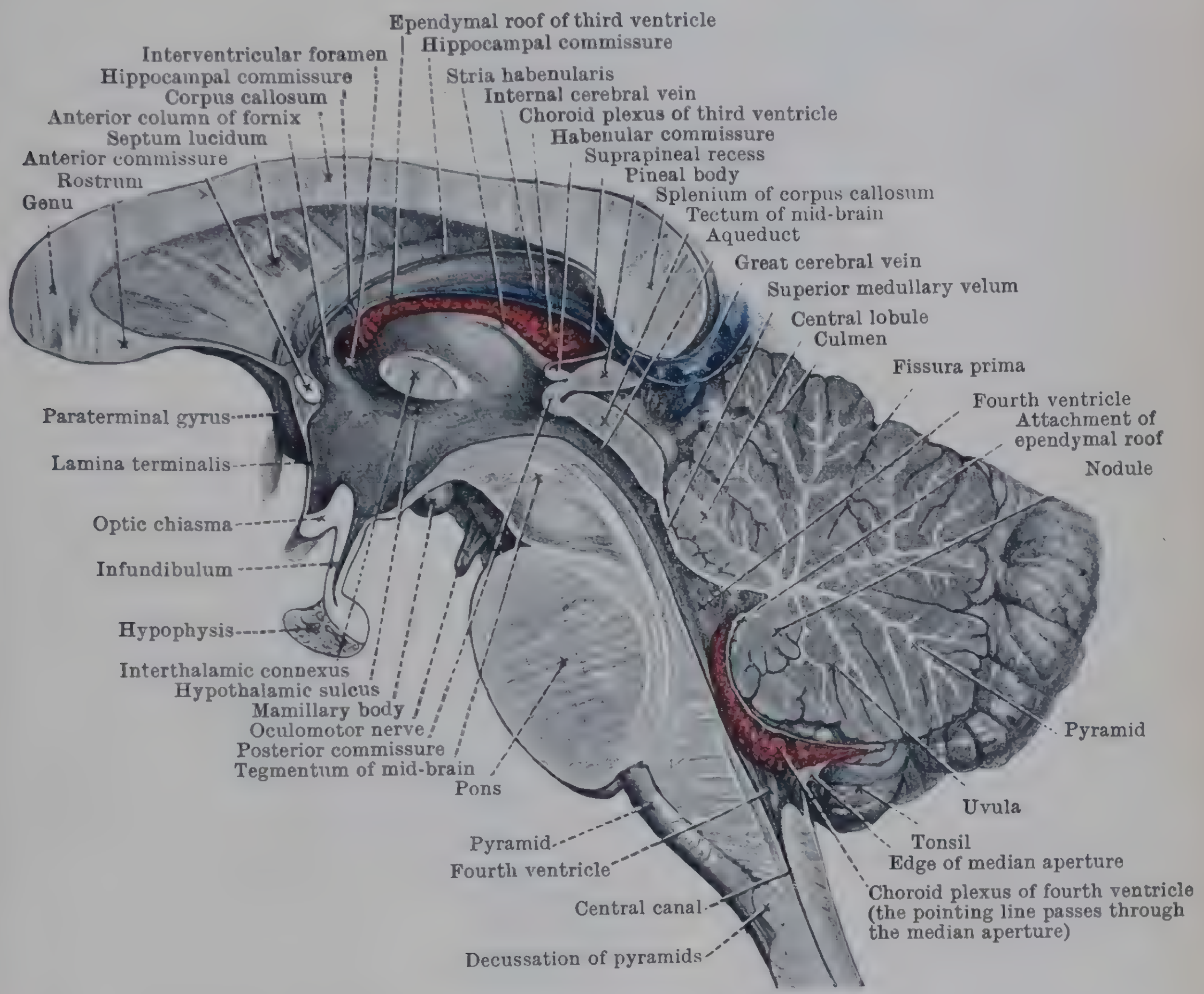


FIG. 764.—THE PARTS OF THE BRAIN CUT THROUGH IN A MEDIAN SECTION.
The side-walls of the ventricular cavities also are shown.

shallow by numerous external arcuate fibres which emerge between its lips and then curve laterally to reach the posterior part of the medulla oblongata. At the lower margin of the pons the fissure expands slightly and ends in a blind pit named the **foramen cæcum.**

The **posterior median fissure** is present only on the lower half of the medulla oblongata. As it ascends it rapidly becomes shallower. Half-way up, where the central canal opens into the fourth ventricle, the lips of the posterior median fissure are thrust apart and constitute the boundaries of a triangular field which is seen when the ependymal roof of the lower part of the fourth ventricle is removed. This triangular field is the lower part of the floor of the fourth ventricle. The lower half of the medulla oblongata, containing as it does the continuation of the central canal of the spinal cord, is frequently termed the closed part of the medulla oblongata; the upper half, above the opening of the canal, which contains the lower part of the fourth ventricle, is called the open part of the medulla oblongata.

The examination of the floor of the fourth ventricle will be deferred for the present, and the appearance presented by the surface of the medulla oblongata may now engage our attention. In the spinal cord the corresponding surface area is divided into three districts by the motor and sensory roots of the spinal nerves. Of those the sensory enter along the bottom of a narrow groove, whilst the motor are spread over a relatively broad surface area and have no groove in relation to their emergence. In the medulla oblongata, corresponding rows of rootlets enter and emerge from the surface of each side. The rootlets of the hypoglossal nerve carry up the line of the anterior nerve-roots of the spinal cord. In one

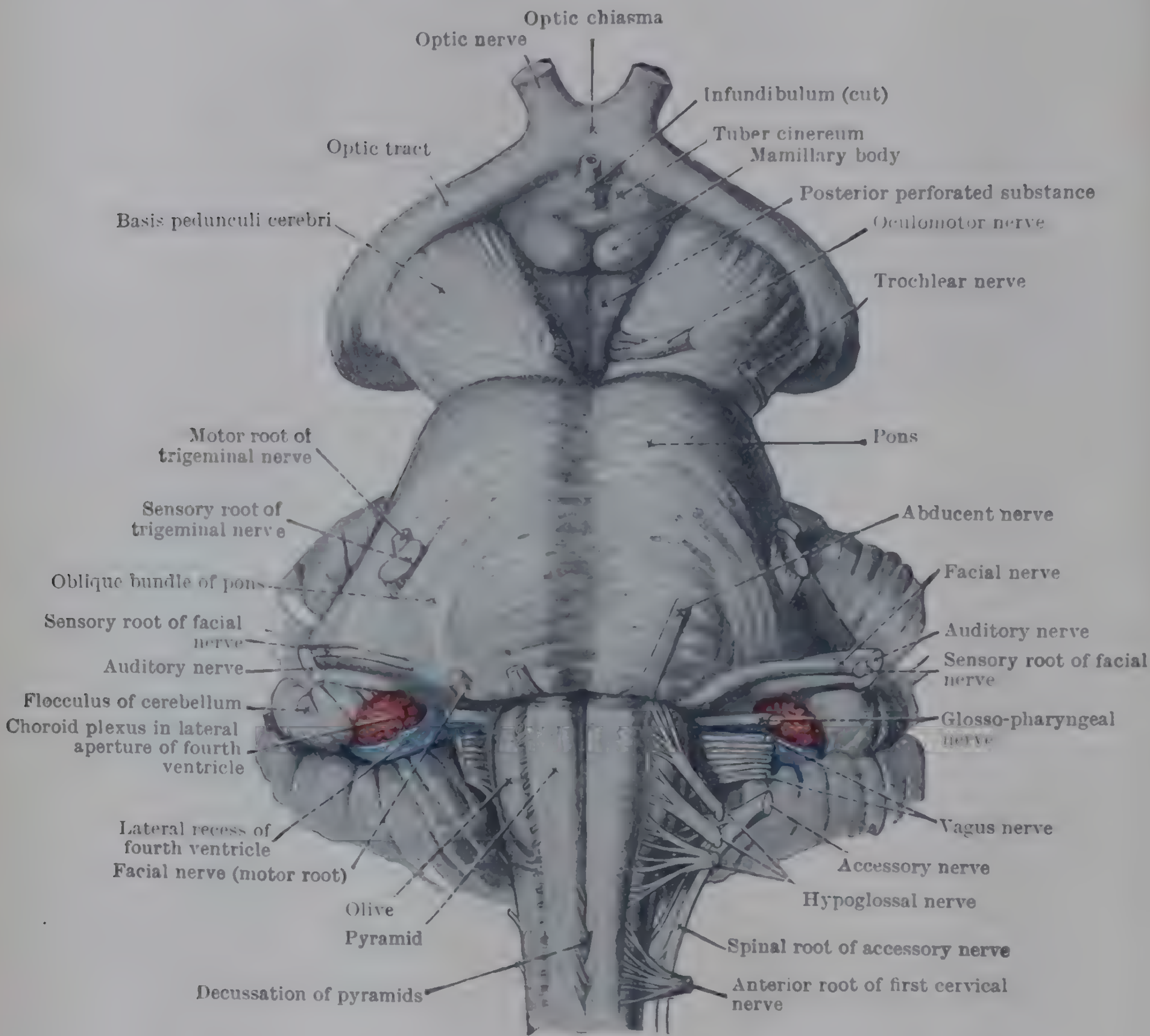


FIG. 765.—FRONT VIEW OF MEDULLA OBLONGATA, PONS, AND MID-BRAIN.

respect, however, they differ: they emerge in linear order and along the bottom of a distinct furrow termed the antero-lateral sulcus. The rootlets which carry up the line of the posterior nerve-roots are those of the accessory, the vagus, and the glosso-pharyngeal nerves. They are attached along the bottom of a furrow named the postero-lateral sulcus. The root-bundles of these nerves differ, however, in that they are not all composed of afferent fibres. Certain of them are purely efferent (roots of accessory), whilst others contain a considerable number of efferent as well as afferent fibres and are therefore to be regarded as mixed roots.

The sulci and the two rows of nerve-roots divide the surface of each half of the medulla oblongata into three districts, viz., an anterior, a lateral, and a posterior, similar to the surface areas of the three white columns of the spinal cord. Indeed, at first sight, they appear to be direct continuations upwards of those three columns; that, however, is not the case, because the fibres of the columns undergo a rearrangement as they proceed upwards into the medulla oblongata.

Anterior Area of Medulla Oblongata—Pyramid.—The district between the anterior median fissure and the groove through which the rootlets of the hypoglossal nerve issue from the medulla oblongata receives the name of the **pyramid**. An inspection of the surface is sufficient to show that the pyramid is a compact strand of longitudinally directed nerve-fibres. It represents, in fact, the portion of the great cerebro-spinal tract which carries fibres from the cerebral hemisphere to all the motor nuclei on the opposite side of the medulla oblongata and spinal cord. Slightly constricted at the place where it emerges from the pons (Fig. 765), it swells immediately to form a prominent rounded column which passes vertically downwards, separated from the pyramid of the other side by the anterior median fissure. Towards the lower part of the medulla oblongata it gradually tapers.

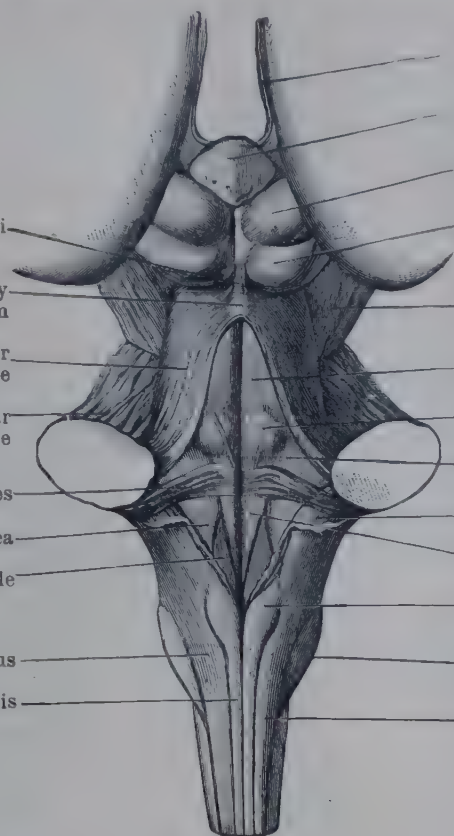


FIG. 766.—POSTERIOR VIEW OF MEDULLA, PONS, AND MID-BRAIN OF FULL-TIME HUMAN FŒTUS.

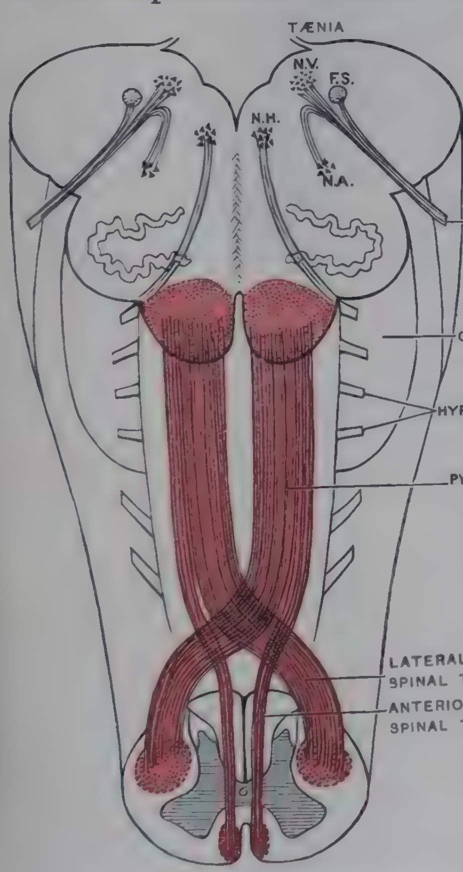


FIG. 767.—DIAGRAM OF THE DECUSSATION OF THE PYRAMIDS. (Modified from van Gehuchten.)
N.H., Hypoglossal nucleus; N.V., Vago-glosso-pharyngeal nucleus; F.S., Tractus solitarius; N.A., Nucleus ambiguus.

Although the pyramid at first sight appears to be continuous with the anterior white column of the cord, only a very small proportion of the fibres contained in that column are derived from the pyramid. At the level of the lower end of the medulla oblongata, the pyramid divides into two parts, viz., a small portion composed of a variable number of the most lateral fibres of the pyramid, which forms the anterior cerebro-spinal tract, and a much larger portion, situated next the median fissure, called the lateral cerebro-spinal tract. As we have seen, the anterior cerebro-spinal tract is continued down into the anterior white column, where it takes up a position next the median fissure. The lateral cerebro-spinal tract is broken up into three or more coarse bundles which sink backwards and at the same time cross the median plane to take up a position in the posterior part of the opposite lateral white column of the cord. The term **decussation of the pyramids** is applied to the intercrossing of the bundles of the lateral cerebro-spinal tracts of opposite sides.

The anterior cerebro-spinal tract is therefore the only part of the pyramid which has a place in the anterior white column of the cord. The largest part of this

column is the anterior intersegmental tract, and as it is traced up into the medulla oblongata, it is thrust aside by the decussating bundles of the lateral cerebro-spinal tract and thus comes to occupy a deep position in the substance of the medulla oblongata, behind and to the lateral side of the pyramid.

Lateral Area of Medulla Oblongata.—This is the district between the hypoglossal roots in front and the root-bundles of the accessory, vagus, and glosso-pharyngeal nerves behind. It presents a very different appearance in its upper

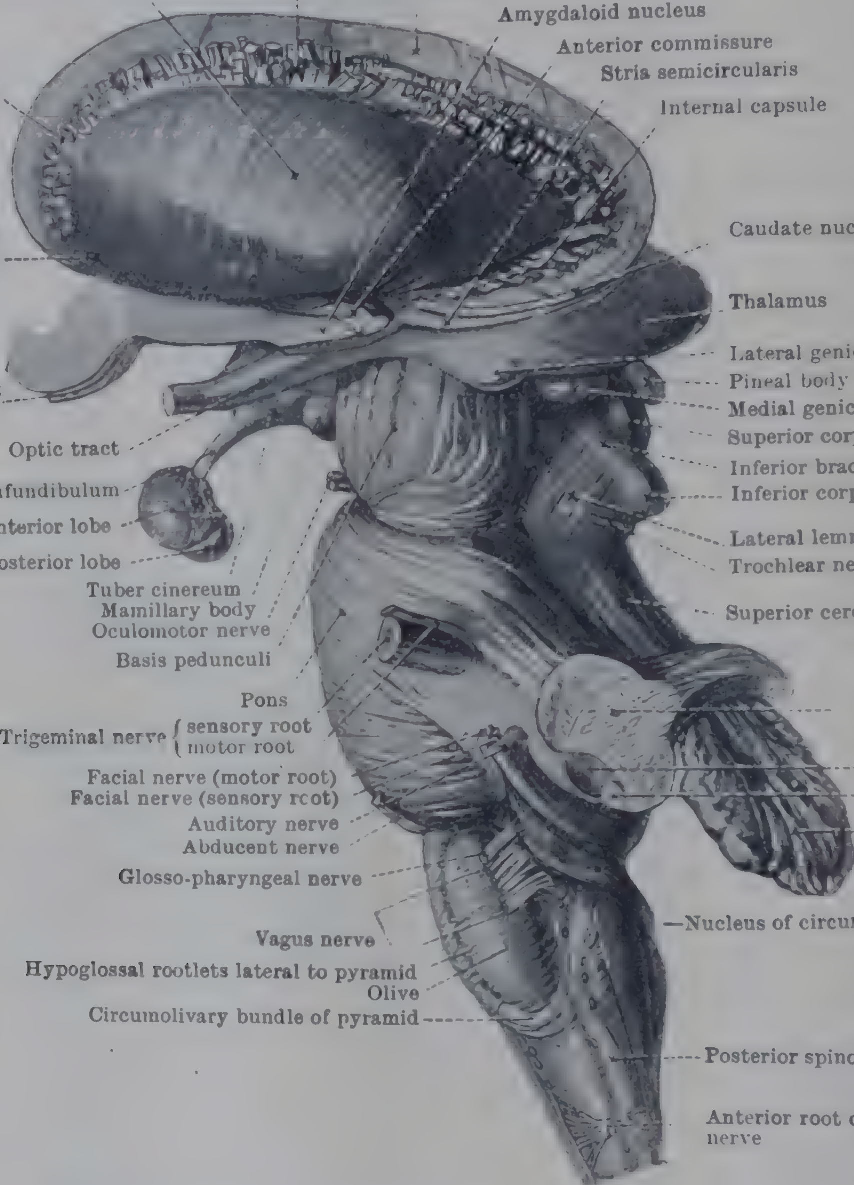


FIG. 768.—LEFT LATERAL ASPECT OF BRAIN AFTER REMOVAL OF THE CEREBRAL HEMISPHERE (EXCEPT CORPUS STRIATUM) AND THE CEREBELLUM (EXCEPT DENTATE NUCLEUS).

and lower parts. In its lower portion it simply appears to be a continuation upwards of the lateral area of the cord; in its upper part a striking oval prominence bulges out on the surface and receives the name of the **olive**.

The lower part of this district, however, is very far from being an exact counterpart of the lateral white column of the cord. The lateral cerebro-spinal tract is no longer present, seeing that, in the medulla oblongata, it forms the greater part of the pyramid of the opposite side. Another strand of fibres, viz., the posterior spino-cerebellar tract, prolonged upwards in the lateral white column, gradually leaves this portion of the medulla oblongata. This tract lies on the surface, and is frequently visible to the naked eye as a white band (Fig. 768) which inclines obliquely backwards into the posterior district of the medulla oblongata to join the inferior cerebellar peduncle. The remainder of the fibres

of the lateral white column are continued upwards in the lateral area of the medulla oblongata.

The **olive** is a smooth oval prominence on the upper part of the lateral area of the medulla oblongata. Its long axis is vertical and is about half an inch long. It is the bulging produced by the subjacent **olivary nucleus**—a crumpled thin-walled sac of grey matter which is separated from the surface by a thin layer of white matter.

External Arcuate Fibres.—The external arcuate fibres are seen as a number of fine curved bundles crossing transversely over the surface of the olive or skirting its lower pole. They vary greatly in number and distinctness, and not infrequently it is difficult to detect them on surface inspection. They take their origin in the arcuate nuclei, which form a thin stratum of grey matter covering the pyramids, and, after crossing the median plane, curve laterally and backwards to enter the inferior cerebellar peduncle. Since the arcuate nuclei are to be regarded as caudal extensions of the pontine nuclei (see p. 899), the external arcuate fibres are evidently aberrant fibres of the pons which do not enter the cerebellum by way of the middle peduncle, but make use of the inferior peduncle instead.

There is frequently present, especially on the left side, a bundle of fibres that is often mistaken for a group of arcuate fibres. It is the **circumolivary bundle of the pyramid** (Figs. 768, 782). It is a bundle of varying size which emerges from the pyramid, bends backwards, curving round the lower border of the olive, and then passes obliquely upward and backwards to end in a fusiform ridge of grey matter—the **nucleus of the circumolivary bundle**—which crosses the inferior peduncle very obliquely (Fig. 768, the ridge immediately behind the roots of the vagus nerve).

Posterior Area of Medulla Oblongata.—In its lower half, this area is bounded behind by the posterior median fissure, and in its upper half by the lateral margin of the medullary part of the floor of the fourth ventricle. In front it is separated from the lateral area by the row of rootlets that belong to the accessory, vagus, and glosso-pharyngeal nerves. The upper and lower parts appear to be continuous but in reality are almost quite distinct from each other—as in the lateral area.

The lower part of the posterior area corresponds more or less closely with the posterior white column of the cord. In the cervical region the posterior white column is divided by a septum of pia mater into the **fasciculus gracilis** medially and the **fasciculus cuneatus** laterally. They are prolonged upwards into the medulla oblongata, and in the lower part of the posterior area they stand out distinctly and are separated one from the other by a groove. When they reach the level of the lower part of the fourth ventricle, they end in slight prominences called respectively the **gracile tubercle** and the **cuneate tubercle**. The right and left gracile tubercles are thrust apart by the opening up of the medulla oblongata to form the floor of the fourth ventricle, and the central canal opens into the fourth ventricle in the angle between the two.

The elongated prominences formed by the enlarged extremities of the fasciculi gracilis and cuneatus are due to two elongated nuclei which lie subjacent to the strands and represent the termini of the uppermost extensions of the spinal posterior root fibres. They are termed respectively the **nucleus gracilis** and **nucleus cuneatus**.

A third longitudinal elevation is present on the lower part of the posterior area of the medulla, though it is frequently too ill-defined to be readily apparent on surface inspection. This is placed on the lateral side of the fasciculus cuneatus—between it and the posterior row of nerve-roots—and it has no counterpart in the posterior white column of the cord. It is called the **tubercle of the trigeminal nerve.** It is produced by a mass of substantia gelatinosa coming close to the surface and forming a bulging in that situation. Extremely narrow below, it widens as it is traced upwards, and finally ends in an expanded extremity. A thin layer of white matter, composed of longitudinally arranged fibres, is spread over this district, and separates the substantia gelatinosa from the surface. These fibres constitute the **spinal tract of the trigeminal nerve**, which here assumes a

the medulla the spinal tract lies immediately in front of the inferior cerebellar peduncle—so closely applied that, on surface view, the tract seems to form part of the peduncle. In this part of its course, the tract is shut off from the surface by the posterior spino-cerebellar tract, the external arcuate fibres, and the circum-olivary bundle as they incline backwards towards the peduncle, and, further, the root-fibres of the glosso-pharyngeal and vagus nerves emerge through it.

Inferior Cerebellar Peduncle.—The inferior cerebellar peduncle forms almost the whole of the upper part of the posterior area of the medulla oblongata. It lies between the floor of the fourth ventricle and the roots of the vagus and glosso-pharyngeal nerves. It is a thick, round bundle which inclines upwards and laterally, and then takes a sudden bend backwards to enter the cerebellum. It is one of the links that connect the cerebellum with the medulla oblongata and spinal cord. A study of the surface of the medulla oblongata yields some important information regarding the constitution of the inferior cerebellar peduncle. Thus, the posterior spino-cerebellar tract (Fig. 768), from the lateral column of the cord, can be traced into it: large numbers of fibres which take a curved course on the surface of the medulla oblongata may likewise be followed into it; these are the external arcuate fibres. Numerous other fibres enter this peduncle on its deep aspect, but they will be studied at a later stage.

PONS

The **pons** is the conspicuous white prominence seen on the base of the brain between the medulla oblongata and the cerebral peduncles in front of the cerebellum. It is convex from side to side and from above downwards, and transverse streaks on its surface show that, superficially at least, it is composed of bundles of nerve-fibres, most of which course transversely. On each side these transverse fibres form a large compact strand which sinks in a backward and lateral direction into the hemisphere of the cerebellum. This strand is termed the **middle cerebellar peduncle.** It forms the second stage in the connexion between the cerebral cortex of one side and the cerebellum of the opposite side (Fig. 769). This connexion is effected by cortico-pontine fibres which run from most areas of the cerebral cortex to reach the pons, terminating there in relation to the pontine nuclei; from these nuclei ponto-cerebellar fibres take origin and cross the median plane to the opposite cerebellar hemisphere. It is these fibres which constitute the middle cerebellar peduncles.

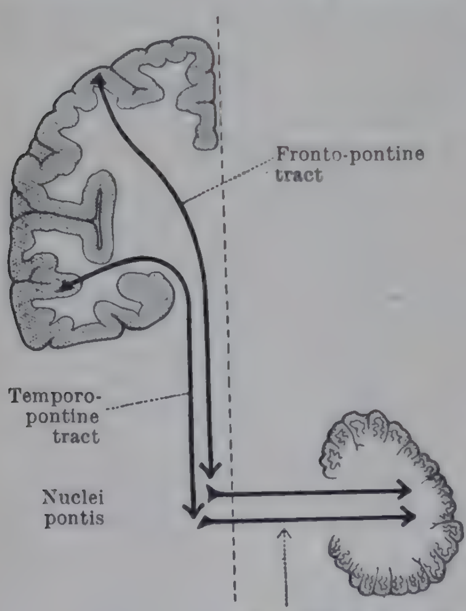


Fig. 769.—Diagram of Cortico-Cerebellar connexion.

The *anterior surface* of the pons is in relation to the dorsum sellæ and the upper part of the clivus of the skull. It presents a median groove (**basilar sulcus**) which gradually widens as it is traced upwards; this lodges the basilar artery. The median depression is produced by the prominence caused on each side by the passage of the cerebro-spinal bundles downwards through the pons. The **trigeminal nerve**, with its large, entering sensory root and its small, emerging motor root, is attached to the side of the pons, nearer its upper than its lower border (Fig. 768). The term *pons* is conventionally restricted to that portion which lies between the two trigeminal nerves, and the designation *middle cerebellar peduncle* is applied to the part which extends beyond the nerve into the hemisphere of the cerebellum. The **abducent nerve**, the **facial nerve**, and the **auditory nerve** are attached to the brain at the lower border of the pons—the abducent nerve opposite the lateral border of the pyramid and the facial and auditory farther from the

median plane. The auditory nerve is in contact with a little pedunculated lobule of the cerebellum called the **flocculus**; the motor root of the facial is on its medial side, and the sensory root, which is very much thinner, is more or less hidden between them (Figs. 765, 768). The sensory root, it should be noted, also contains visceral efferent fibres (see p. 930). A large bundle of fibres on the front of the pons departs from the transverse course pursued by most of the pontine fibres, and, starting at the medial side of the trigeminal nerve, passes almost vertically downwards between the motor and sensory roots of the facial nerve (Fig. 765) and reaches the side of the medulla oblongata, where it passes into the nucleus of the circumolivary bundle (Fig. 768). This bundle is known as the **oblique bundle of the pons.**

Immediately below the insertion of the auditory nerve at the lower margin of the pons a small pouch of the ependymal roof of the fourth ventricle (**lateral recess**) projects laterally, partly behind the glosso-pharyngeal nerve. Through an elliptical aperture in this ependymal process (**lateral aperture of the fourth ventricle**) a little cauliflower-like mass of choroid plexus is extruded between the auditory and the glosso-pharyngeal nerves (Fig. 765).

The *posterior surface* of the pons looks towards the cerebellum, and presents a triangular area covered with grey matter which forms the upper part of the floor of the fourth ventricle. This area is directly continuous inferiorly with the medullary part of the floor of the ventricle, and is bounded on each side by a band of white matter termed the **superior cerebellar peduncle** (Fig. 770).

Superior Cerebellar Peduncles.—The superior peduncles are hidden from view by the upper part of the cerebellum. They emerge from the hemispheres of the cerebellum, and, as they proceed upwards on the back of the pons, they converge towards each other until, at the lower margin of the inferior corpora quadrigemina, the medial margins of the two peduncles become almost contiguous (Fig. 770). At first they form the lateral boundaries of the upper part of the fourth ventricle; but as they ascend and approach closer to each other, they gradually come to overhang that cavity, and thus enter into the formation of its roof. They disappear from the surface by dipping under cover of the quadrigeminal bodies and entering the substance of the mid-brain.

Superior Medullary Velum.—Filling up the triangular interval between the medial margins of the two superior peduncles there is a thin layer of white matter which completes the roof of the upper part of the fourth ventricle; it receives the name of the **superior medullary velum.** When traced downwards, the velum is seen to be carried, with the superior cerebellar peduncles, into the white matter of the cerebellum. Spread out on its posterior surface there is a small, thin, tongue-shaped prolongation of the cortex of the cerebellum termed the **lingula**; and the fourth pair of cranial nerves (**trochlear**) issues from its substance close to the inferior quadrigeminal bodies.

FOURTH VENTRICLE

The **fourth ventricle of the brain** is rhomboidal in outline. Below, it tapers to a point and becomes continuous with the central canal of the lower half of the medulla oblongata; above, it narrows in a similar manner and is continued into the **aqueduct of the mid-brain.** The **floor** of the fourth ventricle is formed below by the medulla and above by the dorsal surface of the pons. On each side a long, curved, and narrow prolongation of the ventricular cavity is carried laterally from its widest part and curves round the upper part of the corresponding inferior cerebellar peduncle. It is termed the **lateral recess.** The **roof** of the cavity is very thin and is intimately connected with the cerebellum, which conceals it from view.

Roof of Fourth Ventricle.—The roof of the fourth ventricle is tent-shaped (as seen in sagittal section). Above, it is formed by a thin lamina of white matter—the **superior medullary velum**—which stretches across between the superior cerebellar peduncles. Below, it is similarly formed by the **inferior medullary velum** which stretches across between the inferior cerebellar peduncles. Except at its lateral margins the inferior medullary velum consists of little more

than a layer of ependymal epithelium. It is therefore an extremely attenuated structure. Moreover, it is largely deficient in its lower part, so that an opening is formed through which the cavity of the fourth ventricle communicates directly with the subarachnoid space on the surface of the brain. This opening is termed the **median aperture of the fourth ventricle**. Similar openings are present at the extremities of the lateral recesses—the **lateral apertures of the fourth ventricle.** These three openings are of extreme importance, for they provide the only routes whereby the cerebro-spinal fluid (which is secreted inside the ventricular cavities) can escape on to the surface of the brain. It occasionally happens that they become occluded by inflammatory adhesions: in such a case the circulation of the

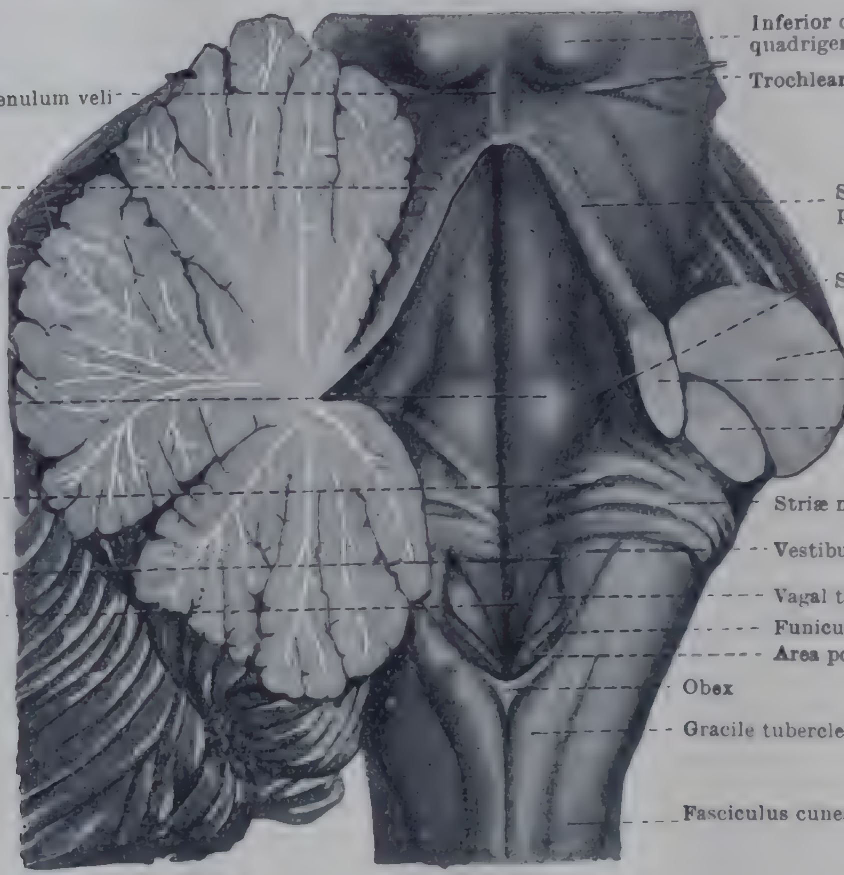


FIG. 770.—FLOOR OF THE FOURTH VENTRICLE. The right half of the cerebellum has been removed. The left half is drawn over to the left so as to expose the floor of the ventricle fully.

cerebro-spinal fluid is obstructed and the ventricles become progressively distended by its accumulation, leading to a condition of hydrocephalus.

The ependymal epithelium of the inferior medullary velum is invaginated into the cavity, on each side of the median plane, by vascular tufts of pia mater. These form the **choroid plexuses** of the fourth ventricle and, like similar plexuses found in the other ventricular cavities of the brain, they are concerned with the secretion of cerebro-spinal fluid. On each side, an extension of the choroid plexus becomes extruded through the lateral aperture of the fourth ventricle, and (as already noted) reaches the subarachnoid space on the base of the brain close to the root of the auditory nerve.

Floor of Fourth Ventricle.—The widest part of the floor is opposite the inferior cerebellar peduncles as they turn backwards to enter the cerebellum (Fig. 770). Above this level the floor is formed by the pons, and below it by the ventral part of the upper half of the medulla oblongata. Beneath the ependyma of the floor there is a thick layer of grey matter continuous below with that which surrounds the central canal and above with that around the aqueduct. The floor is circumscribed by definite lateral boundaries. From below upwards these are: (1) the gracile tubercle, (2) the cuneate tubercle, (3) the inferior peduncle, and (4) the superior peduncle of the cerebellum.

The floor of the fourth ventricle is divided into two symmetrical portions by

a median groove. Crossing each half of the floor, at its widest part, there are several more or less conspicuous bundles of fibres termed the **striæ medullares.** They appear on the side and the back of the inferior peduncle, pass transversely medially, and disappear from view in the median furrow. The striæ vary in different specimens, both in direction and prominence. It is not uncommon to find that no trace of them is visible on the surface. The connexions and functional significance of the striæ medullares are obscure. They were at one time believed to arise from the dorsal cochlear nucleus and to constitute some of the pathways for auditory impulses; hence they were called "auditory striæ". Recent studies, however, have thrown some doubt on this supposition (Rasmussen & Peyton, 1946).

In each half of the lower part of the floor there is a small, triangular, and rather sharply circumscribed depression immediately below the striæ medullares. It is termed the **inferior fovea.** The apex points upwards towards the striæ, and the basal angles are prolonged downwards as diverging grooves (Fig. 770). In this manner the lower half of the floor is mapped out into three triangular areas. The medial division is slightly elevated and is termed the **hypoglossal triangle,** because subjacent to the medial part of this area is the nucleus of the hypoglossal nerve. The intermediate area, between the two diverging grooves, is the **vagal triangle**—so called because the dorsal nucleus of the vagus nerve is subjacent to it. Near the lateral angle is the **vestibular area.** The base of this area is directed upwards and runs directly into an eminence over which the striæ medullares pass. Subjacent to that district of the floor of the ventricle lies the chief nucleus of the vestibular division of the auditory nerve.

When the floor of the ventricle is examined under water with a magnifying glass, the hypoglossal triangle is seen to consist of a narrow medial strip which corresponds to the hypoglossal nucleus, and a wider lateral part which has been shown to be the surface representation of another nucleus termed the **nucleus intercalatus.**

In the upper half of the floor also there is a slight depression which is termed the **superior fovea.** The longitudinal prominence between the superior fovea and the median fissure is called the **eminentia medialis**; it swells out inferiorly to form a rounded hillock called the **colliculus facialis,** and, below that, it is continuous with the floor of the hypoglossal triangle. As already stated, the **vestibular area** extends upwards into the pontine part of the ventricular floor and forms an elevated region in the most lateral part of its widest portion, below and to the lateral side of the superior fovea. Proceeding upwards from the superior fovea to the opening of the aqueduct there is a shallow depression termed the **locus cœruleus,** because it usually presents a faint slate-blue colour. When the ependyma is scraped away from the surface of the locus cœruleus, the colour is seen to be due to the **substantia ferruginea**—a name applied to a linear group of strongly pigmented cells. In transverse sections through the upper part of the pons, the substantia ferruginea appears on the cut surface as a small, brown spot.

General Plan and Development of Hind-Brain

The structure of the hind-brain differs in a marked degree from that of the spinal cord: indeed, in its upper part, it presents very little in common with the cord. Some of the largest fasciculi which come up from the spinal cord (such as the posterior white columns) end in the lower part of the medulla oblongata; others leave the medulla oblongata and pass into the cerebellum; and most of the bundles of fibres which pass upwards or downwards, from or to the spinal cord, come to occupy very different positions in the medulla oblongata and pons.

The grey matter, instead of being moulded into compact columns, becomes broken up into a series of discrete nuclei. Thus, there are developed from the basal lamina of the rhombencephalon, not one compact mass like the spinal anterior grey column, but three distinct broken columns of efferent nuclei (Figs. 767 and 774): (1) a **medial somatic column**, which in turn is broken up into two parts, a medullary nucleus (*hypoglossal*) which supplies the motor fibres to the

tongue muscles, and a pontine nucleus (*abducent*) which supplies the lateral rectus muscle of the eye; (2) a **branchial column**, broken up into separate nuclei, viz., *ambiguus, facial*, and *trigeminal*, which supply the striated muscles of the larynx, pharynx, and face and those concerned with mastication; and (3) a **splanchnic column** of nuclei, giving efferent fibres which pass out in the vagus, glossopharyngeal, and facial nerves, to be widely distributed to plain muscle, glands, and other tissues in the head, neck, thorax, and abdomen.

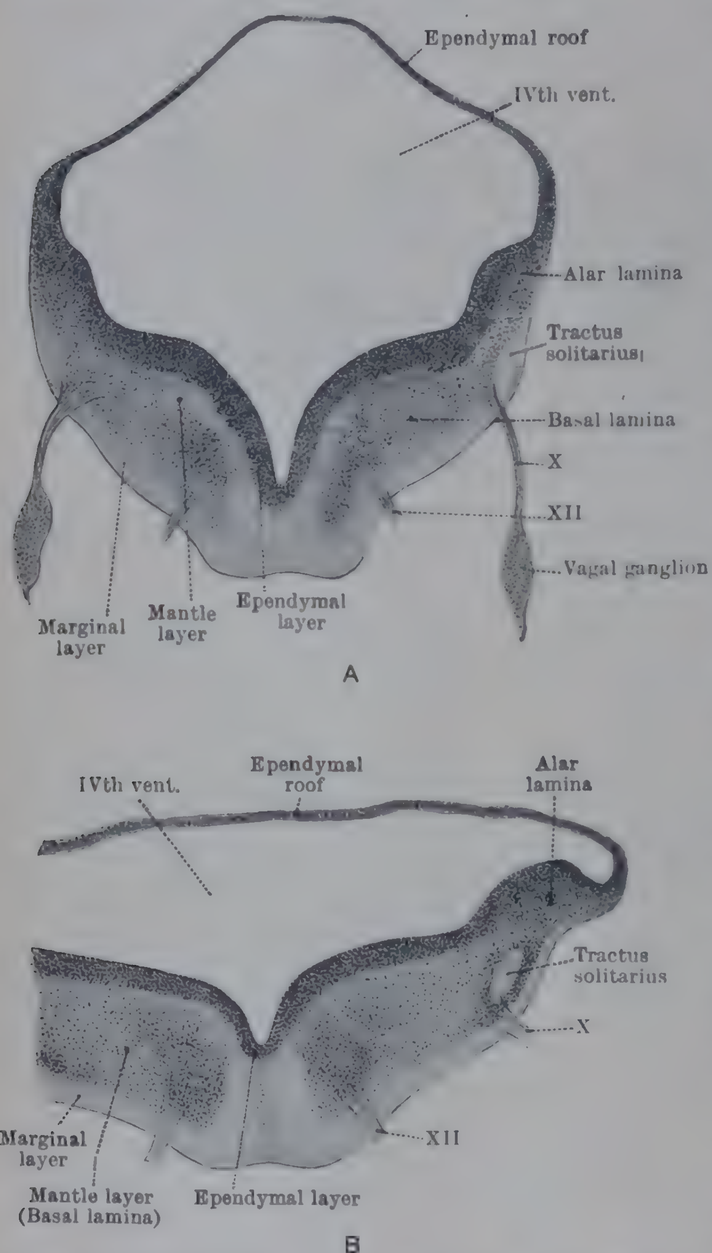


Fig. 771.—Transverse Sections across the Medulla Oblongata in two Human Embryos, representing Different Stages in the Expansion of the Roof and the falling laterally of the Side-Walls. (From His, slightly modified.)

Further, the terminal nuclei of the sensory nerves which are developed in the alar lamina of the rhombencephalon do not unite to form a definite posterior grey column, as happens in the spinal cord, but form discrete masses; and as these act as receptive centres for a much greater variety of sensory nerves than are represented in the spinal nerves there is a much greater number of nuclei than would be formed if the various components of the posterior grey column in the spinal cord were dissociated. Thus, there are terminal nuclei in the medulla oblongata not only for the ordinary cutaneous nerves, but also for nerves coming from the mucous membranes of the alimentary and respiratory organs as well as from other visceral structures; and there are also special nerves of taste (glossopharyngeal and the sensory root of the facial), of hearing (cochlear part of the auditory), and of equilibration (vestibular part of the auditory). But that does not exhaust the peculiar features of the terminal sensory nuclei of the rhombencephalon. In the description of the spinal cord attention was called to the fact that certain of the fibres of the posterior nerve-roots do not end in the grey matter of the cord but pass upwards to the medulla oblongata. Special terminal nuclei are developed from the alar lamina to receive these fibres. They are the nucleus gracilis and nucleus cuneatus.

The development of the cerebellum (as an elaboration and extension of the terminal nucleus of the vestibular nerve) is another disturbing factor, for it receives and gives off large numbers of fibres which add considerably to the complexity of the hind-brain. Moreover, there is developed from the alar lamina a whole series of other masses of grey matter—the **olivary nucleus, arcuate nuclei, nucleus of the circumolivary bundle**, and **nuclei pontis**—as links in the complex chains that bind many parts of the central nervous system to the great co-ordinating mechanism of the cerebellum.

Thus it comes about that, instead of having, as in the spinal cord, a definite column of grey matter ensheathed in a thick mass of white substance, the rhomb-

encephalon is composed of many scattered masses of grey matter; and its white substance is represented partly by great longitudinal strands, and also by many great systems of fibres that pass transversely through its substance or on its surface, *e.g.*, the superficial fibres of the pons and many of the arcuate fibres.

From what has already been said concerning the external form of the medulla oblongata and pons it will be apparent that the distortion of the neural tube which occurred as the result of the pontine flexure has also been largely responsible for the distinctive features of this region of the brain.

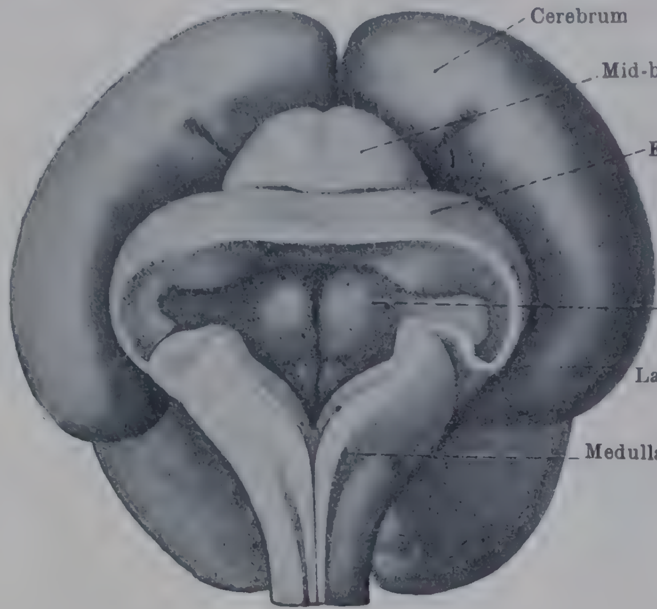


Fig. 772.—Brain of Fœtus of Eleven Weeks, viewed from behind. The ependymal roof of the fourth ventricle has been removed. At this stage the cerebellum is in the form of a simple band or plate which arches over the back of the anterior part of the cavity of the hind-brain. (His, 1904.)

As the pontine flexure develops, a strain is thrown upon the thin roof-plate, which yields and becomes stretched so as to permit the thick lateral walls of the neural tube to fall laterally (Figs. 771 and 772). One result of this process is the great lateral expansion of the cavity of the hind-brain, which assumes the characteristic rhomboid form. If the thin and greatly attenuated ependymal roof is torn away from the rhombencephalon of an embryo of the third month the fourth ventricle will present the appearance (viewed from behind) shown in Fig. 772. The ventricle is seen to be prolonged laterally, on each side, to form a little recess on the lateral side of the rhombencephalon. This is the **lateral recess.**

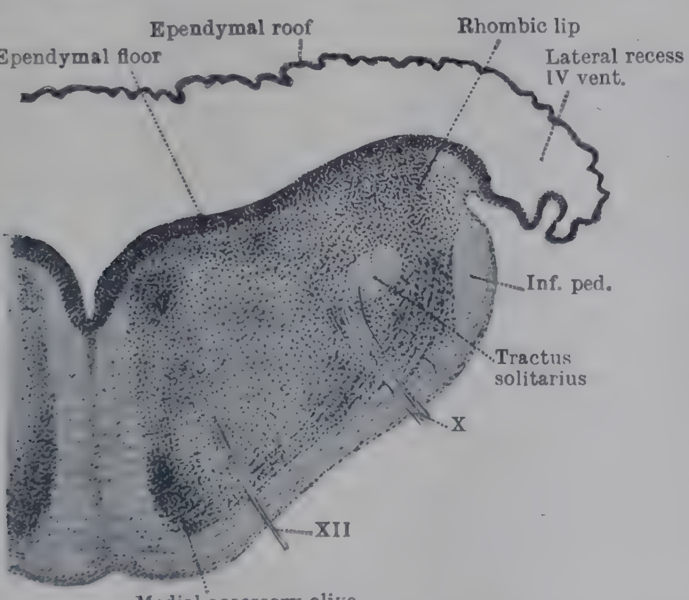


Fig. 773.—Transverse Section of Medulla Oblongata at a Later Stage than those shown in Fig. 771. (After His.)

As a result of the pontine flexure, also, the side-walls of the neural tube in the neighbourhood of the bend fall away from each other and eventually come to be placed in the same transverse plane, one with the other and also with the floor-plate. At the time this process is in operation (see Fig. 771) the alar and basal laminæ are particularly well defined, and the limiting sulci are accentuated by the bending of the side-wall; but that sharp distinction is soon lost as the result of the great expansion of the basal lamina (Fig. 773). This is due not only to growth of its intrinsic elements, but even more to the displacement into it of large numbers of neuroblasts which give the appearance of migrating from the alar into the basal lamina. Later still, the development of the great sensory and motor tracts contributes largely to the increase of the dimensions of the basal lamina.

As the two basal laminæ (one on each side of the median plane) increase in

thickness the epithelial cells in the intervening floor-plate become stretched and lengthened (Fig. 771), so that a definite septum or **raphe** is formed between the two halves of the rhombencephalon.

The fate of the extreme dorsal edge of the alar lamina is very interesting. The auditory nerve is inserted into it in the region of the lateral recess, and from it masses of neuroblasts develop to form receptive nuclei for the two parts (cochlear and vestibular) of the nerve—the **cochlear nuclei** and **vestibular nuclei**. Afferent fibres, bringing impulses from muscles, joints, and related structures in all parts of the body, make their way into a portion of the terminal vestibular nuclei, and these grow to form a large thickening of the edge of the alar lamina above the lateral recess. Eventually, as the thickening extends medially (Fig. 772), it reaches and invades the roof-plate and fuses with the corresponding rudiment of the other side. Thus, a semilunar band—the primitive cerebellum—is formed as an arch across the roof of the metencephalon. The part of the dorsal edge of the alar lamina which lies below the vestibular nuclei becomes everted to form what is known as the **rhombic lip** (Fig. 773). It is destined to be transformed into a series of masses of grey matter, some of which emit fibres to carry impulses into the cerebellum. But most of these fibres pass not so much to the part of the cerebellum derived from their own side as to that of the opposite side. Thus, from above downwards, the thickened margin of the fourth ventricle on each side develops into the following structures: cerebellum, the vestibular nuclei, the cochlear nuclei, the nuclei pontis (and arcuate nuclei), the olivary nucleus, the nucleus gracilis and the nucleus cuneatus. At an early stage of development the neuroblasts which form the rudiments of the nuclei pontis, arcuate nuclei, and the olivary nucleus appear to undergo a migration whereby they become displaced from their site of origin in the alar lamina to a more ventral position in the basal lamina.

It has been suggested that this apparent migration is an expression of a principle of neural differentiation which has been termed **neurobiotaxis**. This principle, enunciated by Kappers in 1907, refers to the tendency of nerve-cells during embryological development (and also in the course of evolution) to shift their position towards the source of the impulses which predominantly influence their activity. Thus, if we imagine a group of nerve cells which are mainly activated by stimuli reaching them from a direction x, the cells will tend gradually to change their relative position and move towards x. In the present instance, it seems that the cells of the nuclei pontis (for example) " migrate " into the basal lamina for the reason that they come under the influence of impulses conveyed by efferent paths from the cortex which are situated in this region of the neural tube. It may be noted that the " neurobiotactic " migration of nerve-cells is probably due to a relative rather than an actual displacement. As the result of differential growth of the embyro, neurons tend to become greatly elongated in order to reach the tissues which they supply. This elongation involves almost entirely the axonal (or efferent) processes, and as a result the cell-bodies become apparently approximated, *relatively* to the termination of their axons, more and more to the fibres from which they receive their afferent impulses (Kappers, 1921).

Internal Structure of Medulla Oblongata

Olivary Nuclei.—The most conspicuous of the isolated clumps of grey matter in the medulla are the olivary nucleus and the two accessory olivary nuclei. The **olivary nucleus** is the grey substance which produces the swelling known as the olive, and is a very striking object in transverse sections through this region. It is seen as a thick wavy line of grey matter folded on itself to enclose a space filled with white matter. It is in reality a crinkled lamina arranged in a purse-like manner, with an open mouth or **hilum** directed towards the median plane. The hilum does not reach the upper and lower ends, and in transverse sections through either end of the nucleus the grey lamina is seen in the form of a completely closed capsule. Out of the hilum streams a dense mass of fibres. These are efferent fibres destined for the cerebellar hemisphere of the opposite side, and they have their origin in the nerve-cells which compose the grey matter of the olivary nucleus.

The **accessory olivary nuclei** are two short bands of grey matter which are

placed the one dorsal to the main nucleus and the other medial to it. In transverse section each of these nuclei is rod-like (Fig. 774).

The **medial accessory olivary nucleus** extends lower down than the main nucleus, and its lower part is much larger than its upper. It begins immediately above the decussation of the pyramids, where it is seen on the lateral side of the cerebro-spinal tract and the medial lemniscus (Fig. 776). Higher up, it lies across the hilum of the main nucleus and on the lateral side of the medial lemniscus. The **dorsal accessory olivary nucleus** is immediately dorsal to the main nucleus. The two accessory nuclei fuse together at their upper ends.

The nerve-cells of the olivary nucleus are small and round, and emit a large series

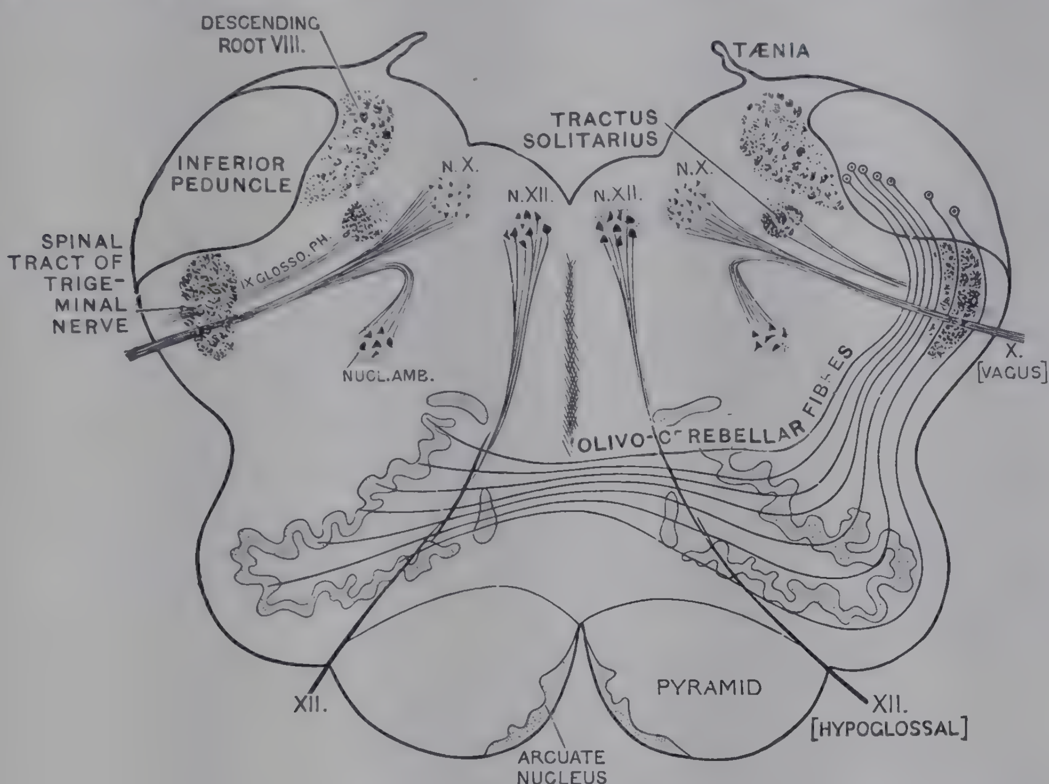


Fig. 774.—Diagram of Section of Medulla Oblongata to show the Course of the Olivo-Cerebellar Fibres.

N.X., Vago-glossopharyngeal nucleus. N.XII., Hypoglossal nucleus.

of short, radiating, complexly branched dendrites, so that the cell-body seems to lie in the centre of a spherical mass formed by its own dendrites and an almost equally complex mass of intertwined end-branches of the axons which carry impulses to these cells. A large descending tract which arises in the globus pallidus of the corpus striatum descends in the mesencephalon and rhombencephalon to end amidst the cells of the lateral part of the olivary nucleus. It is the **pallido-olivary tract** (Fig. 779).

The axons emitted by the cells of the olivary nucleus cross the median plane to the opposite inferior peduncle and pass into the cerebellum. These fibres are seen only in the upper part of the medulla oblongata. They form the deep part of the inferior cerebellar peduncle and constitute its chief bulk. Streaming out from the hilum of the olivary nucleus, they cross the median plane, and in the opposite side of the medulla oblongata they pass through and around the olivary nucleus of that side. Ultimately they are gathered together behind the olivary nucleus to take up a position in the deep part of the inferior peduncle. In passing back, they traverse the spinal tract of the trigeminal nerve and break it up into several separate bundles. The olivo-cerebellar fibres thus connect the olivary nucleus of one side with the opposite side of the cerebellum, and each part of it is connected with a definite part of the cerebellum.

The connexion of the cerebral cortex with the cerebellum by means of cortico-pontine and ponto-cerebellar fibres (Fig. 769) is found only in mammals. In all other vertebrates the olivary nucleus is the link between the higher, subcortical motor centres (the globus pallidus of the corpus striatum) and the cerebellum. Fibres from this motor controlling centre descend (in the brain of birds, reptiles, amphibians, and fishes) to terminate in

a structure homologous with the medial accessory olivary nucleus in the human brain, which is connected with the vermis of the cerebellum. In the mammalian brain, when motor functions are assumed by the cerebral cortex, the cortex becomes connected (Fig. 769) with the opposite cerebellar hemisphere by means of a new system of fibres—the middle peduncle. The assumption of motor control by the cerebral cortex, however, does not minimize the importance of the olive. On the contrary, a new olivary structure develops on the lateral side of the archaic olive, and in monkeys and Man this lateral nucleus attains a large size and complexity so as to become much the largest element in the olivary complex. The newly developed lateral olive receives fibres (pallido-olivary tract) from the globus pallidus, and each part of the rapidly expanding olivary lamina becomes connected with a definite part of the hemisphere of the cerebellum (Fig. 796, p. 910). As the cerebellum develops, the olivary nucleus increases in size. The function of the cerebellum is now believed to be concerned with the control of muscular tone. Hence, as more highly skilled movements are made possible by the development of the cerebral cortex, the connexions of the globus pallidus with the parts of the cerebellum which regulate the tone that is essential for the development of skill keep pace with the cerebral connexion of the corresponding cerebellar areas.

Decussation of Pyramids and Resulting Changes.—As a series of successive transverse sections through the lower part of the medulla oblongata and the upper part of the spinal cord are examined under the microscope, the most striking change which meets the eye is the decussation of the lateral cerebro-spinal tracts. We have already seen that, from their position alongside the anterior median fissure of the medulla oblongata, most of the fibres of the pyramid cross the median plane and, after passing through the anterior grey column, turn downwards in the lateral white column of the opposite side of the cord. Strands from the right lateral cerebro-spinal tract alternate with corresponding strands from the left side, and the interval between the bottom of the anterior median fissure and the grey matter surrounding the central canal becomes filled up with a great mass of intercrossing bundles of fibres.

As we have noted, the decussating pyramidal bundles pass through the anterior grey column, and cut it into two portions (Fig. 775). The basal part remains in position on the front and lateral side of the central canal, and forms part of the thick layer of grey matter which surrounds it. The detached head of the anterior column is set free; and from the large multipolar cells which lie in its midst some of the fibres of the anterior root of the first cervical nerve, and also some of the fibres of the accessory nerve, take origin.

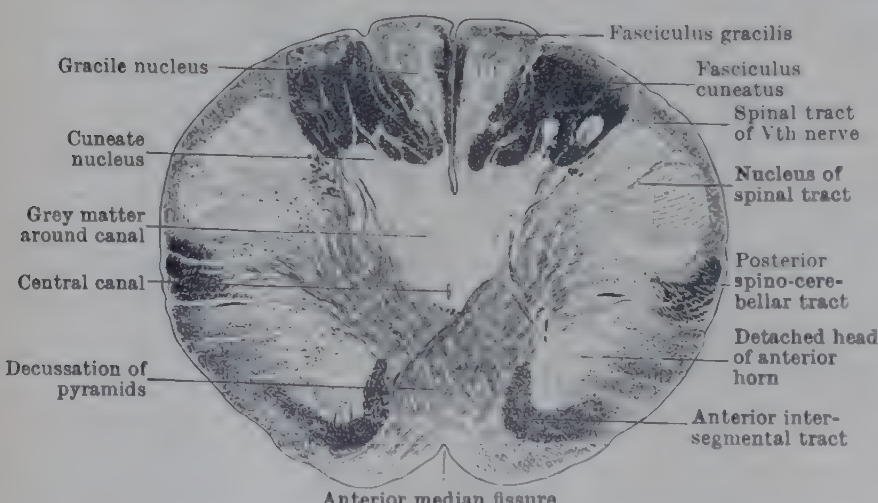


Fig. 775.—Transverse Section of Lower End of Medulla Oblongata of Full-time Fœtus.

Treated by the Weigert-Pal method. The grey matter is bleached white, and the tracts of medullated fibres are black.

In the medulla oblongata another effect of the decussation of the pyramids is seen in the submergence from the surface of the anterior intersegmental tract. At the site of the decussation, the intersegmental tract is thrust aside, and in the medulla oblongata it takes up its position as a flattened band on the lateral side of the pyramid (Fig. 775). Above the decussation, this strand lies close to the median plane behind the pyramid, where it is separated from its fellow of the opposite side by the median raphe alone (Fig. 776). In the upper part of the medulla oblongata it approaches still nearer to the dorsal surface and appears to form the greater part of a strand termed the medial longitudinal

bundle (Figs. 778 and 779). The detached head of the anterior grey column of the cord, as it is traced upwards, clings closely to its original relationship with the anterior intersegmental tract. It is applied to the lateral side of that strand, and, gradually becoming smaller, finally disappears at the level of the lower part of the olivary nucleus.

Cuneate and Gracile Fasciculi, with their Nuclei.—As the fasciculus gracilis and the fasciculus cuneatus of the spinal cord are traced up into the medulla oblongata they seem to increase in bulk, and in transverse sections appear as wedge-shaped strands quite distinct from each other. They increase in width and lose considerably in depth, and consequently the transverse diameter of the area which they occupy becomes greater. As a result of this, and also owing to the removal of the lateral cerebro-spinal tract from the lateral white column of the cord immediately in front, the posterior horn of grey matter is gradually

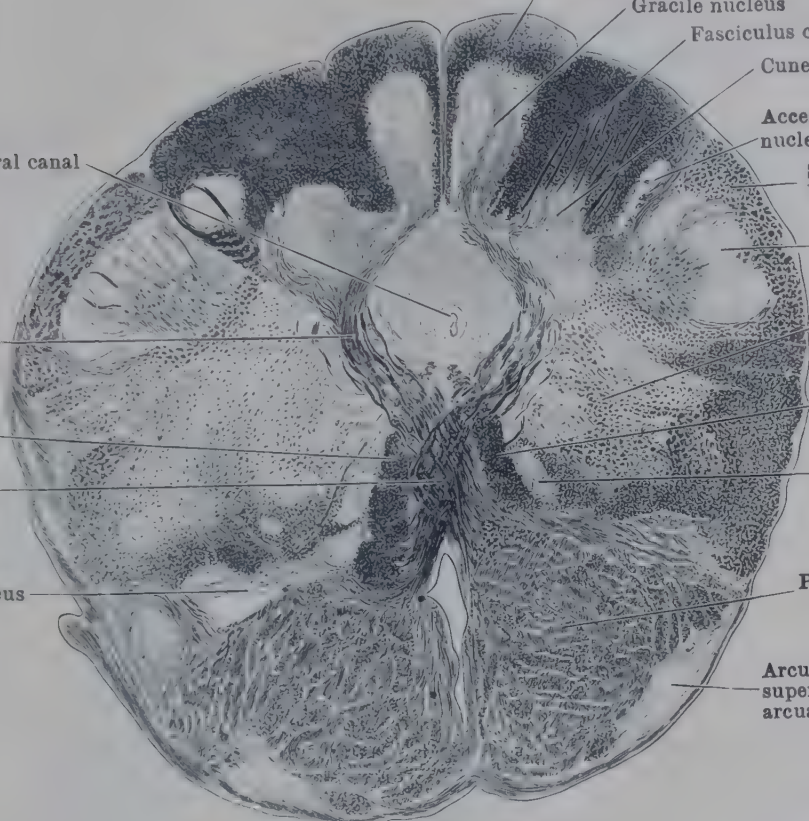


FIG. 776.—SECTION THROUGH ADULT MEDULLA OBLONGATA IMMEDIATELY ABOVE THE DECUSSATION OF THE PYRAMIDS (Weigert-Pal specimen).

rotated forwards and comes to lie transversely and in the same straight line with its fellow of the opposite side (Figs. 775 and 776). The substantia gelatinosa, simultaneously, becomes increased in quantity and presents a horseshoe-shaped outline in transverse section. It clasps within its concavity the slightly reduced head of the posterior horn, and forms with it a conspicuous circular mass of grey matter which lies close to the surface, producing a slight bulging called the **tubercle of the trigeminal nerve** (see p. 883). The basal portion of the posterior horn remains posterior and lateral to the central canal, and forms a portion of the central grey mass of the closed part of the medulla oblongata; but very soon the neck of the posterior horn, which at that level is greatly reduced owing to the absence of entering posterior nerve-roots, is invaded by bundles of fibres which traverse it in different directions and convert it into a diffuse mass of nerve-cells and interlacing fibres—the *formatio reticularis.* By this means the rounded head of the posterior horn is cut off from the central grey matter, and from that point upwards it remains as an isolated grey column intimately associated with the spinal tract of the trigeminal nerve. It has, in fact, become the **nucleus of the spinal tract of the trigeminal nerve.**

The gracile and cuneate nuclei are seen in their most typical form in sections

immediately above the level of the decussation of the pyramids (Figs. 776 and 777).

The **gracile nucleus** appears as a relatively slender mass of grey matter in the interior of the fasciculus gracilis.

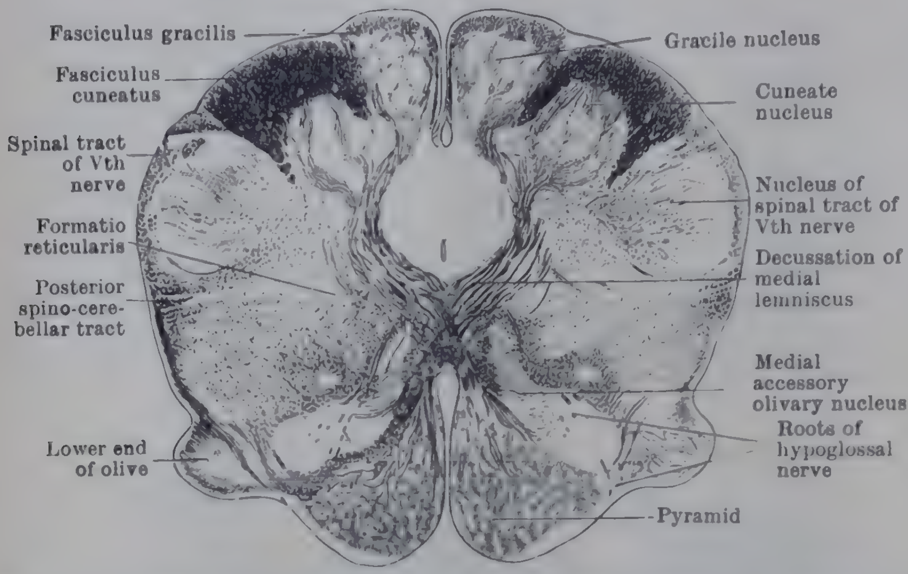


Fig. 777.—Transverse Section through Fœtal Medulla Oblongata immediately above the Decussation of the Pyramids. (Weigert-Pal specimen.)

The **cuneate nucleus** is a direct offshoot from that part of the base of the posterior grey column which is preserved as a portion of the central grey mass. In transverse section it is seen to invade the deep part of the fasciculus cuneatus, and it gradually grows dorsally into its substance. It differs in appearance from the gracile nucleus, because throughout its whole length the grey nucleus and the fibres of the strand are separated from each other by a sharp line of demarcation. A little higher up, a second and much smaller mass of grey matter termed the **accessory** or **lateral cuneate nucleus** appears in the fasciculus cuneatus superficial to the main nucleus (Fig. 776). This accessory nucleus receives fibres of the fasciculus cuneatus which are derived from the posterior roots of the cervical nerves and convey proprioceptive impulses from the neck and upper limb. Experimental evidence indicates that the accessory cuneate nucleus sends fibres to the same side of the cerebellum.

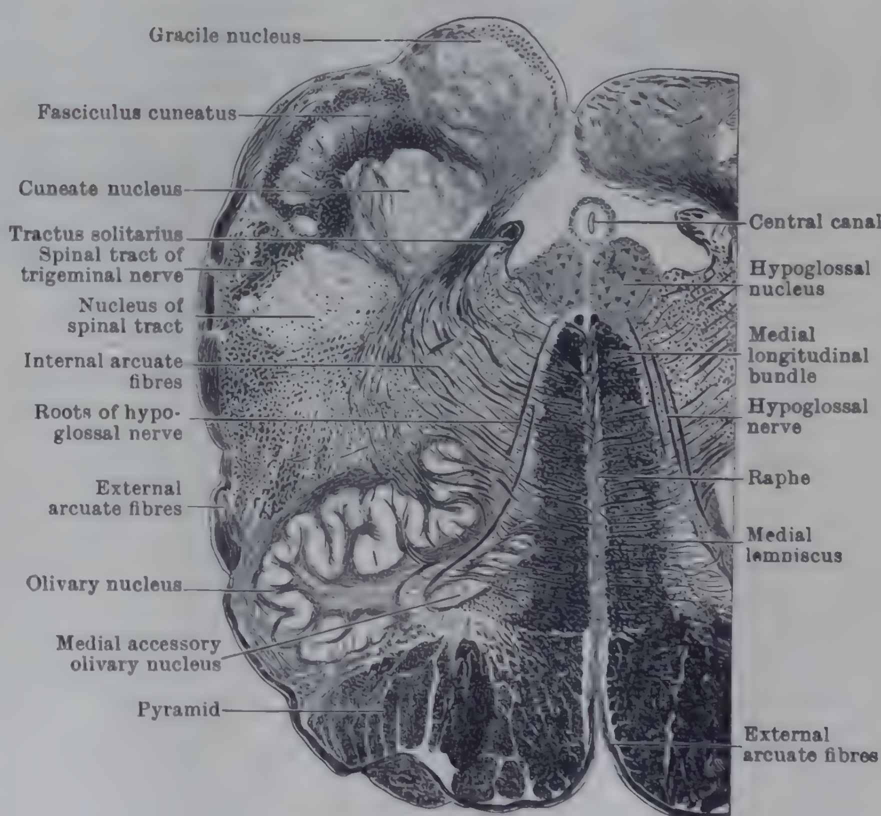


Fig. 778.—Transverse Section of Medulla Oblongata at the Level of the Olive.

As a series of sections is studied from below upwards, it will be noticed that the number of fibres in the gracile and cuneate fasciculi rapidly decreases, until, at the level of the gracile and cuneate tubercles, these eminences are composed almost entirely of the grey nuclei, covered by a thin layer of the few remaining fibres of the two fasciculi.

When the central canal of the medulla oblongata opens up into the fourth ventricle the gracile and cuneate nuclei are pushed laterally, and the gracile nucleus soon comes to an end; but the cuneate nucleus extends upwards for a

short distance farther and terminates only when the inferior cerebellar peduncle begins to take definite shape.

Sensory Decussation.—Immediately above the level of the decussation of the pyramids another decussation of fibres takes place in the substance of the medulla oblongata in the median plane behind the pyramids. This is the **decussation of the lemniscus medialis**, or the **sensory decussation**, so called in contradistinction to the term "motor decussation" which is sometimes applied to the decussation of the pyramids. The fibres which take part in this decussation are called **internal arcuate fibres**, and they are derived from the cells of the gracile and cuneate nuclei (but not the accessory cuneate nucleus). From the deep aspects of these nuclei fibres stream forwards and medially towards the median raphe, forming a series of concentric curves in the substance of the medulla oblongata.

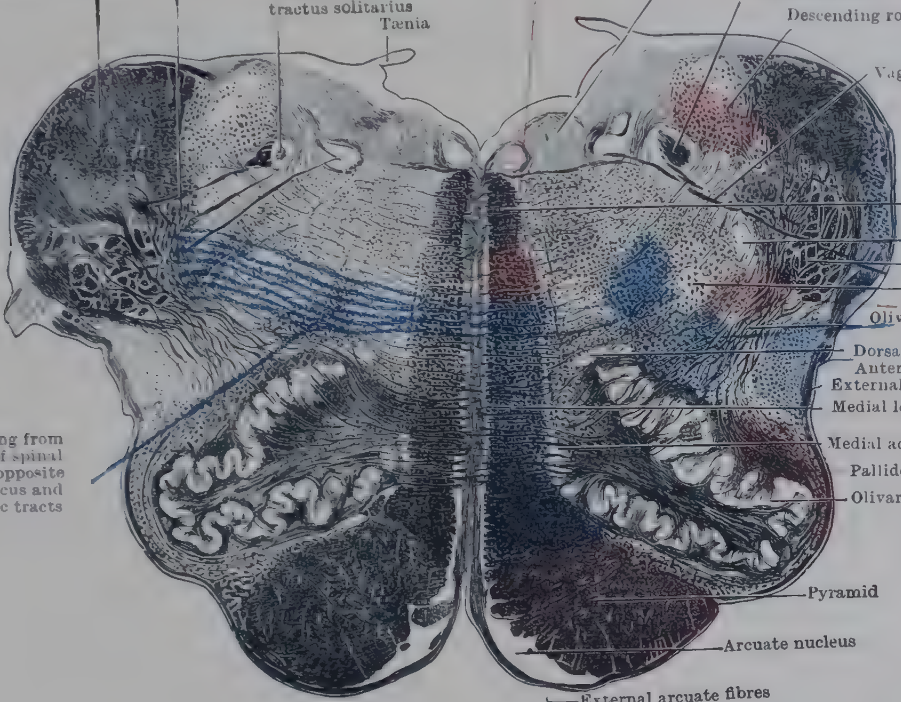


FIG. 779.—TRANSVERSE SECTION AT THE LEVEL OF THE MIDDLE OF THE OLIVE.

The floor of the fourth ventricle is seen, and it will be noticed that the inferior cerebellar peduncles have now taken definite shape. Some of the descending tracts in red ; ascending tracts in blue.

They cross the median plane and decussate with the corresponding fibres of the opposite side behind the pyramids. Having gained the opposite side they immediately turn upwards and form a conspicuous strand of longitudinal fibres which ascends close to the median plane and is separated from its fellow of the opposite side by the median raphe alone. This strand is termed the **medial lemniscus.**

As we proceed up the medulla oblongata, the first internal arcuate fibres seen are coarse bundles which curve forwards in a narrow group round the central grey matter (Figs. 776 and 777). Soon, finer bundles are seen describing wider curves on the lateral side of the coarser group, until a very large part of each half of the medulla is seen to be traversed by these arcuate fasciculi (Fig. 778). The internal arcuate fibres decussate in the median plane with their fellows of the opposite side. They then change their direction and turn upwards, and the lemniscus, as already stated, takes form and gradually increases in volume as it ascends. This great and important tract is thus laid down between the pyramid and the medial longitudinal bundle, and, as a result, this bundle is pushed still farther backwards; therefore, when the lemniscus is fully established, the longitudinal bundle comes to lie immediately beneath the grey matter of the floor of the fourth ventricle (Fig. 779). But the lemniscus is not in direct contact with the longitudinal bundle, for a strand of fibres—the **tecto-spinal tract**—separates them, as well as fibres from the sensory nucleus of the fifth cranial nerve which are crossing the raphe to join the medial lemniscus (Fig. 779).

It is important to realize at this stage the full significance of the decussation of the lemniscus and to have a clear conception of the connexions of the fibres which take part in it. The posterior white column, which ends in the cuneate and gracile nuclei, is derived from the posterior roots of the spinal nerves. The lemniscus fibres therefore carry on the impulses which are conveyed up the spinal cord in the posterior white column of the opposite side. These impulses are relayed through the gracile and cuneate nuclei. At its origin, the lemniscus is transferred to the opposite side of the medulla oblongata. But it will be remembered that a large proportion of the fibres of the entering posterior nerve-roots of the spinal nerves end in connexion with the cells of the posterior grey column of the cord. It must not be supposed that the path represented by the latter fibres comes to a termination thereby; for, from the cells of the posterior column, other fibres arise which cross in the white commissure to the opposite side and proceed up the spinal cord to the lateral part of the medulla oblongata. These fibres constitute the **spino-thalamic tracts** already referred to. The practical bearing of this is that, owing to the crossing of the medial lemniscus and lower down of the spino-thalamic fibres, unilateral lesions of the medulla oblongata are apt to produce complete hemi-anæsthesia; whilst unilateral lesions of the spinal cord produce only partial hemi-anæsthesia.

The pyramid forms a massive tract in front of and quite distinct from the medial lemniscus. The medial lemniscus, the tecto-spinal tract, and the medial longitudinal bundle are, in the first instance, not marked off from each other. They appear as a broad flattened band applied to the raphe with its posterior edge in contact with the grey matter on the floor of the fourth ventricle, and the anterior edge with the pyramid, but in the upper part of the medulla the lemniscus and medial longitudinal bundle begin to draw asunder, and to grow denser, making the intervening tecto-spinal tract more distinct (Fig. 779).

The **medial longitudinal bundle** occupies a position corresponding to that occupied in the spinal cord by the anterior intersegmental tract, with which it appears to be continuous. As they are followed upwards, these fibres are thrust back by the two decussations: the lower decussation pushing them behind the pyramids, and the upper decussation displacing them still farther backwards to a position behind the medial lemniscus. The bundle consists of a heterogeneous collection of fibres, ascending and descending, which link together the nuclei of the cranial nerves at different levels in the brain-stem. Its most important element consists of fibres from the lateral vestibular nucleus proceeding to motor nuclei, in particular those of the third, fourth, sixth, and eleventh cranial nerves of both sides.

Inferior Cerebellar Peduncle.—The gracile and cuneate nuclei gradually give place to the **inferior peduncle** in the upper part of the medulla oblongata. Fibres from various quarters converge to form this great strand. It first takes shape as a thin superficial layer of longitudinal fibres which are gathered together immediately lateral to the cuneate nucleus; but after that nucleus has come to an end, and as the upper part of the medulla oblongata is reached, the inferior peduncle is seen to have grown into a massive strand which presents a kidney-shaped or an oval outline on transverse section (Fig. 779); and it ultimately enters the white central core of the cerebellum. The principal fibres which build up this peduncle are the following: (1) the posterior spino-cerebellar tract (conveying proprioceptive impulses mainly from the same side of the body), (2) external arcuate fibres from the arcuate nuclei;

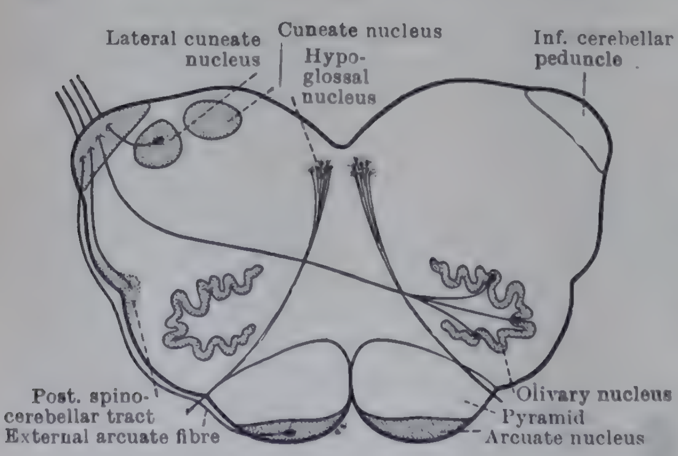


Fig. 780.—Diagram showing the Origin of some of the Fibres which enter into the Composition of the Inferior Cerebellar Peduncle.

(3) fibres from the accessory (lateral) cuneate nucleus (conveying impulses from the neck and upper limb of the same side); and (4) olivo-cerebellar fibres (Fig. 780).

Thus, the inferior peduncle conveys to the cerebellum: (1) fibres that conduct impulses from the posterior spinal roots, mainly of the same side; and (2) fibres from the olivary and arcuate nuclei which convey impulses from the higher regions of the brain.

It is commonly stated that the inferior cerebellar peduncle contains also numerous fibres from the gracile and cuneate nuclei (in addition to the accessory cuneate nucleus). However, there is no certain evidence that this is so; on the contrary, the results of recent experimental work indicate that the efferent fibres of the gracile and cuneate nuclei all enter into the composition of the medial lemniscus along which they are conveyed to the thalamus.

Formatio Reticularis.—Behind the olive and the pyramid is the **formatio reticularis.** In the medulla oblongata it occupies a position which, to a large extent, corresponds with that of the deeper part of the lateral white column in the spinal cord. In transverse section it appears as an extensive area divided into a lateral and a medial field by the roots of the hypoglossal nerve as they traverse the substance of the medulla oblongata to reach the surface. In the lateral portion, which lies behind the olive, a considerable quantity of grey matter, continuous with that in the spinal cord, is present in the reticular formation; it is therefore called the **formatio reticularis grisea**. In the medial part, which lies behind the pyramid, the grey matter is extremely scanty, and the reticular matter here is termed the **formatio reticularis alba.**

The nerve-fibres which traverse the formatio reticularis run both in a transverse and in a longitudinal direction. The **transverse fibres** are the internal arcuate and olivo-cerebellar fibres. The **longitudinal fibres** are derived from different sources in the two fields. In the formatio grisea they represent to a large extent the fibres of the lateral white column of the cord, after the removal of the posterior spino-cerebellar and the lateral cerebro-spinal tracts. They consist, therefore, of the fibres of the rubro-spinal, pallido-olivary, spino-thalamic, and anterior spino-cerebellar tracts of the spinal cord. In the formatio alba the longitudinal fibres are the medial lemniscus, the tecto-spinal tract, and the medial longitudinal bundle, all of which have been described already.

Central Canal and the Grey Matter which surrounds it.—The central canal, as it proceeds upwards through the lower half of the medulla, is gradually forced backwards, owing to the accumulation of fibres in front of it. First the decussation of the pyramids and then the sensory decussation tend to push it backwards; and the formation of the longitudinal strands in which those intercrossings result (viz., the pyramid and the medial lemniscus), together with the continuation upwards of the anterior intersegmental tract, leads to a great increase in the amount of tissue which separates it from the anterior surface of the medulla oblongata. The canal is surrounded by a thick layer of grey matter which is continuous with the basal portions of the anterior and posterior grey columns of the cord. This central grey matter is sharply defined on each side by the internal arcuate fibres as they curve forwards and medially around it. Finally, the central canal opens, in the upper part of the medulla oblongata, into the cavity of the fourth ventricle. The central mass of grey matter which surrounds the canal is now spread out in a thick layer on the floor of the fourth ventricle, and in such a manner that the portion which corresponds to the basal part of the anterior grey column is close to the median plane, whilst the part which represents the base of the posterior grey column occupies a more lateral position. It is important to note this, because it explains why the nucleus of origin of the hypoglossal nerve is placed in the medial part of the floor, whilst the nuclei of termination of the afferent fibres of the vagus, glosso-pharyngeal, and auditory nerves lie in the lateral part of the floor.

Three Areas of Flechsig.—In transverse sections through the upper part of the medulla oblongata, the root-fibres of the hypoglossal and vagus nerves are seen traversing its substance. The nucleus of origin of the hypoglossal is placed in the grey matter of the floor of the fourth ventricle close to the median plane; the nucleus of the vagus is situated immediately to the lateral side of the hypoglossal nucleus. From these nuclei the root-bundles of the two nerves, passing forwards, diverge from each other and divide the substance of the medulla, as seen in transverse section, into the three areas of Flechsig, viz., an anterior, a lateral, and a posterior.

The **anterior area**, which is bounded medially by the median raphe and laterally by the hypoglossal roots, contains: (*a*) the pyramid; (*b*) the medial lemniscus; (*c*) the tecto-spinal tract; (*d*) the medial longitudinal bundle; (*e*) the medial accessory olivary nucleus; (*f*) the arcuate nucleus.

The **lateral area** lies between the root-fibres of the hypoglossal and those of the vagus. It contains: (*a*) the olivary nucleus; (*b*) the dorsal accessory olivary nucleus; (*c*) the nucleus ambiguus; (*d*) the splanchnic efferent nucleus of the vagus and glosso-pharyngeal nerves; (*e*) the formatio reticularis grisea.

The **posterior area** is situated behind the vagus roots, and within its limits are seen: (1) the inferior cerebellar peduncle; (2) the upper part of the cuneate nucleus; (3) to the medial side of that a crowd of transversely cut bundles of fibres, loosely arranged and forming the descending root of the vestibular nerve; (4) close to them, but placed more deeply, a round, compact, and very conspicuous bundle of transversely cut fibres, viz., the tractus solitarius; (5) a large bundle—the spinal tract of the trigeminal nerve—close to the lateral side of its nucleus, which is composed of substantia gelatinosa.

Internal Structure of Pons

When transverse sections are made through the pons, it is seen to be composed of a basilar part and a dorsal part. The dorsal part is the upward prolongation

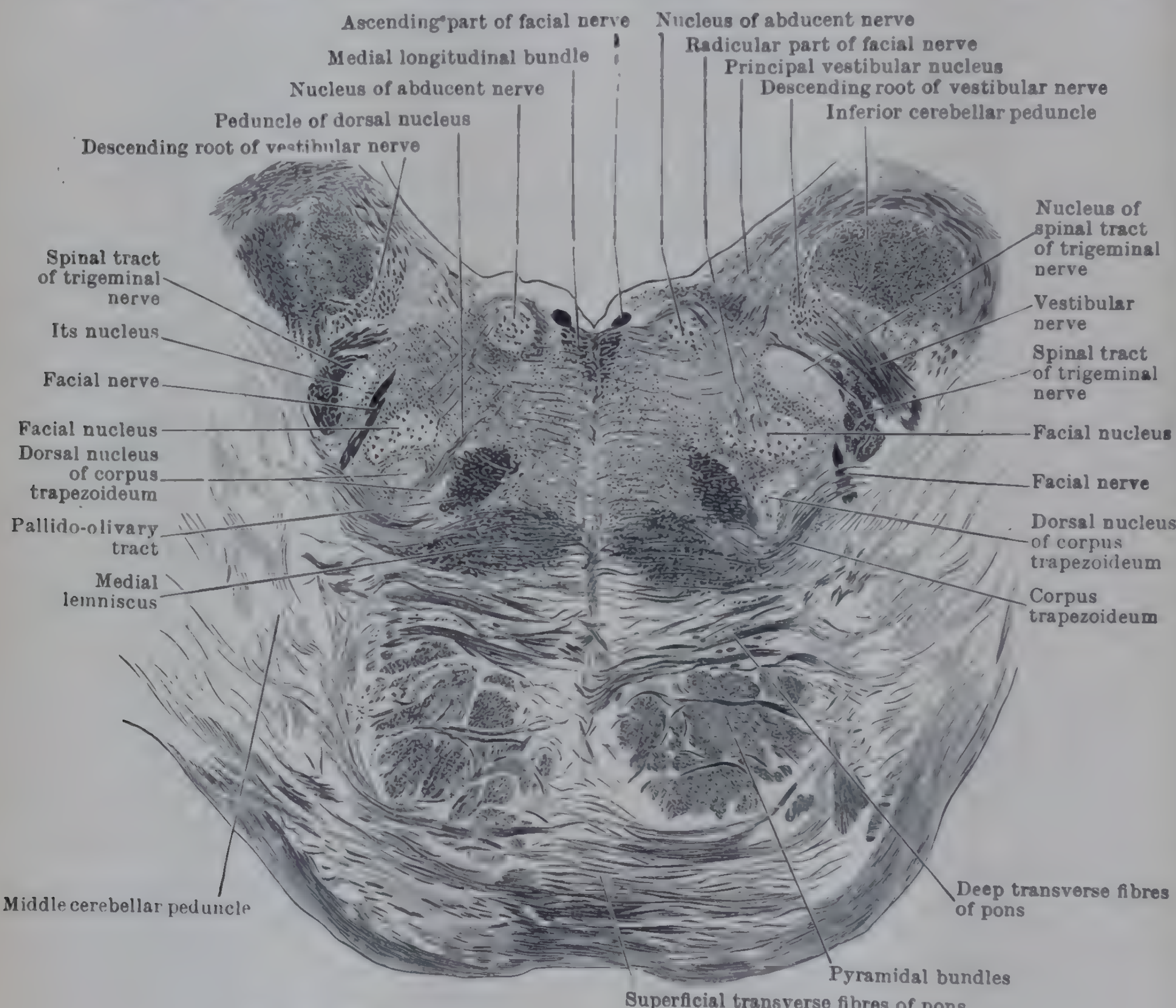


Fig. 781.—Section through the Lowest Part of the Pons.

of the medulla oblongata, exclusive of the pyramids (which are drawn forward into the basilar part).

Basilar Part of Pons.—This constitutes the chief bulk of the pons, and it is the part to which the name "pons" was originally applied by Varolius, as it appears to form a bridge between the hemispheres of the cerebellum. It is composed of: (1) **transverse fibres** arranged in coarse bundles; (2) **longitudinal fibres**, gathered together in massive bundles; and (3) a large amount of grey matter, termed the **nuclei pontis**, which fills up the interstices between the intersecting bundles of fibres.

The **longitudinal bundles**, to a large extent, consist of the same fibres which,

lower down, are gathered together in the two pyramids of the medulla oblongata. When the pyramids are traced upwards into the pons they are first a pair of compact bundles, and then are broken up by the transverse fibres of the pons into smaller bundles which are spread out over a wider area. At the upper border of the pons they again come together and form a pair of solid strands, each of which is continuous with the middle part of the corresponding basis pedunculi. Added to these bundles of the pyramid, there are many other fibres that enter the pons from the basis pedunculi to terminate in the nuclei pontis.

The **transverse fibres** are placed in front of the pyramidal bundles at the lower border of the pons. Farther up they increase in number, and many are seen breaking through the pyramids and also passing behind them. Laterally, these transverse fibres are collected together into one compact mass which enters the white core of the cerebellum as the **middle cerebellar peduncle**. In the median plane the transverse fibres of the two sides form a coarse decussation.

There is some analogy between the pyramidal portions of the medulla oblongata and the basilar part of the pons. In the medulla oblongata fine external arcuate fibres sweep over the surface of the pyramids. These resemble the transverse fibres of the pons, and, like them, reach the cerebellum—although by a different route, viz., the inferior peduncle. The nuclei pontis are represented also in the pyramidal part of the medulla oblongata by the arcuate nuclei, which are covered over by the external arcuate fibres, and even tend to penetrate into the pyramids. These arcuate nuclei, as already pointed out, are continuous with the nuclei pontis.

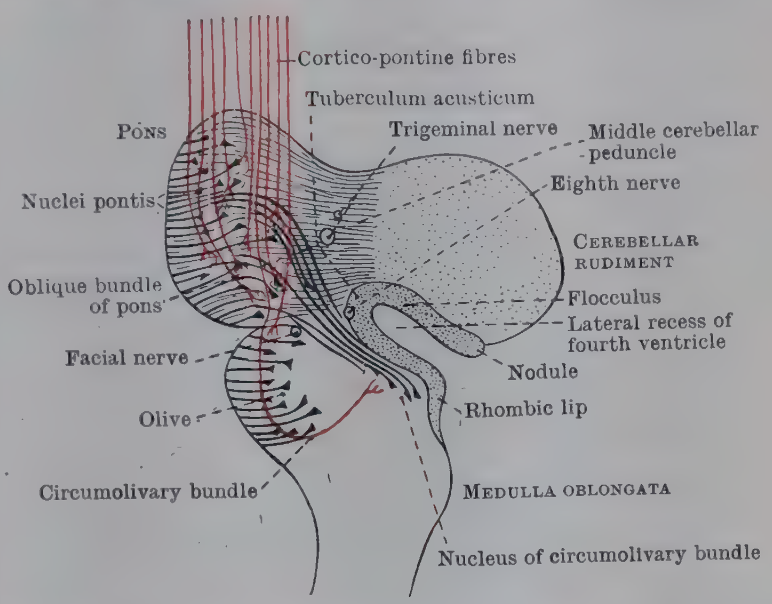


Fig. 782.—Diagram of Left Lateral Aspect of Fœtal Rhombencephalon representing some of the Cell-Groups and Fibre-Tracts.

Connexions of Longitudinal and Transverse Fibres.—When a transverse section through the upper part of the pons is compared with one close to its lower border, it becomes at once apparent that the numerous scattered bundles of longitudinal fibres which enter the basilar part of the pons from above, if brought together into one tract, would form a strand very much larger than the two pyramids. The reason is this: a large proportion of the fibres of the basis pedunculi—those forming its lateral and medial parts—are **cortico-pontine fibres**; they arise in the cerebral cortex and end in the nuclei pontis. The pyramidal fibres, which occupy the intermediate part of the basis pedunculi, also suffer loss when they descend into the hind-brain, because some of them end there by effecting synapses with the cells of the motor nuclei of the trigeminal, abducent, facial and hypoglossal nerves; but that accounts for only a very small part of the difference between the bulk of the basis and that of the pyramid.

The transverse fibres take origin as axons of the cells of the nuclei pontis. They cross the median plane and enter the middle peduncle of the opposite side, and thus reach the cerebellar cortex, where they end in ramifications around certain of the cortical cells. Some authorities believe that there are also fibres passing in the opposite direction, *i.e.*, from the cerebellum to the nuclei pontis; but there is some doubt concerning the existence of any such fibres. The middle peduncle thus may contain both efferent and afferent cerebellar fibres; but no fibres pass continuously through the pons from one middle peduncle into the other.

Corpus Trapezoideum.—This name is applied to a group of transverse fibres which traverse the lower part of the pons (Fig. 781). They are quite distinct from those which have been just described as entering the middle peduncle, and they

lie in the boundary between the dorsal and basilar parts of the pons, but encroaching considerably into the ground of the former. They arise from the cells of the terminal nuclei of the cochlear nerve, and constitute a tract which establishes certain central connexions for that nerve. They will be more fully described when we treat of the cerebral connexions of the auditory nerve.

Dorsal Part of Pons.—On the dorsal surface of the pons there is spread a thick layer of grey matter, covered with ependyma, which forms the floor of the upper or pontine part of the fourth ventricle. Beneath this grey matter the median raphe of the medulla oblongata is continued up into the pons, so as to divide its dorsal part into symmetrical halves.

In the *lowest part of the pons* the inferior cerebellar peduncle is placed on

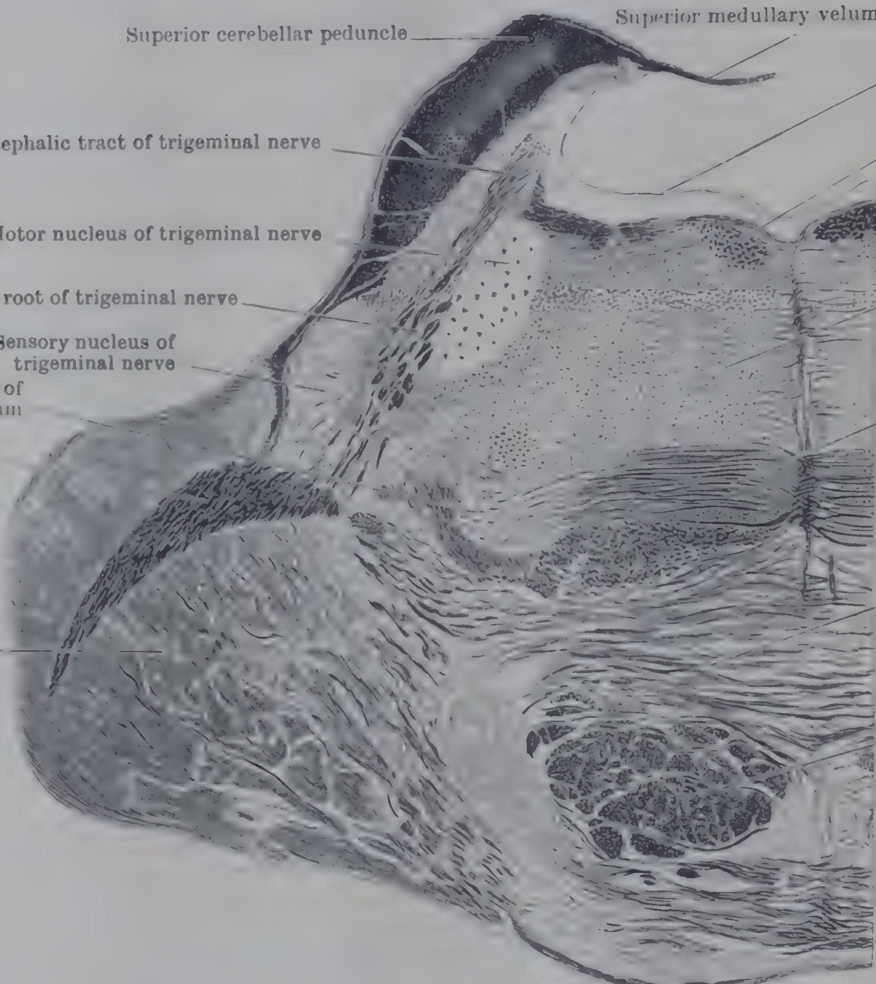


FIG. 783.—TRANSVERSE SECTION THROUGH PONS AT LEVEL OF TRIGEMINAL NUCLEI.

the lateral side of the dorsal part (Fig. 781). In transverse sections it appears as a large, massive, oval strand of fibres which inclines backwards into the cerebellum and thus leaves the pons. Between the inferior peduncle and the median raphe the dorsal part of the pons is composed of formatio reticularis, continuous with the same formation in the medulla oblongata. Thus, transverse fibres, curving in towards the raphe, and also longitudinal fibres, are seen breaking through the mass of grey matter which occupies the interstices of the intersecting bundles. To the naked eye the formatio reticularis appears uniformly grey, but its constituent parts are revealed by low powers of the microscope in properly stained and prepared specimens. Embedded in the formatio reticularis are various clumps of compact grey matter and certain definite strands of fibres. These we shall describe as we pass from the inferior peduncle towards the median raphe.

(1) **Spinal Tract of Trigeminal Nerve and its Nucleus.**—Close to the medial side of the inferior peduncle, but separated from it by the vesitibular nerve as it proceeds backwards through the pons, is seen a large crescentic group of coarse bundles of fibres. This is the spinal tract of the trigeminal nerve; and applied to

its medial, concave side there is a small mass of grey matter which is the direct continuation upwards of the substantia gelatinosa (Fig. 781).

(2) The **nucleus of the motor root of the facial nerve** comes next. It is a conspicuous, obliquely placed, ovoid clump of grey matter that lies close to the corpus trapezoideum. The root-fibres of the facial nerve stream backwards and medially from it towards the floor of the fourth ventricle. Passing forwards between the facial nucleus and the trigeminal sensory nucleus a solid nerve-bundle may be observed. This is the facial nerve, traversing the pons towards its place of emergence from the brain.

(3) Immediately medial to the facial nucleus, but partly sunk in the corpus trapezoideum, is the **dorsal nucleus of the corpus trapezoideum**, and some of the fibres of the corpus may be observed penetrating into its substance. In Man, it is a very small mass of grey matter. In sections through the part of the pons where it attains its greatest size, it appears in the form of two, or it may be three,

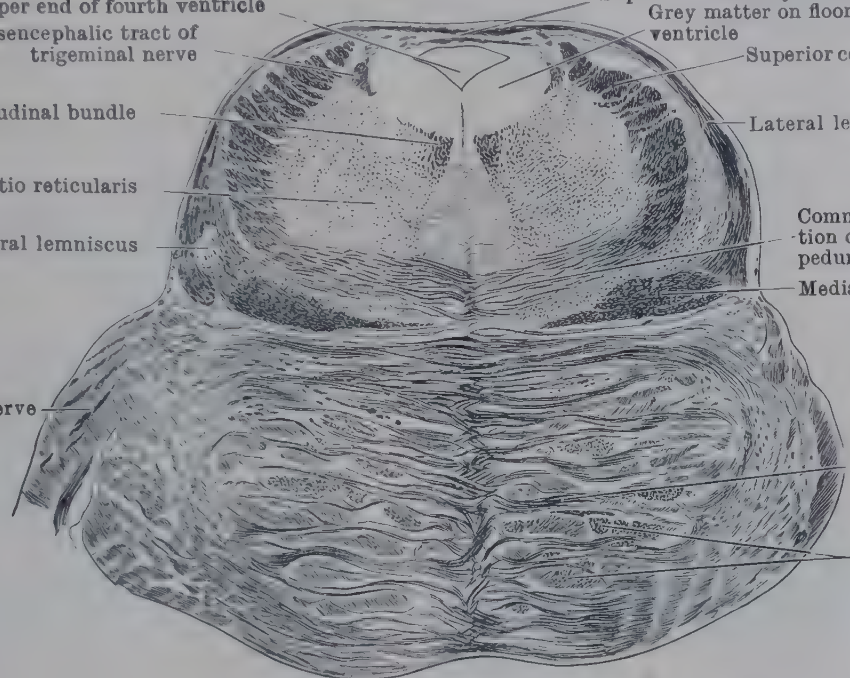


FIG. 784.—SECTION THROUGH PONS, ABOVE LEVEL OF THE MAIN TRIGEMINAL NUCLEI.

small isolated masses. It is intimately connected with the auditory fibres, and establishes manifold connexions between them and the nuclei of other nerves. A dense group of longitudinal fibres lies behind and medial to it; they constitute the **pallido-olivary tract**, to which we have already referred in discussing the olivary nucleus (Fig. 781).

(4) The **medial longitudinal bundle** and the **medial lemniscus** come next. As they proceed upwards through the pons, they occupy the same relative position as in the medulla oblongata. They are placed close to the median raphe and are separated from each other by the **tecto-spinal tract**. The **medial longitudinal bundle** lies immediately under cover of the grey matter of the floor of the fourth ventricle. The **medial lemniscus** is placed close to the corpus trapezoideum, many of whose fibres traverse it as they pass towards the median plane.

(5) The **nucleus of the abducent nerve** also forms a conspicuous object in sections through the lower part of the pons. In such sections it appears as a round mass of grey matter situated close to the lateral side of the medial longitudinal bundle and immediately under cover of the grey matter of the floor of the fourth ventricle. From its medial side numerous root-bundles of the abducent nerve pass out and proceed forwards between the medial lemniscus and the dorsal nucleus of the corpus trapezoideum. They occupy in the pons, therefore, a position similar to that occupied by the hypoglossal root-fibres in the medulla oblongata.

Up to the present only the lowest part of the dorsal portion of the pons has been described. As we proceed upwards and gain a point *above the level of*

the corpus trapezoideum, the floor of the ventricle becomes narrower, and the medial lemniscus becomes markedly increased in size by the addition of the fibres of the spino-thalamic tracts. On the other hand, many of the structures that have attracted attention lower down gradually disappear, while other objects make their appearance in the formatio reticularis.

The **superior cerebellar peduncle** is the group of fibres proceeding from the nuclei of the cerebellum to the red nucleus in the opposite side of the brain-stem and to the opposite thalamus. It is a very conspicuous object in sections through the middle and upper parts of the pons. In transverse section it has a semilunar outline, and as it emerges from the cerebellum it lies immediately on the lateral side of the fourth ventricle, towards which its concave aspect is turned (Fig. 783). Its dorsal border is joined with the opposite peduncle by the thin lamina of white matter termed the *superior medullary velum*, whilst its ventral border is sunk to a small extent in the dorsal part of the pons. As it is traced upwards it sinks deeper and deeper into the pons until it becomes completely submerged, with the exception of the dorsal border. It now lies on the lateral side of the reticular formation of the pons, and this position it maintains until the mid-brain is reached (Fig. 785).

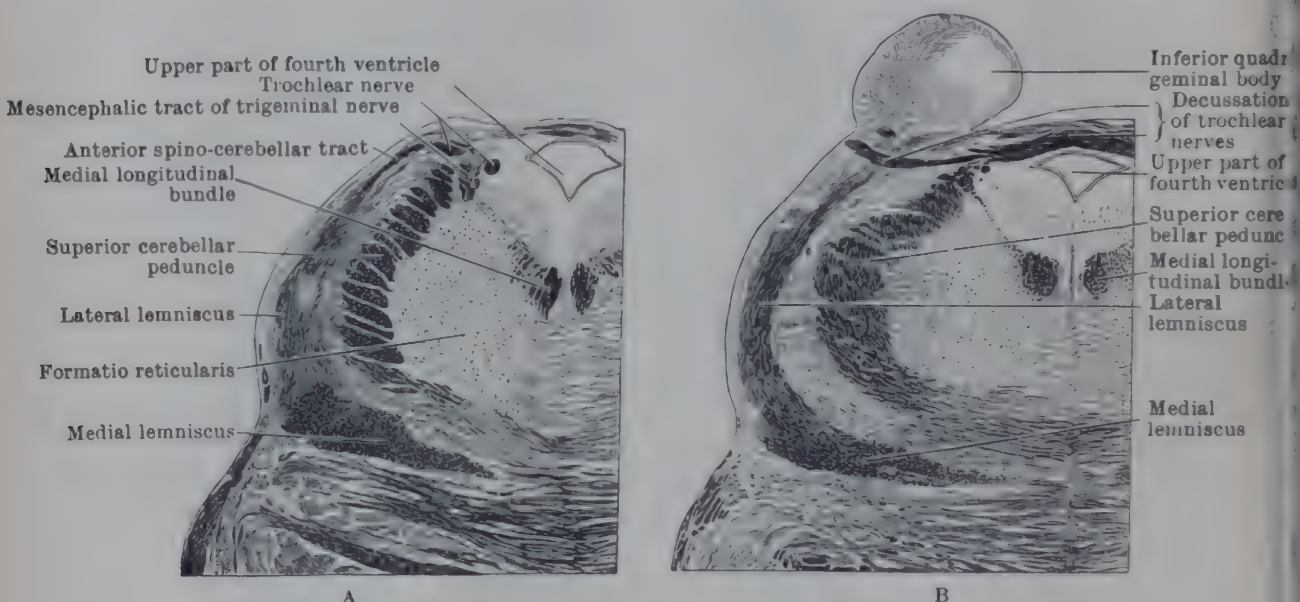


FIG. 785.—SECTIONS THROUGH DORSAL PART OF PONS CLOSE TO THE MID-BRAIN.
A is at a slightly lower level than B.

About *half-way up the pons* the main nuclei of the trigeminal nerve come into view. These nuclei are two in number on each side, viz., a large oval terminal nucleus for certain of the sensory fibres of the nerve and a nucleus of origin, equally conspicuous, for the motor fibres (Fig. 783). The **sensory nucleus** lies close to the lateral surface of the dorsal portion of the pons. The **motor nucleus** is placed on the medial side of the sensory nucleus, but rather nearer the floor of the fourth ventricle. At this level the spinal tract of the trigeminal nerve begins by the bending downwards of certain of the fibres of the sensory portion. The sensory and motor roots of the fifth nerve traverse the basilar part of the pons on their way to and from the nuclei.

Above the level of the nuclei of the trigeminal nerve a new tract of fibres comes into view—the **mesencephalic tract of the trigeminal nerve**. It is a small bundle of nerve-fibres, semilunar in cross-section, which lies close to the medial side of the superior peduncle and on the lateral and deep aspect of the grey matter on the floor of the fourth ventricle (Figs. 783-785).

On a slightly deeper plane than the mesencephalic tract of the fifth nerve, between it and the medial longitudinal bundle, and in close relation to the grey matter of the floor of the ventricle, there is the collection of pigmented cells which constitutes the **substantia ferruginea**.

The **medial longitudinal bundle**, as it is traced upwards, maintains the same position throughout, and as it ascends it becomes more clearly mapped out as a

definite and distinct tract. It lies close to the median raphe, and immediately subjacent to the grey matter of the floor of the fourth ventricle.

The **medial lemniscus**, as it ascends, undergoes striking changes in shape. In the lower portion of the pons its fibres, which in the medulla oblongata are spread out along the side of the median raphe, are collected together in the form of a loose bundle which occupies a wide field immediately behind the basilar portion of the pons. As it proceeds up, the fibres spread out laterally until a compact ribbon-like layer is formed which ascends between the dorsal and ventral parts of the pons (Figs. 784 and 785).

Above the level of the main trigeminal nuclei another flattened layer of fibres comes into view to the lateral side of the medial lemniscus. To it the name of **lateral lemniscus** is given. Its fibres spread laterally and backwards, and finally take up a position on the lateral surface of the superior cerebellar peduncle. Among the fibres of the lateral lemniscus a little knot of compact grey matter, termed the **nucleus of the lateral lemniscus**, comes into view (Fig. 785). It gives origin to many of the fibres of the lateral lemniscus.

CEREBELLUM

The **cerebellum** forms the largest subdivision of the hind-brain. It lies behind the pons and medulla oblongata and occupies the greater part of the posterior cranial fossa. Above it lies the tentorium cerebelli, which separates it

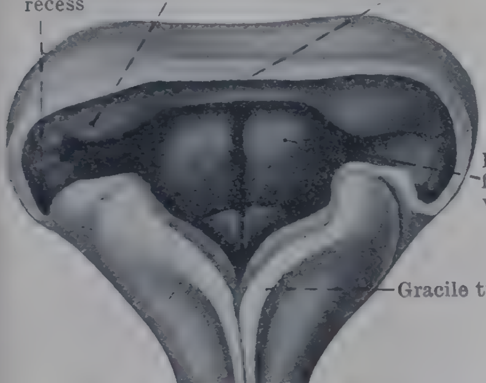


FIG. 786.—DORSAL ASPECT OF RHOMBENCEPHALON IN HUMAN EMBRYO. (His, 1904.)

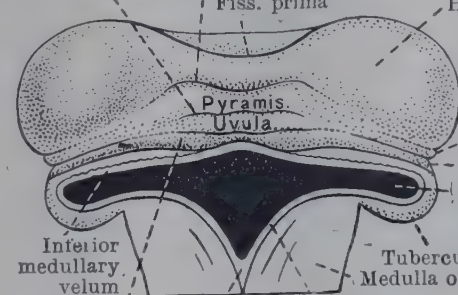


FIG. 787.—DORSAL ASPECT OF FŒTAL (FOURTH MONTH) CEREBELLUM, MEDULLA OBLONGATA AND FOURTH VENTRICLE.

from the posterior part of the cerebral hemispheres. Laterally the cerebellum is related to the temporal bone; behind and below it occupies a deep fossa of the occipital bone. In the dura mater of the posterior fossa there are various venous sinuses which are related to the cerebellum (Fig. 877, p. 977).

The whole organ is divisible for descriptive purposes into a pair of **hemispheres** united by a narrow median part called the **vermis** (Fig. 791). When viewed from above, the vermis projects as a low ridge but is not clearly separable from the hemispheres. Inferiorly (Fig. 792) the vermis lies in a deep gutter—**the vallecula**—between the hemispheres and is clearly demarcated from them by deep furrows. Anteriorly the cerebellum, as it faces the pons and medulla, is related to the fourth ventricle of the brain (Fig. 793).

DEVELOPMENT AND SUBDIVISION OF CEREBELLUM

It has been shown that the cerebellum is formed from two distinct rudiments, one on each side derived from the dorsal edge of the alar lamina close to the insertion of the eighth nerve. During the second month of intra-uterine life there is a rapid proliferation of the cells of the mantle layer of the cerebellar rudiments, which thus becomes considerably thickened (Fig. 786).

The accentuation of the pontine flexure brings the cerebellar rudiments into a transverse direction. The roof-plate that unites them becomes thickened by immigrant neuroblasts from the medial parts of the cerebellar rudiments; it thus

comes about that one organ is formed by the fusion of the two original rudiments in the roof-plate, and a dumb-bell shaped mass results (Fig. 787). On the lower aspect of this mass the inferior medullary velum and the choroid plexus of the fourth ventricle develop. In the third month, lateral bulgings of the cerebellar rudiment give the first evidence of cerebellar hemispheres (Fig. 787).

The basic plan of the adult human cerebellum is obscured to a considerable degree by the complexity of its fissuration. Hence, before attempting to describe its main divisions it is desirable to give a brief schematic account of the basic plan by reference to the presumed stages in the evolutionary development of the cerebellum. (For a general account of the structural organization of the cerebellum, see Dow, 1942.)

It has already been noted that the cerebellum is developed primarily as an extension and elaboration of part of the terminal nucleus of the vestibular nerve. In other words, it may be supposed that in its most primitive form the whole of

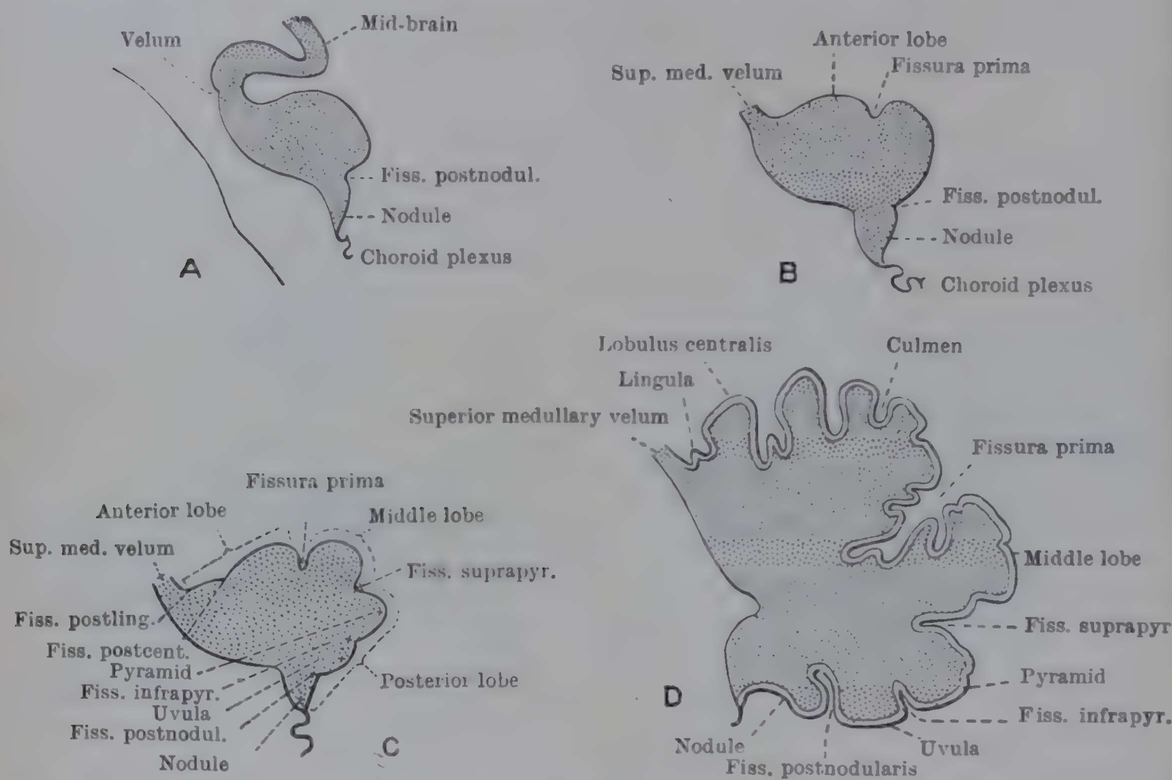


FIG. 788.—MEDIAN SAGITTAL SECTIONS OF FŒTAL CEREBELLA IN FOUR STAGES OF DEVELOPMENT. A and B, third month ; C, fourth month ; D, fifth month.

the cerebellum receives direct and indirect vestibular connexions and is therefore concerned entirely with functions of equilibration. In fishes generally, in which the semicircular canals and lateral lines play a very important rôle as a balancing and orientating mechanism in swimming, the primitive vestibular part of the cerebellum develops on each side a lateral expansion—the *auricular lobe* (Fig. 789 A). This expansion is retained in all mammals, including Man ; and in them it is termed the *flocculus* (Figs. 789, 792).

In the next phase of development (Fig. 789 B), the spino-cerebellar tracts make their appearance, conveying proprioceptive impulses on the basis of which the postural tone of the limb-muscles comes under the regulatory influence of the cerebellum. This leads to the differentiation of a new element, the "spinal cerebellum", which appears in the middle of the older "vestibular cerebellum" and divides it into anterior and posterior parts. The anterior part is represented by a small median lobule—the *lingula*—and the posterior part by a central thickening called the *nodule* and the laterally situated flocculi. The newer, spinal, part of the cerebellum also sends out on each side a lateral expansion—the *paraflocculus*—which lies in close topographical relation with the flocculus. It should be noted that the divisions which we have described are not to be quite sharply distinguished on the basis of fibre-connexions, for afferent fibres from

the spinal cord reach the lingula in addition to vestibular fibres, while direct vestibular connexions encroach to a slight degree on to the posterior part of the "spinal cerebellum".

A third phase in the development of the cerebellum is an expression of the increasing domination of the cerebral cortex in the central nervous system of the higher vertebrates. In all mammals the activities of the cerebellum are to some extent under the control of the fore-brain, and to effect this control descending fibres pass from most areas of the cerebral cortex down to the pons. Here they are relayed on to the cerebellum by fibres which take their origin in the nuclei pontis. The irruption of these *ponto-cerebellar fibres* into the cerebellum leads to the differentiation of yet another element, and this again makes its appearance in the middle of the older parts of the cerebellum. The new element, which becomes relatively larger and more elaborate as the cerebral cortex undergoes a progressive expansion, is termed the **lobus medius.** It is also sometimes referred to as the "neocerebellum", in contradistinction to the older and more primitive spinal and vestibular elements which are collectively termed the "palæocerebellum". The lobus medius consists of a central portion which enters into the formation of the vermis, and a pair of large lateral expansions which form the greater part of the hemispheres of the human cerebellum. It can be divided into two main parts, the larger *ansiform lobe* and the smaller *paramedian* or *tonsillar lobe.* Both these lobes become extremely complicated in higher mammals by an intricate system of fissures and folia, and by reference to some of the deeper fissures further topographical subdivisions can be defined.

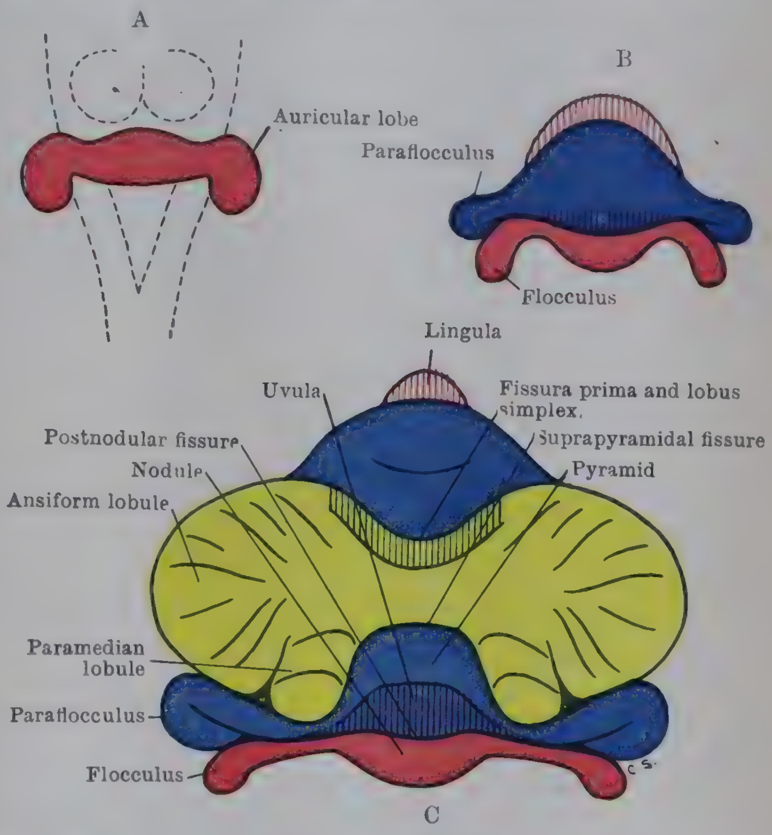


FIG. 789.—DIAGRAMS ILLUSTRATING EVOLUTIONARY DEVELOPMENT OF CEREBELLUM AND THE CONSTITUTION OF ITS THREE LOBES.

Red, Vestibular cerebellum ; *Blue,* Spinal cerebellum ; *Yellow,* Neocerebellum (lobus medius).

A. Hypothetical primitive cerebellum with vestibular connexions only ; B. Cerebellum of reptile showing addition of part that receives spino-cerebellar tracts ; C. Mammalian cerebellum showing addition of part (lobus medius) that receives cortical impulses by way of the pontine nuclei.

We can now appreciate the general plan on which the cerebellum is built in Man by reference to Figs. 788, 789, 794, 795. From these diagrams it is perfectly clear that the whole cerebellum is naturally divisible into three lobes—anterior and posterior lobes which are composed of the older vestibular and spinal elements, and the middle lobe or lobus medius. The anterior lobe is separated from the middle lobe by a deep fissure which makes its appearance very early in the embryonic development of the cerebellum. Hence it is termed the **fissura prima.** The anterior lobe is composed of the lingula in front and a larger portion behind which receives afferent connexions from the spinal cord. The middle lobe, as already noted, is distinguished from other parts of the cerebellum by the connexions whereby it is brought into functional relation with the cerebral cortex. It should be noted, however, that its anterior part (immediately behind the fissura prima) receives a few spino-cerebellar fibres which encroach upon it from the anterior lobe. This portion of the middle lobe is marked off from the main

part by a transverse fissure and forms a separate lobule, sometimes termed the *lobus simplex* (Fig. 789). The posterior lobe is divisible into a median part, which forms the inferior vermis in the human cerebellum, and a lateral expansion made up of the flocculus and paraflocculus on each side. The median part is separated into three segments by two transverse fissures. Behind and below is the nodule, which has already been mentioned. Separated from it by the post-nodular fissure is the *uvula*, while in front and above is the *pyramid*. The posterior lobe is marked off from the middle lobe by a relatively deep fissure—the **fissura suprapyramidalis.**

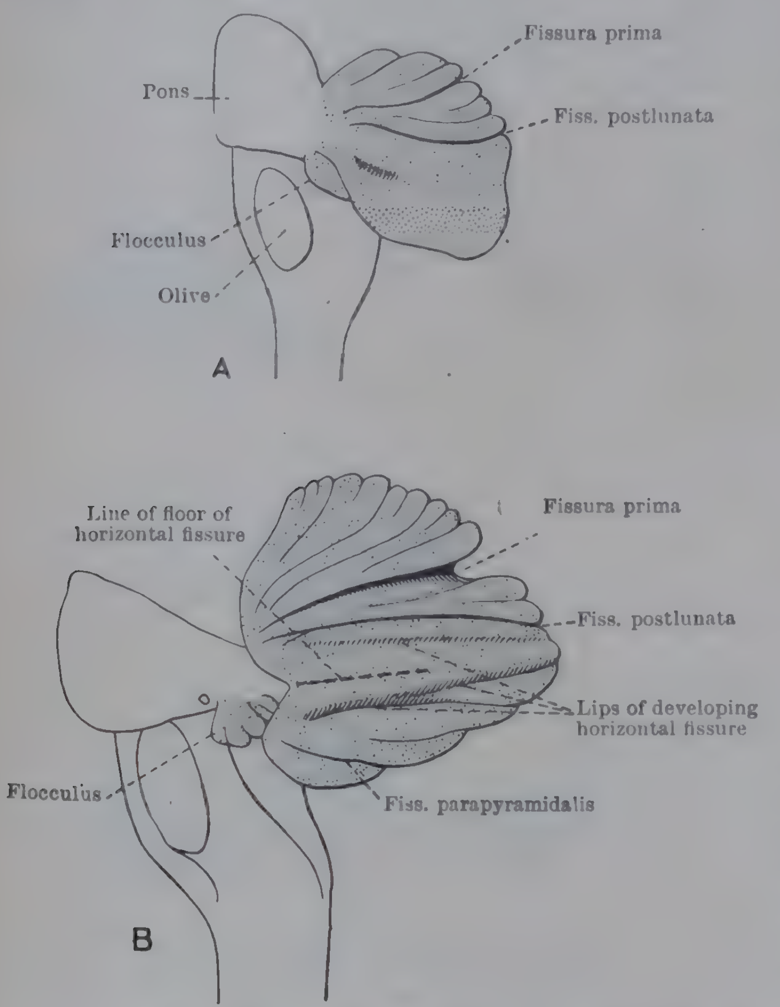


Fig. 790.—Left Lateral Aspect of Fœtal Rhombencephalon at Fourth (A) and Fifth (B) Months.
The cerebellum is stippled.

The fissura suprapyramidalis has been reasonably termed the fissura secunda because of the part it plays with the fissura prima in separating the cerebellum into its three main lobes. Unfortunately, however, the term *fissura secunda* has been applied by various authorities to other fissures in the posterior lobe so that its use is likely to lead to confusion.

The subdivisions of the cerebellum which we have noted have much more than a purely morphological significance. Their different fibre-connexions are an expression of correspondingly different functions, and these differences, again, are reflected in the disorders which arise when they are affected by injury or disease. Hence, the recognition of the three main lobes of the human cerebellum will be found of great assistance in the appreciation of the clinical syndromes related to cerebellar lesions. The nodule and floccular lobes are entirely vestibular in their connexions. Lesions of this part of the cerebellum, therefore, give rise to disturbances of equilibrium without affecting the reflex mechanisms of the spinal cord. Lesions of the spinal part of the cerebellum lead to disturbances of postural mechanisms in relation to the fact that the normal cerebellar control of the distribution of reflex muscular tonus is thrown out of gear. Lastly, lesions affecting the middle lobe, or neocerebellum, always lead to gross defects of voluntary movements, which become inco-ordinate, jerky, and inaccurate.

In the light of what has been said in the previous paragraphs we can now turn our attention to a more detailed consideration of the adult human cerebellum (Figs. 791-795). On the upper surface the deep fissura prima can usually be recognized without difficulty. In front of it lies the **anterior lobe** of the cerebellum. An ill-defined ridge in the median plane marks the position of the superior vermis, while on each side the anterior lobe enters into the composition of the corresponding cerebellar hemisphere. The lingula is an extension forwards of the superior vermis on the surface of the superior medullary velum. It appears as a thin tongue of grey matter (cerebellar cortex) crossed transversely by a few shallow fissures, and it is bounded on each side by the superior cere-

bellar peduncle. The remainder of the anterior lobe can be subdivided (somewhat indistinctly) into the *central lobule*, with lateral expansions termed the *alæ*,

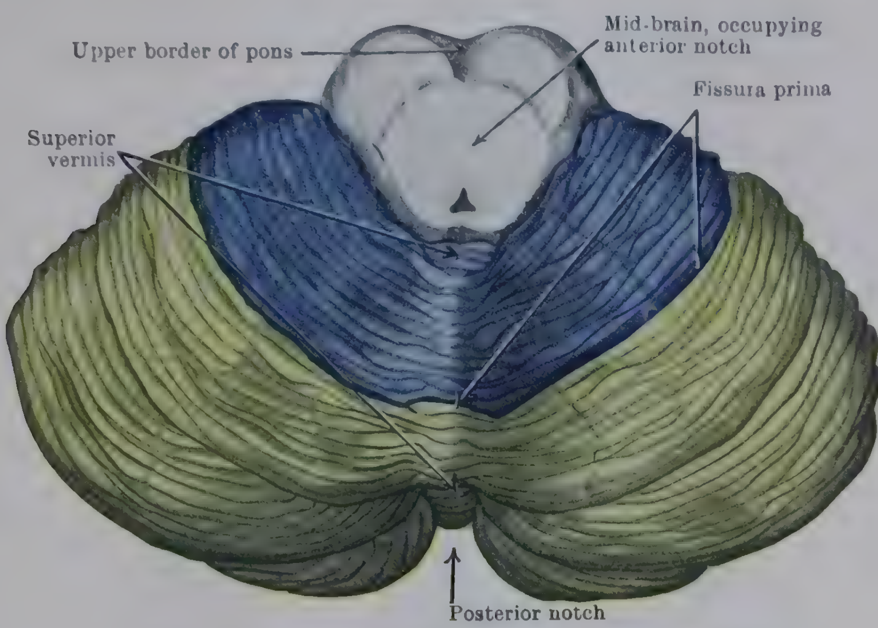


FIG. 791.—SUPERIOR SURFACE OF THE CEREBELLUM.
The anterior lobe is coloured *blue*, the middle *yellow*.

and (immediately above the *fissura prima*) the *culmen* with lateral expansions termed the *anterior lunate lobules*.

The **middle lobe** forms by far the greater part of the bulk of the cerebellum (Figs. 794, 795), in conformity with the pronounced development of the cortico-ponto-cerebellar connexions in the human brain. In the median plane it enters

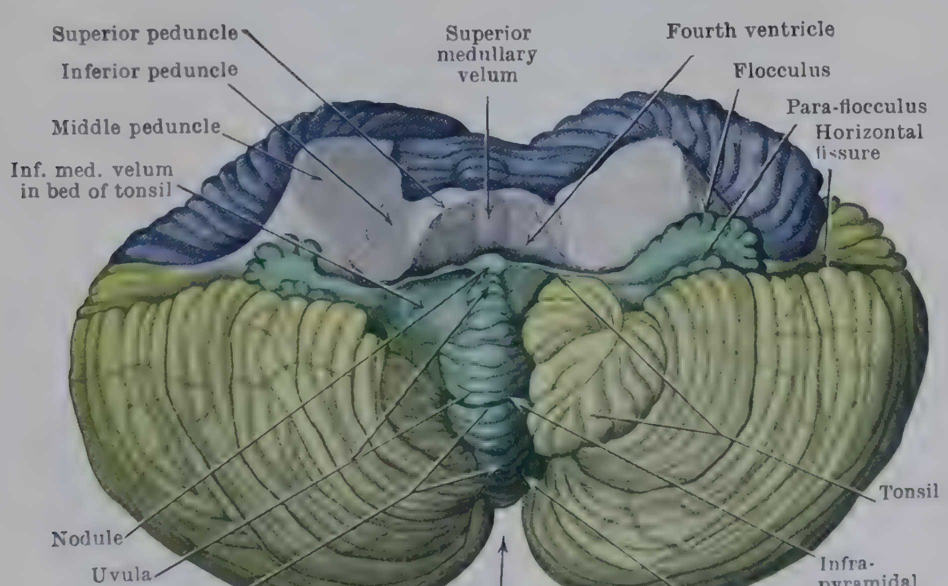


FIG. 792.—INFERIOR SURFACE OF THE CEREBELLUM.
The right tonsil has been removed so as to display more fully the inferior medullary velum. The anterior lobe is coloured *blue*, the middle *yellow*, and the posterior *green*.

into the formation of the vermis of the cerebellum, and this, again, has been topographically subdivided from before back into the *lobulus clivi*, *lobulus folii*, and *lobulus tuberis*. The lateral expansions of the middle lobe form most of the cerebellar hemispheres. Each is divided into upper and lower parts by a deep fissure—the **horizontal fissure**. On the superior surface a curved fissure (post-lunate fissure) separates the *posterior lunate lobule* (or lobus simplex) from the *ansiform lobule* behind. The ansiform lobule extends round on to the inferior surface of the cere-

bellum where it is separated by the retro-tonsillar fissure from the *tonsillar lobule.* The tonsil forms a rather circumscribed rounded lobule, situated at the antero-

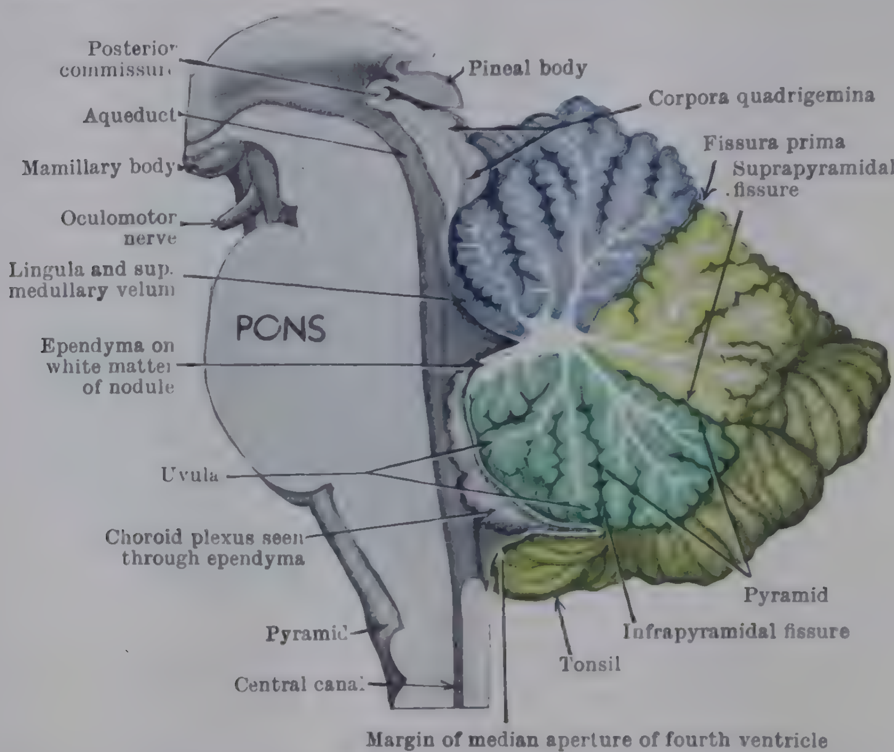


FIG. 793.—MEDIAN SECTION THROUGH BRAIN-STEM AND CEREBELLUM, SHOWING ARBOR VITÆ OF VERMIS AND THE FOURTH VENTRICLE.

The anterior lobe of the cerebellum is coloured *blue*, the middle *yellow*, and the posterior *green.*

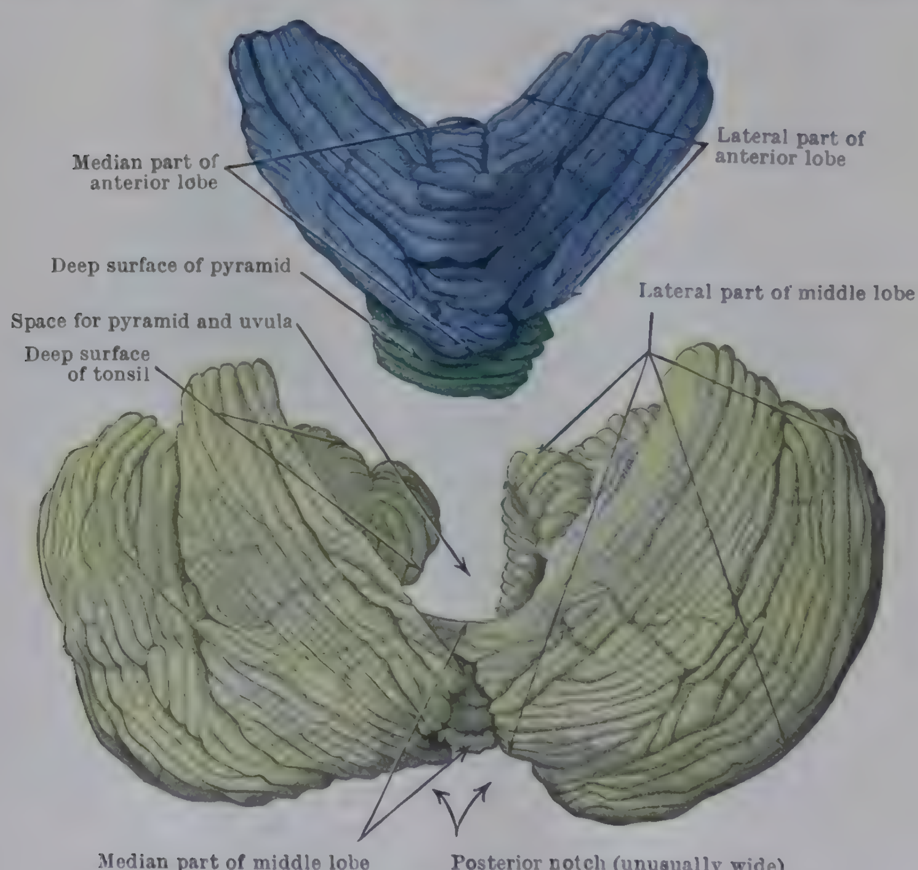


FIG. 794.—DISSECTION OF THE CEREBELLUM, SEEN FROM ABOVE, TO SHOW THE RELATION OF THE THREE LOBES.

The anterior lobe is coloured *blue*, the posterior *green*, and the middle lobe, which has been detached from the others and moved backward, is *yellow.*

medial part of the inferior surface of the cerebellum. Close to its lateral margin the cerebellum is marked by a broad shallow groove where it lies in contact with the

margin of the foramen magnum in the skull. In its position in the body the tonsillar lobules actually bulge down through the foramen magnum so that they are clearly seen when looking up through the vertebral canal.

The **posterior lobe** of the cerebellum in the human brain is relatively small (Fig. 795). The *pyramid, uvula,* and *nodule* can be defined without difficulty as component parts of the inferior vermis. The *flocculus* is evident as a small foliated lobule lying immediately below the eighth nerve at the point where it enters the brain-stem and behind the lateral recess of the fourth ventricle. It is connected with the nodule by a thin lamina of white matter which becomes continuous with

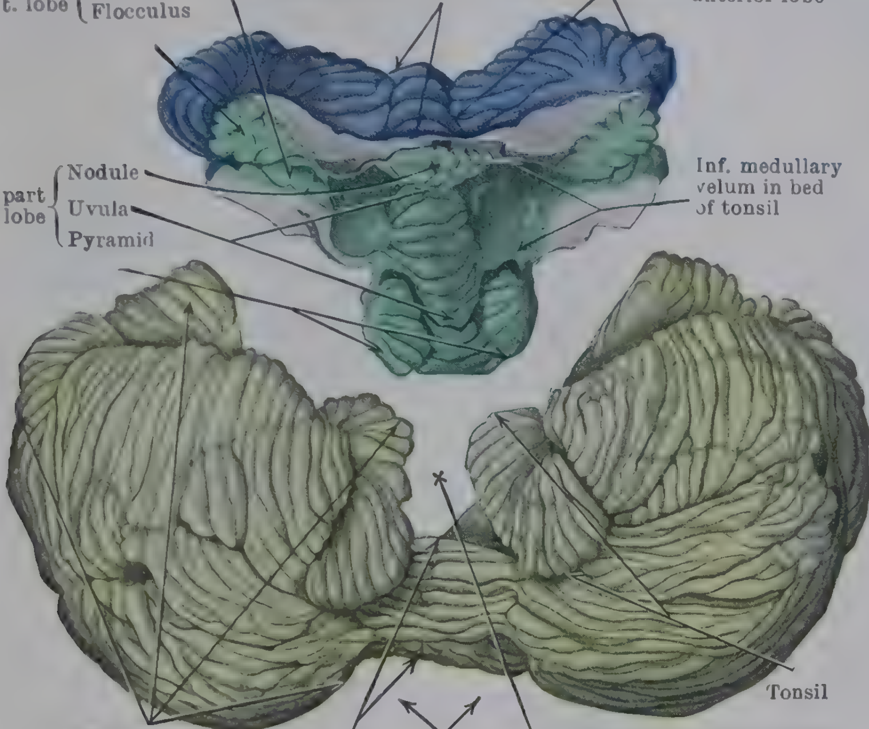


FIG. 795.—DISSECTION OF THE CEREBELLUM, SEEN FROM BELOW, TO SHOW THE RELATION OF THE THREE LOBES.

The anterior lobe is coloured *blue*, the posterior *green*, and the middle lobe, which has been detached from the others and moved backward, is *yellow*.

the upper part of the inferior medullary velum, and lies immediately above and in front of the tonsil. This lamina contains afferent and efferent fibres which link the flocculus with other parts of the cerebellum and with the vestibular nuclei. Closely attached to the flocculus is seen the *paraflocculus*, a minute lobule which in Man is undoubtedly vestigial. The paraflocculus is relatively much larger in most mammals, and in marine mammals its development is even exuberant. There is some evidence to show that it is concerned with the regulation of tone in those muscles which control the tendency to roll in the lateral direction—that is, around the long axis of the body. Hence in Man, in whom the long axis is vertical instead of horizontal, it is perhaps to be expected that the paraflocculus would be relatively insignificant.

STRUCTURE AND CONNEXIONS OF CEREBELLUM

Arrangement of Grey and White Matter of Cerebellum. — The white matter of the cerebellum forms a solid compact mass in the interior, and over it is spread a continuous and uniform layer of grey matter—the cerebellar cortex. In each hemisphere the white central core is more bulky than in the vermis, in which the central white matter is reduced to a relatively thin bridge thrown across

between the two hemispheres. When sagittal sections are made through the cerebellum, the grey matter on the surface stands out clearly from the white matter in the interior. Further, from all parts of the surface of the central core stout stems of white matter are seen projecting into the lobules of the cerebellum. From the sides of these white stems secondary branches proceed at various angles, and from these again tertiary branches are given off. Over the various lamellæ of white matter thus formed the grey cortex is spread, and the fissures on the surface show a corresponding arrangement, dividing up the organ into lobes, lobules, and folia. When the cerebellum is divided at right angles to the general direction of its fissures and folia, a highly arborescent appearance is presented by the cut surface. To this the term **arbor vitæ** is applied (Fig. 793).

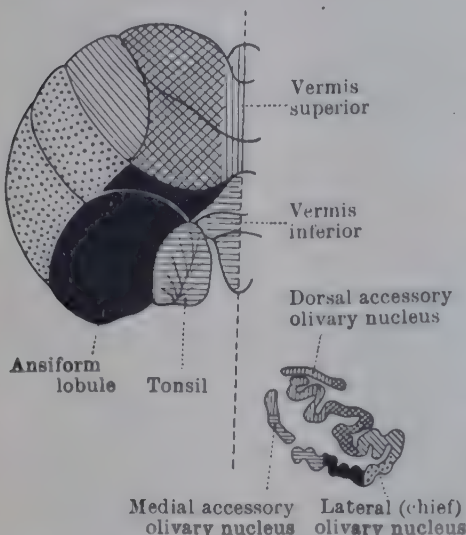


Fig. 796.—Diagram to indicate the Parts respectively of the Right Olivary Nuclei in the Medulla Oblongata and of the Left Half of the Cerebellum, which are linked together by Olivo-Cerebellar Fibres. (After Holmes & Stewart, 1908.)

Dentate Nucleus and other Nuclei in the White Matter of Cerebellum.—Embedded in the midst of the white matter which forms the central core of each hemisphere there is an isolated nucleus which presents a strong resemblance to the olivary nucleus of the medulla oblongata. It is called the **dentate nucleus**, and it consists of a corrugated lamina of grey matter folded on itself so as to enclose, in a flask-like manner, a portion of the central white matter (Figs. 797 and 799). This grey capsule is not completely closed. It presents an open mouth, termed the hilum, which is directed medially and upwards, and out of this streams a stout fasciculus of fibres which form the greater part of the superior cerebellar peduncle.

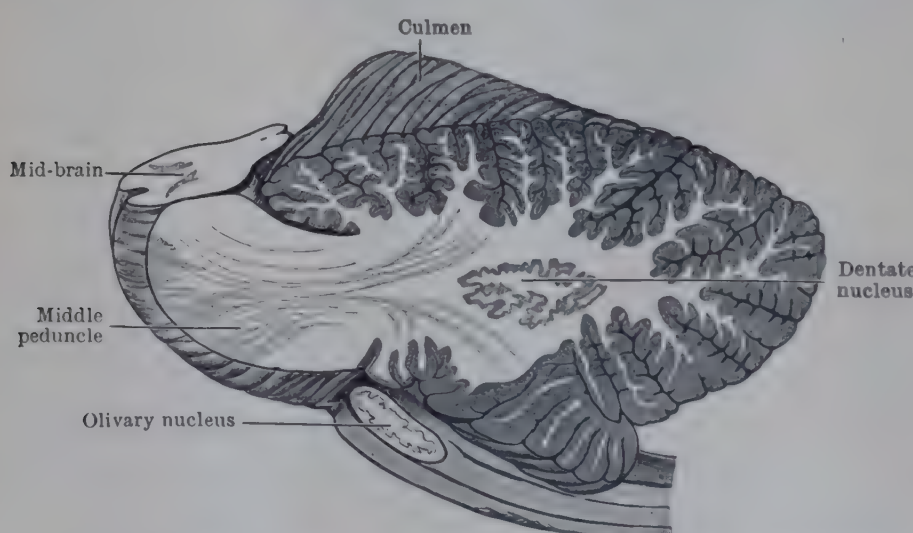


Fig. 797.—Sagittal Section through Left Hemisphere of Cerebellum. Showing the arbor vitæ and the dentate nucleus.

Three small additional masses of grey matter are present on each side of the median plane in the central white matter of the cerebellum. They are termed the nucleus emboliformis, the nucleus globosus, and the nucleus fastigii. The **nucleus emboliformis** is a small lamina of grey matter which lies just medial to the hilum of the dentate nucleus. The **nucleus globosus** lies medial to the nucleus emboliformis and on a slightly deeper horizontal plane. The **nucleus fastigii** or **roof nucleus** is placed in the white substance of the vermis close to the median plane and its fellow of the opposite side. It is, therefore, situated on the medial aspect of the nucleus globosus.

Cerebellar Peduncles.—These are three in number on each side, viz., the middle, the inferior, and the superior (Figs. 770, 799). The fibres of which they are composed all enter or emerge from the white medullary centre of the cerebellum, and they comprise the afferent and efferent connexions whereby the cerebellum is related functionally to the brain-stem and spinal cord.

The **middle peduncle** is much the largest of the three and has already been

described on pp. 884 and 899. It enters the cerebellar hemisphere on the lateral aspect of the other two peduncles. The lips of the anterior part of the horizontal fissure are separated widely to give it admission (Fig. 792). Within the cerebellar hemisphere its fibres are distributed in great bundles to all that part of the grey cortex which belongs to the neocerebellum.

The **inferior peduncle** ascends for a short distance on the dorsal surface of the pons and then turns sharply backwards to enter the cerebellum between the other two peduncles.

The **superior peduncle**, as it issues from the cerebellum, lies close to the medial side of the middle peduncle (Figs. 798, 799). Its farther course upwards towards the inferior quadrigeminal body has been previously described (pp. 885 and 902).

Connexions established by the Peduncular Fibres.—The fibres of the **middle peduncle** represent the second stage of the connexion between the cerebral hemisphere

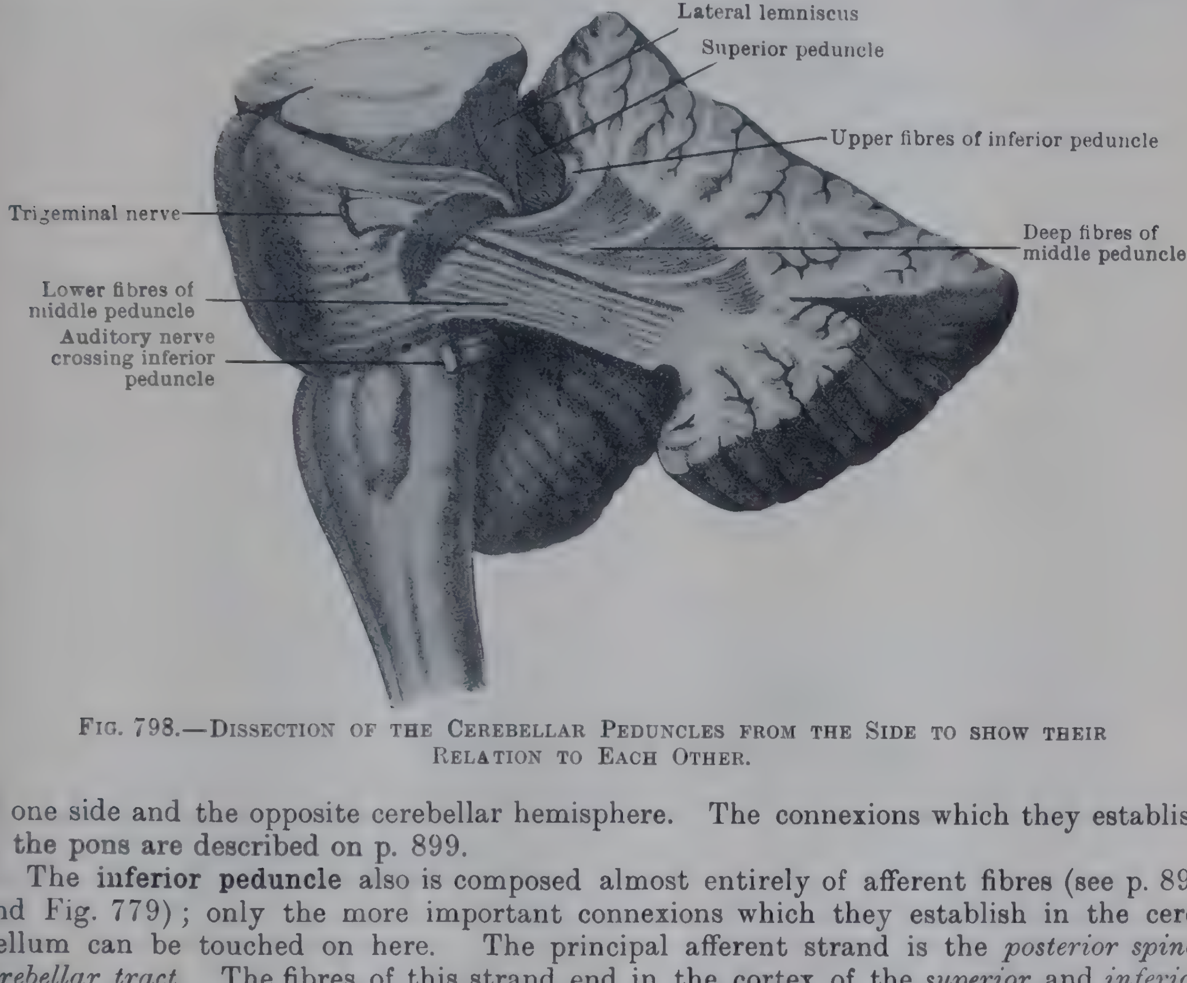


Fig. 798.—Dissection of the Cerebellar Peduncles from the Side to show their Relation to Each Other.

of one side and the opposite cerebellar hemisphere. The connexions which they establish in the pons are described on p. 899.

The **inferior peduncle** also is composed almost entirely of afferent fibres (see p. 896 and Fig. 779); only the more important connexions which they establish in the cerebellum can be touched on here. The principal afferent strand is the *posterior spino-cerebellar tract*. The fibres of this strand end in the cortex of the *superior* and *inferior vermis* on both sides of the median plane and partly in the lobus simplex of the middle lobe. The *olivo-cerebellar tract* is also afferent. Its fibres take origin from the accessory olivary nuclei as well as all parts of the olivary nucleus itself, and they terminate in the cortex of the opposite cerebellar hemisphere and the vermis. The projection of the olivary nuclei on to the cerebellar cortex is of a very precise nature, each portion of the nuclei being related to a definite area of the cortex (Fig. 796). Some of the fibres from the accessory olivary nuclei are said to end in the dentate nucleus, but of this there is some doubt.

The significance of the olivo-cerebellar fibres is quite obscure. However, as indicated on p. 891, they probably transmit impulses which have their origin in the subcortical motor centres of the fore-brain (particularly the globus pallidus of the corpus striatum) and play a part in regulating the tone of muscles involved in voluntary movements. The fibres which take origin from the accessory cuneate nucleus reach the vermis of the anterior and posterior lobes. Lastly, fibres from the medial vestibular nucleus (and also direct vestibular fibres) enter the cerebellum by way of the inferior peduncle to reach the nodule and floccular lobes and the uvula.

The **superior peduncle** is mainly composed of efferent fibres; most of these spring from the cells of the dentate nucleus and other nuclei of the cerebellum, and pass to the red nucleus and thalamus of the opposite side. According to Ramón y Cajal

collateral branches which spring from these fibres descend to the motor nuclei in the medulla oblongata and spinal cord.

A bundle of fibres is also described as passing alongside the superior peduncle to reach the cerebellum from the tegmentum of the mid-brain. They probably arise

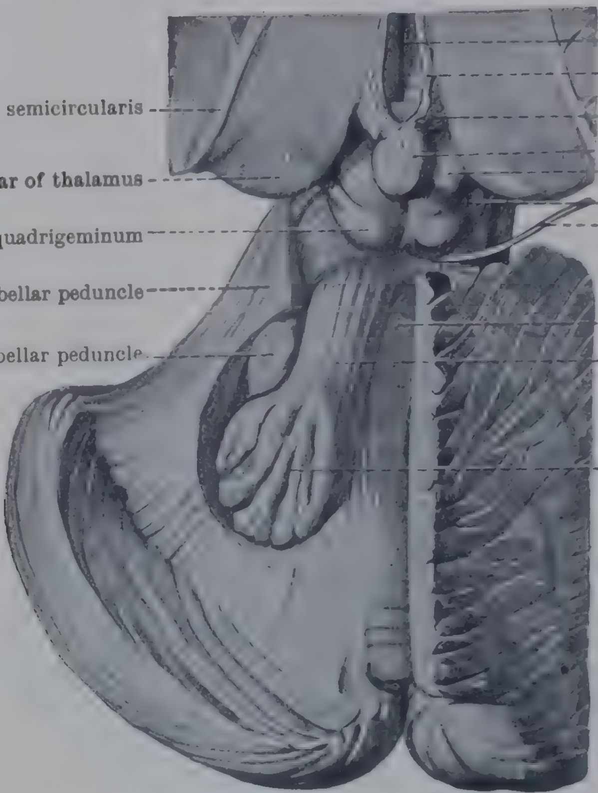


Fig. 799.—Dissection from above to show Dentate Nucleus, Cerebellar Peduncles and Lateral Lemniscus (between Inferior Corpus Quadrigeminum and Middle Cerebellar Peduncle).

from the superior corpus quadrigeminum (tecto-cerebellar fibres) and convey to the cerebellum impulses from the lower visual centres of the opposite side.

The **anterior spino-cerebellar tract** also enters the cerebellum alongside the emerging superior peduncle. It has been noticed in connexion with the lateral white column of the spinal cord (p. 871). The fibres which compose it are carried upwards through the formatio reticularis grisea of the medulla oblongata and the dorsal portion of the pons. In this part of its course the fibres are scattered and do not form a compact strand. Reaching the upper end of the pons the tract turns backwards across the superior peduncle, and proceeds in it to reach the cerebellum. Its fibres are distributed to the cortex of the superior vermis, being limited in their distribution almost entirely to the anterior lobe of the cerebellum.

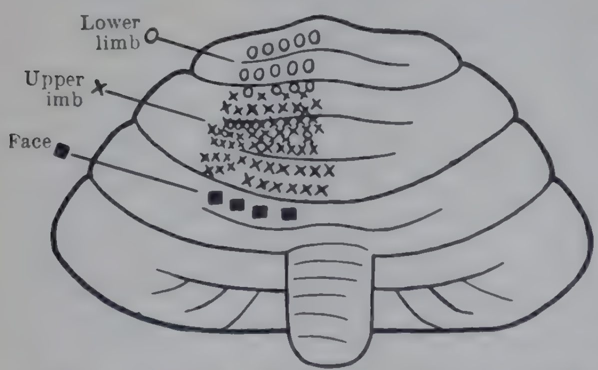


Fig. 800.—Diagram of Projection Areas of Afferent Cerebellar Impulses from Limbs and Face on the Cerebellar Cortex of the Monkey (Adrian, *Brain*, 1943).

For many years, anatomists and physiologists have sought evidence for functional localization in the cerebellum—in the sense that different areas of the cortex are related to different regions of the body—but with inconclusive results. Recently, however, Adrian (1944), with the help of a special electro-physiological technique, has demonstrated (in the monkey) that this form of localization does in fact exist. Afferent cerebellar impulses are projected on to the cerebellar cortex on the upper surface of the cerebellum in such a way that those from the lower limb reach the lobus centralis, those from the upper limb the culmen, and those from the face-region (conveyed presumably through the trigeminal nuclei) reach the lobus simplex immediately behind the fissura prima (Fig. 800). For a discussion of the general question of functional localization in the cerebellum, with bibliography, see Fulton (1949).

Minute Structure of Cerebellar Cortex

A cerebellar folium is composed of a central core of white matter covered with a layer of grey matter. The grey cortex is arranged into two very evident layers—a superficial **molecular layer** and a subjacent **granular layer**. Between these strata a single layer of large cells, termed the **cells of Purkinje**, is disposed in the form of a very nearly continuous sheet. The cells of Purkinje constitute the most characteristic constituents of the cerebellar cortex.

The **cells of Purkinje** are most numerous on the summit of a folium. At the bottom of a fissure they become fewer in number, and, therefore, looser in their arrangement. Each consists of a large flask-shaped cell-body, the narrow end of which projects into the molecular layer, whilst the thicker, deeper end rests on the granular layer. From the deep end arises a **single axon**, which passes down through the granular layer and assumes its medullary sheath almost immediately. From the axon a few collateral branches soon arise, which, taking a recurrent course, enter the molecular layer, to end in connexion with certain of the adjoining cells of Purkinje. They appear to constitute a reinforcing mechanism whereby the activity of any one cell can call adjacent cells into action.

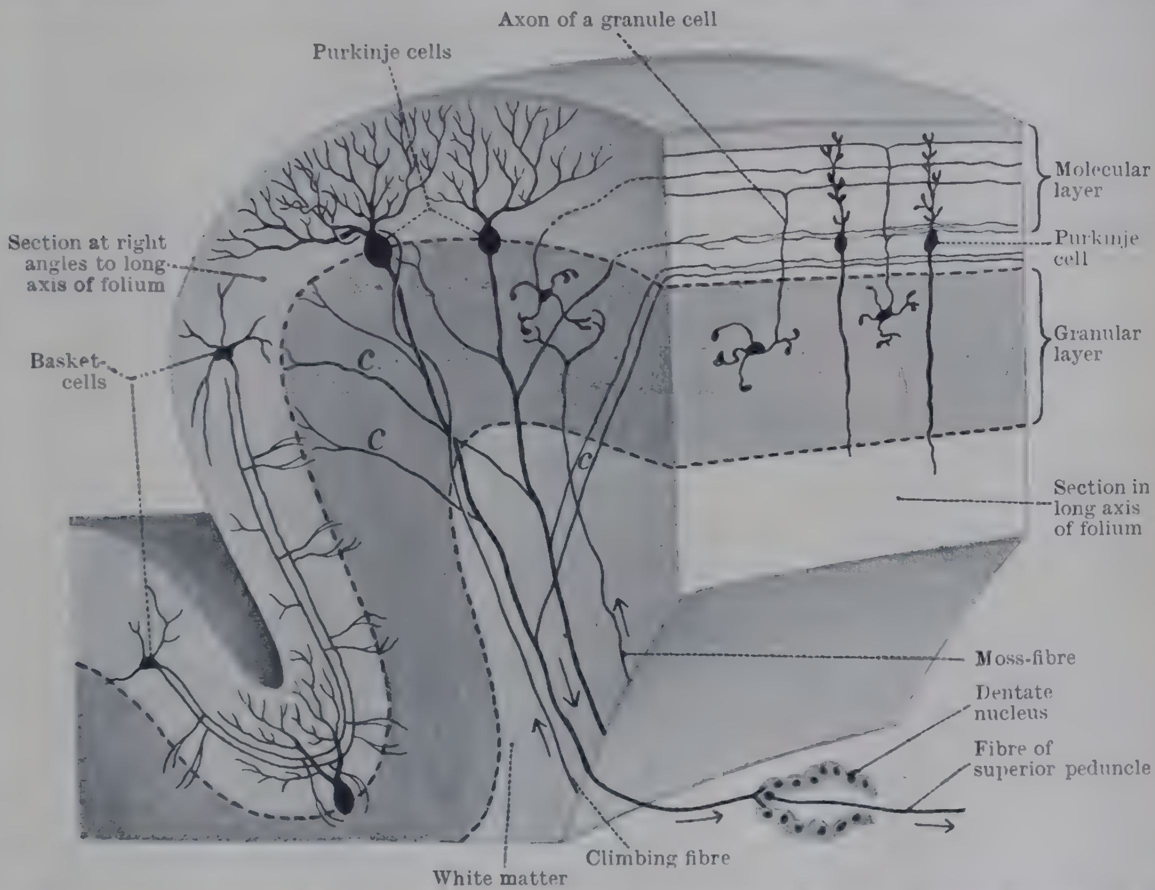


Fig. 801.—Diagram to show Minute Structure of a Cerebellar Folium. The surface to the right shows a section in the long axis of a folium and that to the left is a section at right angles to the long axis of a folium. C=recurrent collaterals from the axons of Purkinje cells.

The **dendrites** spring from the narrow end of the cell in the form of either one or perhaps two stout stalks. They ascend into the molecular layer, branching and rebranching until an arborescent arrangement of extraordinary richness and extent results. The dendritic branches extend throughout the entire thickness of the molecular layer, and the branching takes place in one plane only—transverse to the long axis of the folium. Consequently, it is only when transverse sections through a folium are made that the full dendritic effect is obtained (Fig. 801); in sections made parallel to the long axis of the folium the cells are seen in profile, and are observed to occupy quite a narrow area. The branching of the dendrites of a cell of Purkinje may, therefore, be compared to **the branching of a fruit-tree trained against a wall.**

Terminating in relation to each cell of Purkinje is an afferent fibre which ascends to the cortex from the white substance of the cerebellum. These fibres form fine ramifications which climb up the dendritic processes of each cell of Purkinje, intertwining with them in a very intimate manner, very much like the tendrils of a climbing plant. They are termed **climbing fibres** (Fig. 801).

In the **molecular layer** the cells are not very numerous, and of these the most

characteristic are the **basket-cells** which lie in the deeper part of the layer. In addition to numerous dendrites the basket-cell gives off an axon which runs transversely, as regards the long axis of the folium, between the planes of adjacent dendritic arborizations of the cells of Purkinje. At first very fine, the axons gradually become coarse and thick, and at intervals they give off collaterals which run towards the bodies of the cells of Purkinje. Reaching these, they break up into a great number of fine terminal branches which enclose the cells of Purkinje, as well as the short non-medullated portions of their axons, in a close basket-work of fine filaments.

The **granular layer** is, for the most part, composed of large numbers of small granule-like cells closely packed together. Each of them has a rather large nucleus, with a very small amount of surrounding cytoplasm. From the cell-body three or four, or perhaps five, dendrites and one axon proceed. The **dendrites** are short and radiate out from different aspects of the cell-body. They end in tufts of claw-like twigs which either embrace or are otherwise in contact with neighbouring granule-cells. The granule-cells, therefore, are brought into intimate connexion with one another. The **axon** passes into the molecular layer, in which it ends, at a varying distance from the surface, by dividing into two branches. These diverge so sharply from each other that they form almost a right angle with the parent stem, and they run parallel to the long axis of the folium, threading their way among the branches of the various dendritic processes of the cells of Purkinje and entering into the closest contact with them. When it is borne in mind that the number of granule-cells is very great, and that each sends an axon into the molecular layer, the important part which these fibres, with their longitudinal branches, take in building up the molecular layer will be understood. They are found pervading its entire thickness—from the surface down to the bodies of the cells of Purkinje.

Ending in the granular layer are numerous afferent fibres which ascend from the white substance of the cerebellum and divide into a relatively large number of terminal branches. These branches end in tufts of thickened terminals which have a rather moss-like appearance. Hence the fibres are termed **moss-fibres**, and each one enters into synaptic relation with a large number of granule-cells (Fig. 801).

The **functional implications** of the minute structure of the cerebellar cortex now require consideration. It will be noted that there are two types of afferent fibre, the "climbing" and the "moss" fibres. There is still some doubt regarding the origin of these fibres. According to Cajal the climbing fibres are the terminals of pontine and vestibular fibres while the spino-cerebellar and olivo-cerebellar fibres form the moss-terminals. On the other hand, Dow (1942) takes the view that the climbing fibres are the terminals of the olivo-cerebellar tracts, while the mossy fibres are derived from the vestibular, spinal and pontine systems. Yet another view has been recently put forward, that the climbing fibres are chiefly, if not entirely, derived from the cerebellar nuclei. The impulses conveyed by the *climbing fibres* must be extremely localized in the cortex, for each fibre ends in relation to a single cell of Purkinje. Moreover, the axon of each cell of Purkinje descends straight to the dentate nucleus, whence it is relayed to the red nucleus and thalamus of the opposite side by fibres of the superior cerebellar peduncle. Hence there seems to be an anatomical basis for some form of punctate localization of function in the cerebellar cortex, at least so far as impulses conveyed by the climbing fibres are concerned.

In contrast with this, the impulses conveyed by the *moss-fibres* must be diffused very widely in the cerebellar cortex, mainly in a transverse direction, for they are carried up into the molecular layer by the axons of the granule-cells, which here bifurcate to form the parallel fibres. From this disposition it may be inferred that, if there is any localization in the cerebellar cortex with regard to afferent impulses from the spinal cord, it is presumably a localization in an antero-posterior direction. This, in fact, has been demonstrated to be the case by Adrian (see p. 912). The question whether there is a functional localization in the cerebellum, in the sense that different lobules of the cerebellum are concerned on the efferent side with muscular activities in correspondingly different parts of the body, has been the source of much controversy. Although a small lesion of the cerebellum may produce quite widespread defects of muscular activity in the body, clinical evidence does suggest a motor localization of a very general type.

MID-BRAIN

The **mid-brain** or **mesencephalon** is the short part of the brain-stem which connects the cerebrum with the parts in the posterior cranial fossa; and, in its normal position in the skull, it occupies the notch in the tentorial process of dura

mater. It is about three-quarters of an inch in length, and it consists of a dorsal part called the **tectum**, and a much larger ventral part—the two **cerebral peduncles**.

The cerebral peduncles can be seen to some extent on the base of the brain, where they bound the posterior part of the interpeduncular fossa (see p. 878).

The mid-brain is tunnelled lengthwise by a narrow passage, called the **aqueduct**, which connects the third ventricle above with the fourth ventricle below (Fig. 764, p. 879).

Tectum.—This name is applied to that part of the mid-brain which forms the roof of the cerebral aqueduct. Its free surface is heaped up into two pairs of rounded eminences called the **corpora quadrigemina** (Figs. 766 and 802). The **superior pair** are larger and broader than the **inferior pair**, but they are not so well defined nor are they so prominent. A longitudinal and a transverse groove separate the corpora from one another. The longitudinal groove occupies the median plane and extends upwards to the posterior commissure of the brain. The upper part of the groove widens out into a shallow depression in which the **pineal body** rests. From the lower end of the same groove a short but well-defined ridge—the **frenulum veli**—passes to the superior medullary velum, which lies immediately below the inferior corpora quadrigemina. The transverse groove curves round below each of the superior pair of corpora and separates them from the inferior pair. It is also continued in an upward and forward direction on the side of the mid-brain.

The quadrigeminal bodies are not marked off laterally from the sides of the mid-brain, for each has in connexion with it, on that aspect, a prominent strand which is prolonged upwards and forwards towards the thalamic region of the fore-brain. These strands are called the **brachia quadrigemina**, and they are separated from each other by a continuation of the transverse groove that separates the two pairs of corpora.

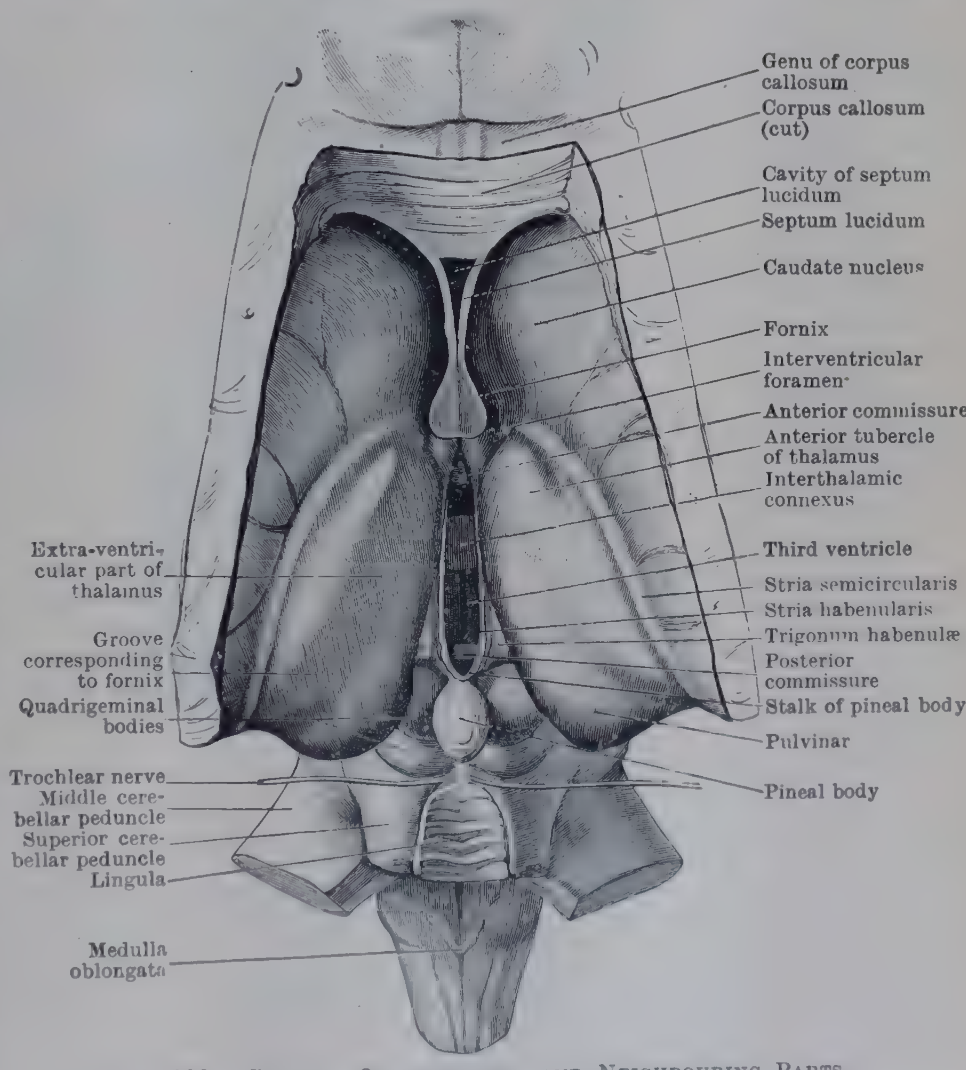


Fig. 802.—Corpora Quadrigemina and Neighbouring Parts.

The **medial geniculate body** is closely associated with the brachia. Strictly speaking, this is not a part of the mesencephalon; it is really a portion of the thalamus of the fore-brain which has been pushed back as the result of the expansion of other thalamic elements; and it has become applied to the side of the mid-brain and secondarily fused with it. It is a small, sharply defined oval eminence which lies on the lateral side of the upper part of the mid-brain under shelter of the pulvinar of the thalamus.

The **inferior brachium**, proceeding upwards and forwards from the inferior corpus, advances towards the medial geniculate body and disappears under cover of it (Fig. 803).

The **superior brachium** is carried upwards and forwards between the overhanging thalamus and the medial geniculate body. A superficial examination of the mid-brain is sufficient to show that while a large part of this strand disappears under cover of the lateral geniculate body (Fig. 831, p. 950) a portion of it is a continuation of the lateral root of the optic tract. The lateral geniculate body is

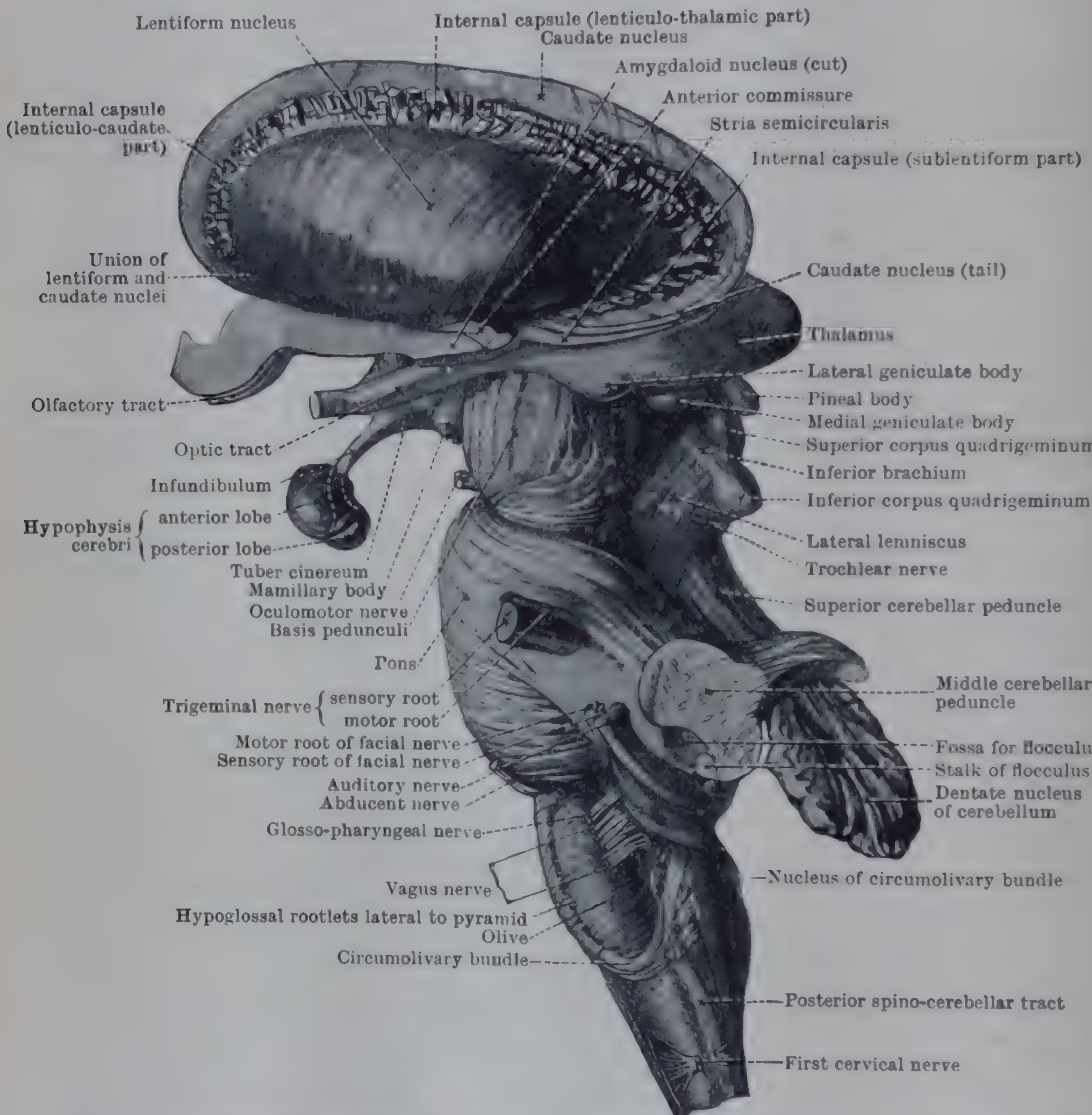


FIG. 803.—LEFT LATERAL ASPECT OF BRAIN AFTER REMOVAL OF THE CEREBRAL HEMISPHERE (EXCEPT CORPUS STRIATUM) AND THE CEREBELLUM (EXCEPT DENTATE NUCLEUS).

an ill-defined prominence at the posterior end of the optic tract; it belongs to the thalamus, and, as its name implies, it lies lateral to the medial geniculate body.

Cerebral Peduncles.—The cerebral peduncles (Figs. 803 and 813) appear on the base of the brain as a pair of large rope-like strands which emerge from the cerebral hemispheres and disappear below by plunging into the basilar portion of the pons. At the place where each peduncle emerges from the corresponding side of the cerebrum it is crossed by the optic tract.

Each cerebral peduncle is composed of three parts:—(1) a dorsal tegmental part (**tegmentum**), which is prolonged upwards into the region below the thalamus (hypothalamus and subthalamus); (2) a ventral portion (**basis pedunculi**), which, when traced upwards into the cerebrum takes up a position on the lateral side of the thalamus and is continuous with the internal capsule of the brain; and (3) an

intervening conspicuous layer of deeply pigmented tissue—the **substantia nigra.** When the base of the brain is examined it is the basis pedunculi which is seen, and it is observed to be white in colour and streaked in the longitudinal direction. It may be noted that in the tegmentum the longitudinally arranged fibres are, in large part, fibres which are ascending towards the thalamus; the basis pedunculi, on the other hand, is composed entirely of longitudinal strands of fibres which are descending from the cerebral hemisphere.

On the surface of the mid-brain the separation between the tegmental and basal portions of the cerebral peduncle is clearly indicated by a medial and a lateral groove. The **medial sulcus** is the more distinct of the two. It faces into the interpeduncular fossa, and through it the roots of the oculomotor nerve emerge.

The **lateral sulcus** extends from the thalamus to the groove between the superior and middle cerebellar peduncles, and the medial geniculate body is lodged at its upper end.

A close inspection of the lateral surface of the tegmental part of the mid-brain, below the level of the brachia, will reveal a faintly marked bundle of fibres curving obliquely upwards and backwards to reach the inferior corpus quadrigeminum (Fig. 803). It contains fibres of the **lateral lemniscus,** coming to the surface at the lateral sulcus and sweeping over the subjacent superior cerebellar peduncle to gain the inferior corpus quadrigeminum and medial geniculate body. They transmit auditory impulses to these structures from the hind-brain.

Internal Structure of Mid-Brain

When transverse sections are made through the mid-brain the aqueduct is seen to be surrounded by a thick layer of grey matter—the **central grey matter of the aqueduct.** Behind this, there is the **tectum** with its *corpora quadrigemina*; in front and laterally there are the **cerebral peduncles,** each divided into *tegmentum, substantia nigra* and *basis pedunculi.* (Fig. 804.)

Central Grey Matter and Aqueduct of Mid-Brain.—The aqueduct is not quite three-quarters of an inch in length, has a variable outline in transverse section, and is much nearer the back than the front of the mid-brain. It is lined with ependymal epithelium, and outside this is the thick layer of central grey matter, which is continuous below with the grey matter of the floor of the fourth ventricle, and above with grey matter on the floor and sides of the third ventricle. Scattered more or less irregularly throughout the central grey matter are numerous nerve-cells of varying form and size, whilst in addition to these there are definite clusters of cells which constitute the nuclei of origin of the trochlear and oculomotor nerves, and the terminal nucleus of the mesencephalic tract of the trigeminal nerve. The position and relations of these nuclei will be given later.

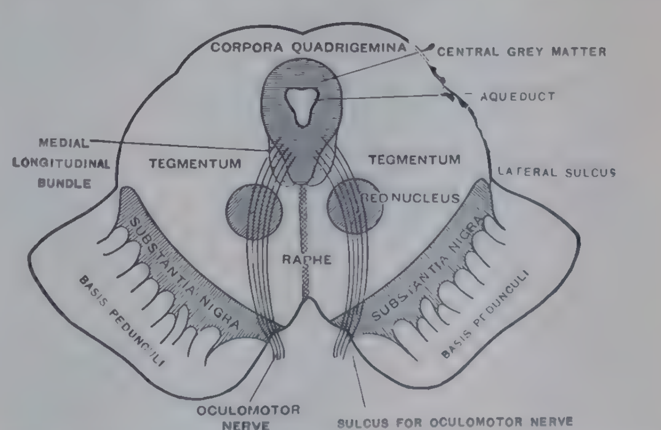


Fig. 804.—Diagrammatic Transverse Section through Upper Part of Mid-Brain.

Inferior Quadrigeminal Bodies.—Each inferior corpus quadrigeminum is composed largely of a mass of grey matter which is oval in transverse section (Fig. 805). This central nucleus is, to a large extent, encapsulated by white matter. Numerous cells of various sizes are scattered throughout it, and the whole mass is pervaded by an intricate interlacement of fine fibres, many of which are derived from the lateral lemniscus.

In transverse sections through this region, the lateral lemniscus is seen to abut against the lateral margin of the central nucleus of the inferior quadrigeminal body. Many of the fibres of this tract enter it at once and become dispersed

amongst its cells; others sweep over its dorsal surface, so as to give it a superficial covering; whilst a third group is carried medially in front of it in the form of a thin layer that marks it off from grey matter of the aqueduct (Fig. 808). In this manner, therefore, the inferior quadrigeminal body becomes partially circumscribed by the fibres of the lateral lemniscus.

The intimate connexion thus exhibited between the fibres of the lateral lemniscus and the nucleus of the inferior corpus quadrigeminum is very significant. The lateral lemniscus, to a large extent, comes from the nuclei of termination of the cochlear nerve of the opposite side, though some also come from the same side. We must associate, therefore, the inferior corpus quadrigeminum and also the medial geniculate body, which likewise receives fibres from the lateral lemniscus, with the nervous mechanism of hearing.

This view regarding the inferior quadrigeminal body is supported both by experimental and by morphological evidence. Speaking broadly, it may be stated that the inferior corpora quadrigemina become prominent only in mammals, and they are correlated with the development of a spirally wound and well-developed cochlea. It is probable that at least some of the fibres of the ventral supra-optic decussation (Gudden's commissure) connect with the cells of the inferior corpus quadrigeminum (see p. 952).

Superior Quadrigeminal Bodies.—The superior quadrigeminal body has a more complicated structure (Fig. 806). Superficially, it is coated with a very thin layer of white matter which is termed the **stratum zonale.** Underneath this there is a layer of grey matter, called the **stratum griseum,** which, in transverse section, exhibits a crescentic outline and rests in a cap-like manner upon the subjacent part of the eminence. The succeeding two strata, which respectively receive the names of **stratum opticum** and the **stratum lemnisci,** present this feature in common, that they are composed of grey matter traversed by numerous fibres. The source from which the fibres are derived is different, however, in each case.

Nerve-fibres reach the superior corpus quadrigeminum through (1) the lemnisci and (2) the superior brachium.

The stratum lemnisci is partly composed of the terminals of the spino-tectal tract of the spinal cord. It contains also cortico-tectal fibres which take origin from the area striata and the area peri-striata of the occipital region of the cerebral cortex; these enter the tectum of the mid-brain by way of the superior brachium, and they convey impulses which enable the visual cortex to influence the oculomotor nuclei through the superior corpus quadrigeminum. In most animals many of the fibres of the optic tract end in the superior quadrigeminal body, but in the human brain these are very considerably reduced. As they penetrate into the substance of the superior corpus quadrigeminum, these mesencephalic fibres of the optic tract form the white matter of the stratum opticum. They ultimately terminate in this stratum, and in the stratum griseum which lies superficial to it.

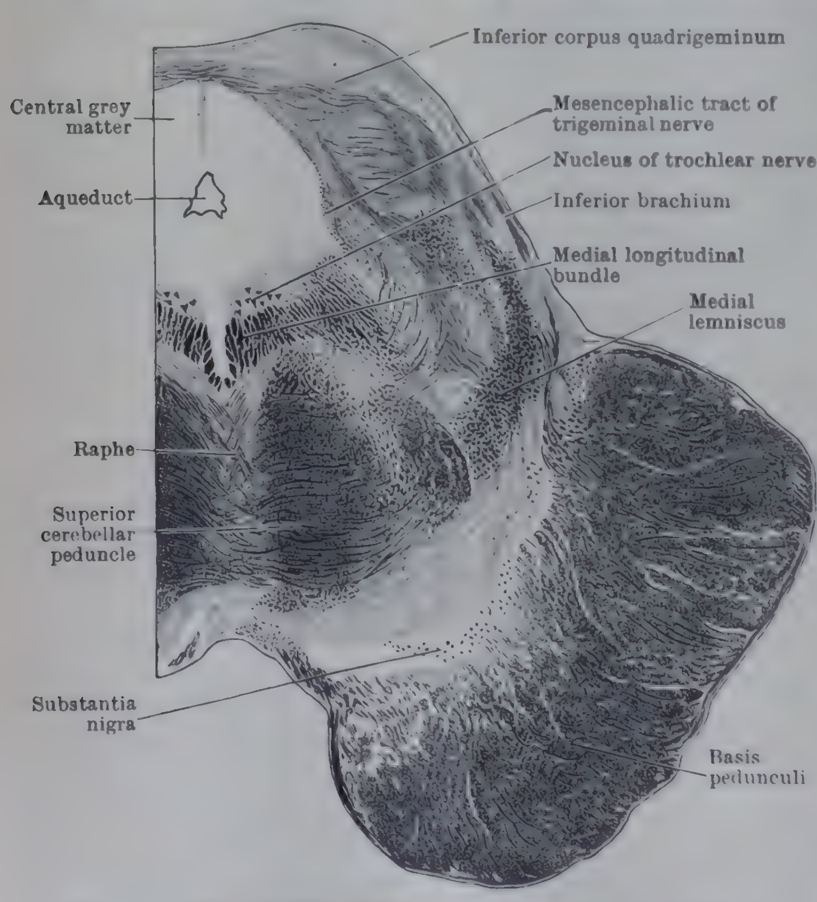


FIG. 805.—TRANSVERSE SECTION OF MID-BRAIN AT LEVEL OF INFERIOR CORPUS QUADRIGEMINUM.

Under cover of the upper and lateral margins of the superior corpus quadri-

geminum is an ill-defined collection of small cells named the **pretectal nucleus.** This nucleus is of some importance since it is the terminal station for those optic fibres which are concerned with the pupillary reflex (Fig. 835). This reflex is still present after the experimental destruction of the superior corpora quadrigemina. From the pretectal nucleus retinal impulses are relayed to the oculomotor nucleus of the same and opposite sides.

Posterior Commissure.—This is a slender band of white matter which extends transversely across the roof of the aqueduct at the point where the aqueduct opens into the third ventricle. The posterior commissure is mainly formed of commissural fibres which connect the superior corpora quadrigemina, the pretectal nuclei, and the medial longitudinal bundles of the two sides. It also contains fibres which proceed from the pretectal nucleus of one side to the oculomotor nucleus of the other.

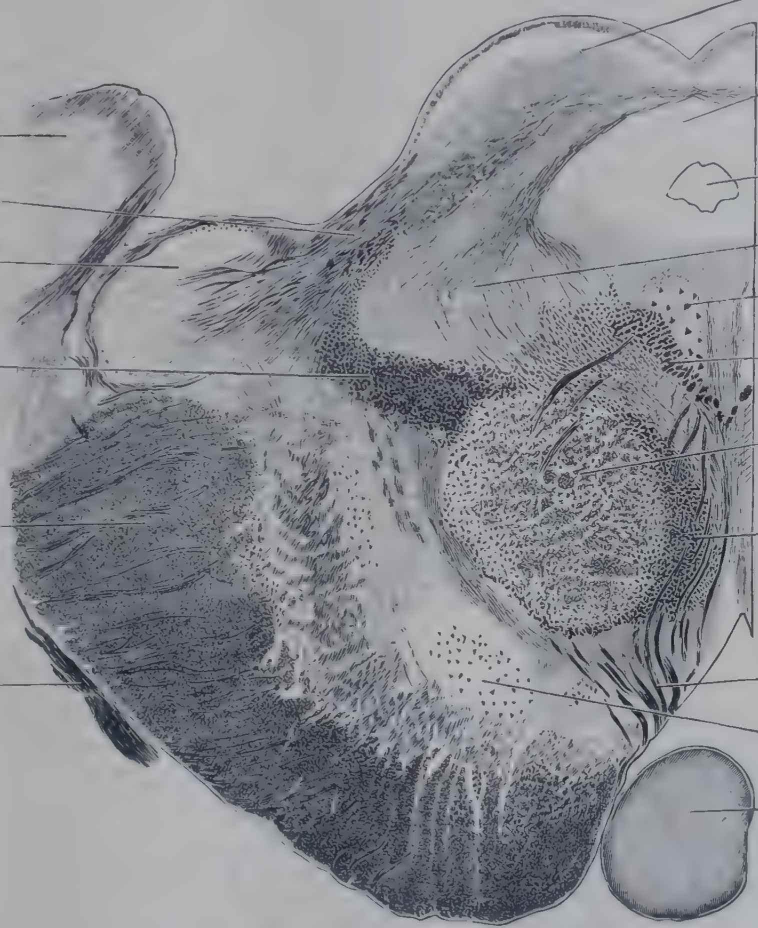


Fig. 806.—Transverse Section of Mid-Brain at Level of Superior Corpus Quadrigeminum.

Tegmentum.—The tegmentum of the mid-brain may be regarded as the continuation upwards of the dorsal portion of the pons. It consists, therefore, of fine bundles of longitudinal fibres intersected by arching fibres which take a transverse and curved course. The interstices between these bundles are occupied by grey matter containing irregularly scattered nerve-cells. Posteriorly the tegmentum is continuous, at the side of the central grey matter, with the bases of the corpora quadrigemina, whilst anteriorly it is separated from the basis pedunculi by the substantia nigra. In the median plane of the tegmentum there is a prolongation upwards of the median raphe of the pons, although, in the lower part, this is much obscured by the decussation of the superior cerebellar peduncles. The two longitudinal strands, termed the **medial longitudinal bundle** and the **medial lemniscus,** are prolonged upwards throughout the entire length of the mid-brain; and they present the same relations to the tegmentum as in the lower parts of the brain—the longitudinal bundle being placed behind the lemniscus.

The tegmentum is divisible into two parts: (1) a lower part subjacent to the inferior corpora quadrigemina, and largely occupied by the decussation of the superior cerebellar peduncles (Fig. 807); and (2) an upper part subjacent to

the superior corpora quadrigemina, and traversed by the emerging bundles of the oculomotor nerves. Each half of the upper part contains a large and striking nuclear mass, termed the **red nucleus** (Fig. 806). The lower part of the central grey matter contains the nuclei of the trochlear nerves; the upper part contains the nuclei of the oculomotor nerves.

Superior Cerebellar Peduncles—As the superior cerebellar peduncles leave the pons and sink into the tegmentum they undergo a complete decussation subjacent to the inferior corpora quadrigemina and the central grey matter (Figs. 805, 806, and 807); the decussation is completed at the level of the upper borders of the inferior corpora quadrigemina. Having crossed to the opposite side, each peduncle proceeds upwards into the upper part of the tegmentum, where it encounters the red nucleus. A large number of its fibres plunge into this nucleus and come to an end in connexion with its cells. Many of the fibres, however, are carried around the nucleus, forming a capsule for it (Fig. 806), and are prolonged into the thalamus to end in connexion with the cells of the ventral nucleus of the thalamus. The superior peduncle is, therefore, a great efferent tract which issues from the dentate nucleus of the cerebellum, crosses the median plane in the lower part of the mid-brain, and ends in the red nucleus and the ventral part of the thalamus of the opposite side.

Substantia Nigra.—When seen in transverse section, the **substantia nigra** appears as a slightly curved dark-brown band between the basis pedunculi and the tegmentum. It consists of a mass of grey matter in the midst of which there are large numbers of deeply pigmented nerve-cells. This remarkable pigment—a melanin—is commonly regarded as a by-product of the cellular activity of the substantia nigra, for it increases with age. It is not found in the homologues of the substantia nigra of many mammals, and in the human subject it is not present at birth, but develops only in the second or third year. In the adult the large cells of the substantia nigra and those of the globus pallidus contain more iron than any other nuclear territories of the nervous system. The substantia nigra begins at the upper border of the pons and extends upwards into the subthalamus (see p. 945). Its margins come to the surface at the medial and the lateral sulci of the mid-brain, and its medial part is traversed by the emerging rootlets of the oculomotor nerve. It is not equally thick throughout. The surface turned towards the tegmentum is concave and uniform; the opposite surface is convex and made irregular by the presence of numerous slender prolongations of the substance into the basis pedunculi.

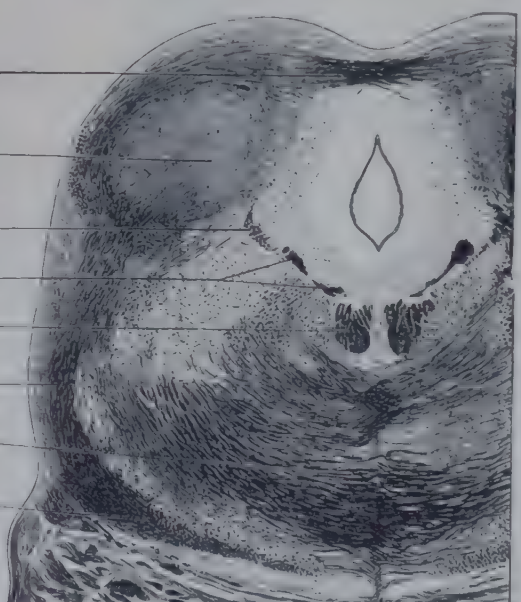


Fig. 807.—Section through Inferior Corpus Quadrigeminum and Tegmentum below the Level of Nucleus of Trochlear Nerve. The decussation of the superior cerebellar peduncles and the course of the trochlear nerve in the central grey matter are seen.

The functional significance of the substantia nigra remains obscure, but the investigation of the damage to the brain in such affections as encephalitis lethargica ("sleepy sickness") has directed particular attention to the substantia nigra and revealed that lesions affecting it are associated with such symptoms as increased muscular tone and involuntary rhythmic movements.

The substantia nigra receives fibres from the globus pallidus and possibly from the red nucleus, and it evidently forms a part of the so-called extra-pyramidal motor system (see p. 970). There is also experimental evidence that it gives rise to ascending fibres which terminate in the caudate nucleus. Other connexions of the substantia nigra have been described, but they are not yet certainly established.

Red Nucleus.—The red nucleus is a rounded nuclear mass, of a reddish tint in the fresh brain, which lies in the upper part of the tegmentum, and in the path of the superior cerebellar peduncle. In transverse section it has a circular outline. It begins at the level of the lower border of the superior corpus quadrigeminum and it extends upwards as far as the subthalamus. The emerging bundles of the oculomotor nerve pass through it on their way to the surface. The relation which the fibres of the opposite superior cerebellar peduncle present to it has been described.

In most mammals the red nucleus consists mainly of a group of large cells that emit fibres, called the **rubro-spinal tract**, which, after crossing to the other side, descend in the tegmentum to reach the lateral white column of the spinal cord (Fig. 755, p. 868). In Man the large-celled element and the rubro-spinal tract become reduced to small proportions, and, as already noted, the tract probably reaches down only to the upper part of the cord. In the higher mammals, and especially in the human brain, a very large element, composed of small cells, develops in front of the older, large-celled element, and forms the major part of the red nucleus. The small-celled element receives descending fibres from the frontal cortex of the cerebral hemisphere, and also from the globus pallidus of the corpus striatum (pallido-rubral fibres). It gives off fibres which end in the reticular substance of the mid-brain and hind-brain. The progressive development of the small-celled element of the red nucleus is simply an expression of the fact that, in higher mammals, the nucleus becomes increasingly dominated by the cerebral cortex. This tendency reaches its highest expression in Man.

Medial Longitudinal Bundle.—This is a very conspicuous tract of longitudinal fibres which extends throughout the whole length of the medulla oblongata, pons, and mid-brain, in the formatio reticularis or dorsal part of each. Below, at the level of the decussation of the pyramids, it becomes continuous with the anterior intersegmental tract of the spinal cord (p. 870); by its opposite end, it establishes intricate connexions in the region immediately above the mid-brain. Throughout its whole length it lies close to the median plane and its fellow of the opposite side. In the mid-brain it is applied to the front of the central grey matter, whilst in the pons and medulla oblongata it is situated immediately subjacent to the grey matter of the floor of the fourth ventricle. One of its most salient features is the intimate association which it presents with the three motor nuclei from which the nerves for the supply of the muscles of the eyeball take origin, viz., the oculomotor nucleus, the trochlear nucleus, and the abducent nucleus. The first two of these are closely applied to its medial and dorsal aspect, whilst the abducent nucleus is placed on its lateral side. Into each of these nuclei it sends many collaterals, and probably also some of its constituent fibres, and they end around the nuclear cells. It would appear, therefore, that one of the most important functions of the strand is to link together those nuclei, and thus enable them to act in harmony with each other. The most important element in the medial longitudinal bundle, however, consists of fibres that come from the vestibular nucleus and proceed to the oculomotor group of nuclei of both sides as well as to both nuclei of the accessory nerve in the medulla oblongata and spinal cord. These connexions provide the anatomical basis for the reflex movements

Fig. 808.—Section through Inferior Corpus Quadrigeminum and Tegmentum of Mid-Brain at a slightly Lower Level than Fig. 807.

of the eye and neck which are elicited by impulses arising in the semicircular canals.

It is evident that it is a brain-tract of high importance from the fact that it is present in all vertebrates, and, further, that its fibres assume their medullary sheaths at an extremely early period. In fishes, amphibians and reptiles, it is one of the largest bundles of the brain-stem. In Man, its fibres medullate between the sixth and seventh months of intra-uterine life, and at the same time as the fibres of the anterior intersegmental tract of the spinal cord, with which it stands in connexion.

Lateral Lemniscus.—The lateral lemniscus is a definite tract of longitudinal fibres which lies in the upper part of the dorsal division of the pons, and extends upwards through it and through the tegmentum of the mid-brain near their lateral surface. It is formed in large part by the fibres of the corpus trapezoideum

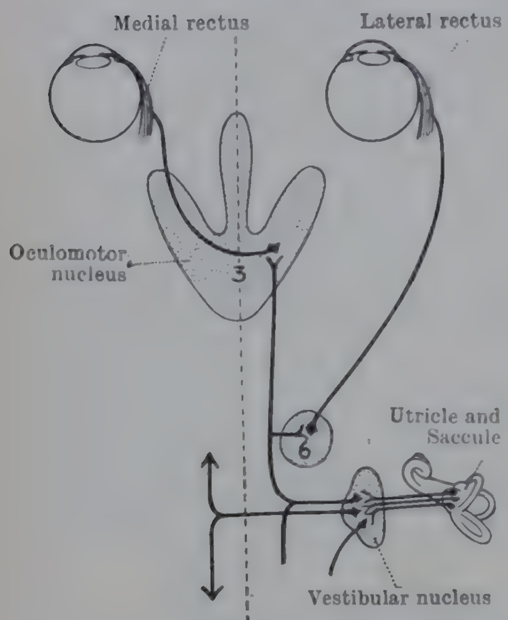


Fig. 809.—Plan of some of the Vestibular Elements in the Medial Longitudinal Bundle.

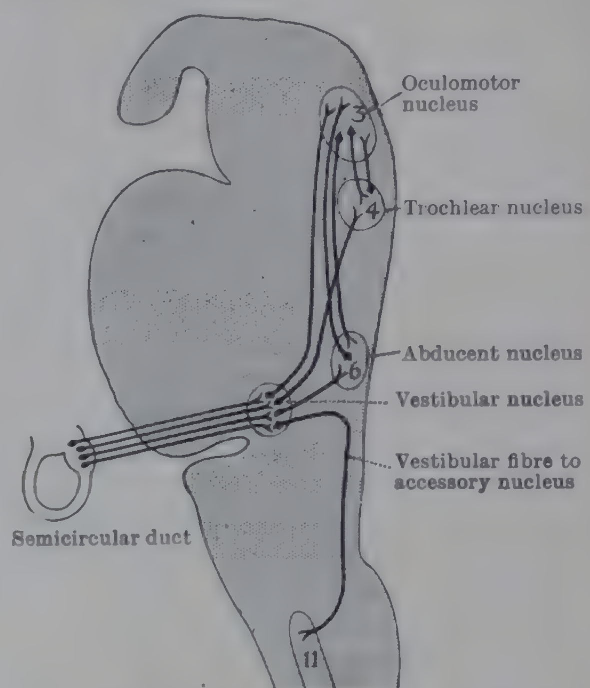


Fig. 810.—Profile Plan of Important Elements in the Medial Longitudinal Bundle.

in the lower part of the pons turning abruptly upwards and taking a course towards the quadrigeminal region. But the details of the arrangement and connexions of this important fasciculus must be left for fuller consideration when we are discussing the central connexions of the auditory nerve. It should be mentioned that, intermingled with the auditory fibres and forming a part of the lateral lemniscus (so far as the latter is defined topographically) are certain other fibres, *e.g.*, tecto-pontine fibres and spino-tectal fibres.

Medial Lemniscus.—The medial lemniscus has already been followed through the medulla oblongata and pons, and its position in each of these portions of the brain-stem has been defined (pp. 895 and 903). In the lower part of the tegmentum of the mid-brain it is carried up in the form of a more or less flattened band in front of the decussating superior cerebellar peduncles. To its lateral side, and forming an angle with it (as seen in transverse section), is the lateral lemniscus (Figs. 784 and 785), and at that level there is no clear demarcation between the two tracts. In the upper part of the mid-brain the appearance of the red nucleus in the tegmentum causes the medial lemniscus to take up a more lateral and dorsal position, so that it now comes to lie subjacent to the medial geniculate body (Fig. 806). At this level it exhibits a crescentic outline in transverse section, and the lateral lemniscus has to a large extent disappeared from its lateral aspect.

The main part of the medial lemniscus takes origin in the lower part of the medulla oblongata from the gracile and cuneate nuclei of the opposite side (p. 894).

Seeing that the posterior white column of the spinal cord ends in these nuclei, the medial lemniscus may be considered to be the functional continuation of this column upwards into the brain. Other fibres arise from the terminal nuclei of the trigeminal nerve of the opposite side. At the lateral margin of the main part of the medial lemniscus are situated the spino-thalamic fibres which convey exteroceptive impulses from the spinal cord. They form a diffuse bundle which is sometimes termed the "*spinal lemniscus*". Intermingled with them are spino-tectal fibres, and in the mid-brain these pass dorsally to reach the superior corpus quadrigeminum. The medial lemniscus and "spinal lemniscus" proceed into the ventral nucleus of the thalamus, and there their fibres end.

Interpeduncular Nucleus and Fasciculus Retroflexus.—Immediately above the pons a small collection of nerve-cells is found in the median plane, wedged in between the two cerebral peduncles. It is all that is found in the human brain to represent a large nucleus that projects into the interpeduncular fossa in many lower animals. In this **interpeduncular nucleus** ends the **fasciculus retroflexus**—a tract of fibres which comes from the habenular nucleus of the epithalamus.

Decussations of Tegmentum.—Three decussations of bundles of fibres take place in the tegmentum—the decussations of the superior cerebellar peduncles, of the tecto-spinal tracts, and of the rubro-spinal tracts. The **decussation of the superior cerebellar peduncles** has been described already (p. 920). If the region ventral to the medial longitudinal bundles is examined in the upper part of the mid-brain, two groups of decussating fibres will be observed in the interval between the red nuclei—one dorsal to the other. The dorsal one is the **decussation of the tecto-spinal tracts**; the other is the **decussation of the rubro-spinal tracts**; both of these pairs of tracts cross the median plane immediately after their origin, decussating with their fellows, and descend in the opposite half of the brain-stem to the spinal cord—the tecto-spinal from the superior corpora quadrigemina, the rubro-spinal from the red nuclei.

Basis Pedunculi.—The basis pedunculi is slightly crescentic in outline in transverse section, and stands quite apart from its fellow. It is composed of a compact mass of longitudinally directed fibres, all of which arise in the cortex of the cerebrum and pursue an unbroken corticifugal course into and through the basis pedunculi. These fibres may be classified into two distinct sets, viz., cortico-pontine and pyramidal.

In their course downwards the **cortico-pontine fibres** are all arrested in the basilar part of the pons and end among the cells of the nuclei pontis. These tracts hold a very definite position in the basis pedunculi. Thus, it has been established that the fibres from the temporal and occipital areas of the cortex form the lateral fifth of the basis pedunculi, whilst those from the frontal and parietal areas occupy the medial fifth.

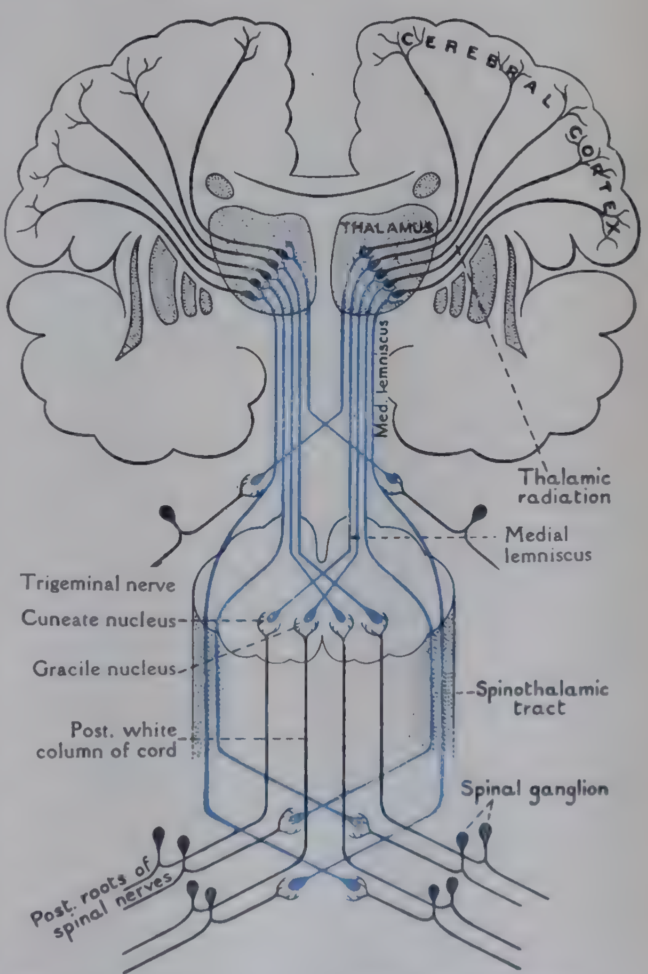


FIG. 811.—DIAGRAM OF CONNEXIONS OF MEDIAL LEMNISCUS AND OF THALAMO-CORTICAL FIBRES.

The **pyramidal fibres** constitute the great motor tract from the cerebral cortex. They occupy the middle three-fifths of the basis. This tract differs from the cortico-pontine strands in being carried downwards through the basilar part of the pons and on the front of the medulla

oblongata into the spinal cord, which it enters in the form of the *anterior* and *lateral cerebro-spinal tracts.* On its way through the mid-brain, pons, and medulla oblongata it sends fibres across the median plane to the various motor nuclei on the opposite side of those sections of the brain-stem; these may be termed *cortico-nuclear fibres.*

Development of Mid-Brain

Even in the early embryo the mesencephalon is the smallest section of the brain-tube, although the disproportion in size between it and the other primitive divisions of the brain is not nearly so marked as in the adult. Owing to the cephalic flexure, the mid-brain for a

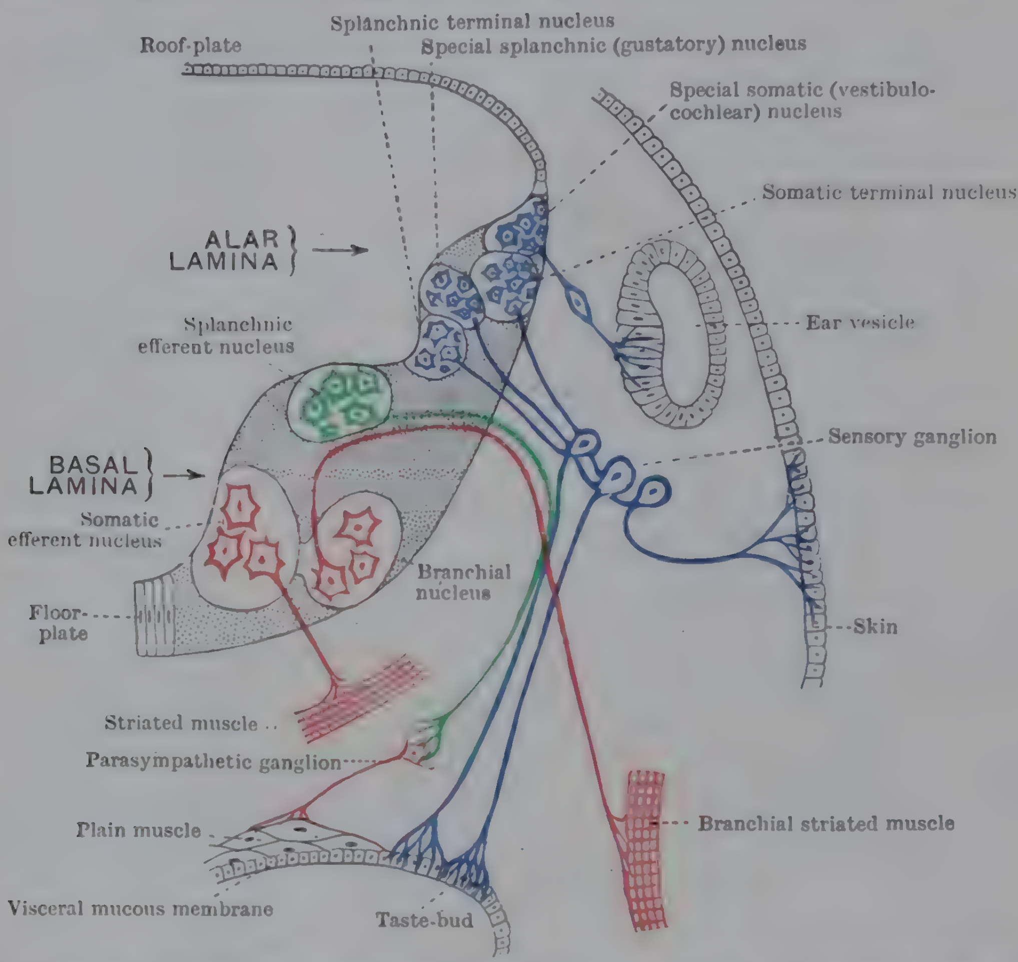


Fig. 812.—Diagram representing in Transverse Section of Fœtal Hind-Brain the Different Kinds of Components found in the Cranial Nerves and the position of their Nuclei of Origin or Termination.

time occupies the summit of the head. Later it becomes completely covered over by the expanding cerebral hemispheres.

The corpora quadrigemina are derived from the alar laminæ of the side-walls of the brain-tube, whilst the basal laminæ thicken and ultimately form the cerebral peduncles. The original cavity of the mid-brain becomes relatively narrowed down to form the aqueduct.

For a considerable time the cavity of the mid-brain remains relatively large, and the lower part of its dorsal wall is carried downwards in the form of a diverticulum or recess which overlaps the cerebellar plate. About that time, also, the dorsal wall shows a median fold or ridge. Both of those conditions are transitory. As the corpora quadrigemina take shape, the median ridge disappears and is replaced by the median longitudinal groove which separates the quadrigeminal bodies. Only its lower part is retained, and that is represented by the frenulum veli of the adult brain. The diverticulum of the cavity gradually becomes reduced, and finally disappears as the aqueduct assumes form.

DEEP CONNEXIONS OF CRANIAL NERVES ATTACHED TO MEDULLA OBLONGATA, PONS, AND MID-BRAIN

There are twelve pairs of cranial nerves, of which the lower eight are attached to the medulla oblongata and pons. From above downwards these eight are named the trigeminal (fifth), the abducent (sixth), the facial (seventh), the auditory (eighth), the glosso-pharyngeal (ninth), the vagus (tenth), the accessory (eleventh), and the hypo-

glossal (twelfth). Two others—the trochlear (fourth) and oculomotor (third)—spring from the mid-brain. The hypoglossal, the accessory, the greater part of the facial, the abducent, the motor root of the trigeminal, the trochlear, and the oculomotor are efferent nerves; the auditory and the sensory root of the trigeminal are purely afferent nerves; the vagus and the glosso-pharyngeal are composed of both efferent and afferent fibres; and the sensory root of the facial nerve contains not only afferent fibres but also the efferent, parasympathetic preganglionic fibres which later pass into the chorda tympani. In all these cases (with the exception of the mesencephalic tract of the trigeminal) afferent fibres arise from ganglionic cells

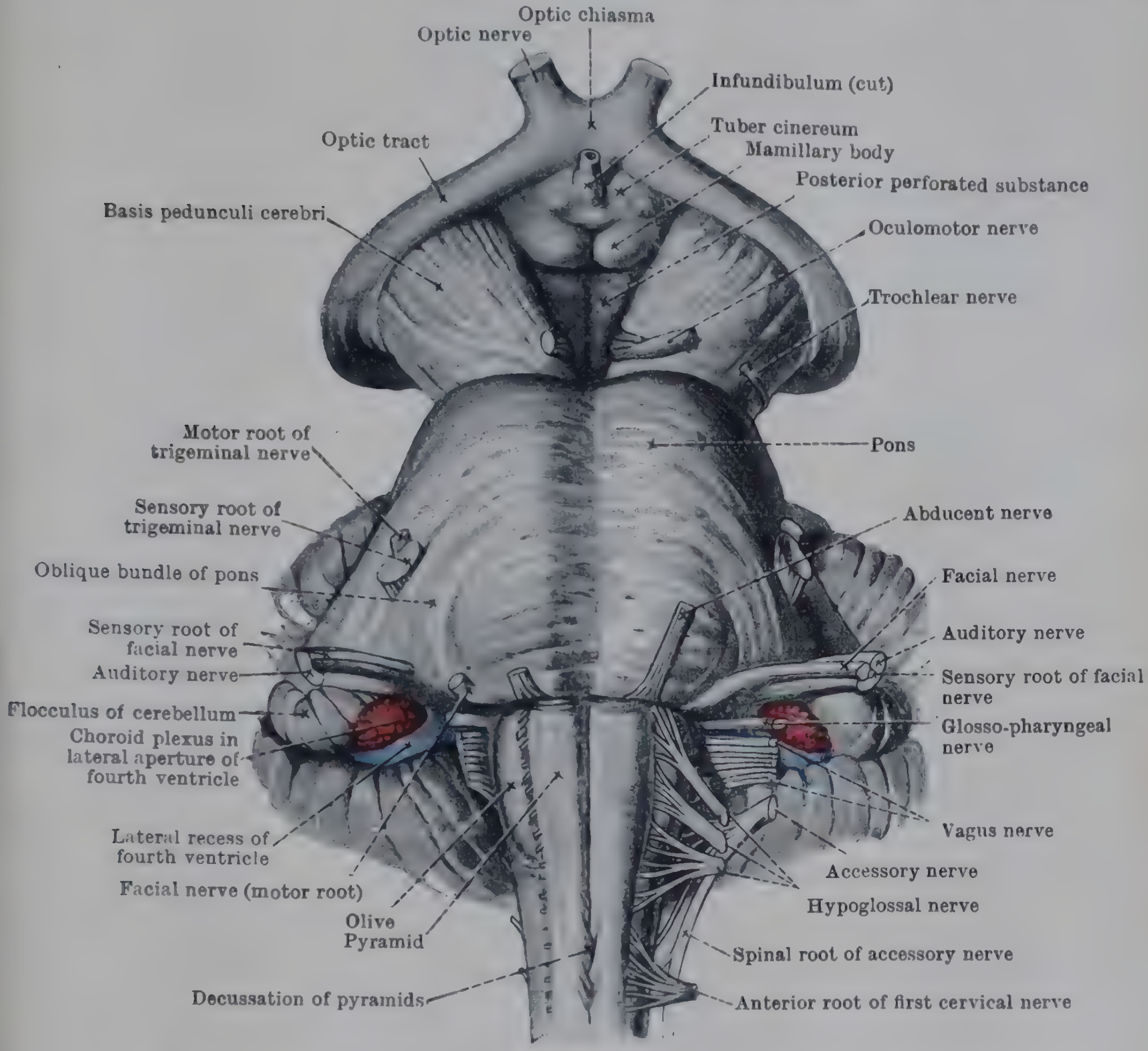


FIG. 813.—ANTERIOR SURFACE OF BRAIN-STEM, SHOWING THE NERVE-ROOTS.

placed outside the brain and penetrate the brain-stem, to end in connexion with the cells of certain **nuclei of termination**. Efferent fibres, on the other hand, take origin within the brain as the axons of cells which are grouped together in certain places in the form of **nuclei of origin**.

Nuclei of Origin, or Motor Nuclei.—In the spinal cord the nuclei of origin are represented by elongated columns of cells which run more or less continuously through successive spinal segments in the anterior grey column, and from them the series of efferent anterior nerve-roots take origin. In the medulla oblongata, pons, and mid-brain the nuclei of origin, or, in other words, the motor nuclei of the individual nerves, become, for the most part, discontinuous, and are represented by certain isolated clumps of compact grey matter in which are placed the clusters of cells from which the efferent fibres of the nerves arise. The nucleus ambiguus, however, which consists of a column of cells from which root-fibres of the upper part of the accessory, of the vagus, and also of the glosso-pharyngeal are derived, is an exception to this rule. At the decussation of the pyramids, the anterior grey column of the spinal cord is broken up by the intercrossing bundles into a

detached head, and a basal part which remains in relation with the antero-lateral aspect of the central canal. Certain of the efferent nuclei of the medulla oblongata, pons, and mid-brain lie in the line of the basal portion of the anterior grey column close to the median plane. They are the **somatic motor nuclei** of the brain-stem and are met with at different levels. This group comprises the hypoglossal nucleus, the abducent nucleus, and, in the mid-brain, the trochlear nucleus and part of the oculomotor nucleus. Other motor nuclei of origin are present in the form of isolated clumps or columns of grey matter which lie at different levels in the medulla oblongata and pons in a more lateral and ventral situation. They are the nucleus ambiguus of the accessory, vagus, and glosso-pharyngeal, the motor nucleus of the facial nerve, and the nucleus of the motor root of the trigeminal nerve. Since these nuclei give origin to fibres which innervate musculature derived from the pharyngeal or branchial arches in the embryo, they may be termed **branchial nuclei** (p. 844).

In addition to these two columns of motor nuclei there is a third efferent column of **splanchnic nuclei** represented by the dorsal nucleus of the vagus and glosso-pharyngeal nerves, and similar nuclei from which autonomic fibres arise and leave the brain with the facial and oculomotor nerves.

The different nuclei of origin of the efferent fibres which belong to the various cranial nerves, both somatic and branchial, are connected with the motor area of the cerebral cortex by cortico-nuclear fibres of the pyramidal tract which enter the nuclei and end in association with their cells.

Terminal Nuclei.—The general scheme of arrangement of the **terminal nuclei** has already been explained (Fig. 812); its details will be further elucidated as the various nerves are considered seriatim.

The axons of many of the cells of the nuclei of termination enter the formatio reticularis as arcuate fibres, and, after crossing the median plane, are carried upwards in the formatio reticularis of the opposite side to establish direct connexions with the thalamus and, indirectly through it, with the cerebral cortex. Others pass to the motor nuclei, to the cerebellum, or other groups of nerve-cells, to form connexions necessary for the performance of reflex actions.

Hypoglossal Nerve.—The nucleus of origin of the hypoglossal nerve—the motor nerve of the tongue—lies in the substance of the medulla oblongata. It is composed of several groups of large multipolar cells which closely resemble the cells in the anterior grey column of the spinal cord, and is pervaded by an intricate network of fine fibres. In form it is a slender rod about 18 mm. in length. It extends from a point immediately above the decussation of the pyramids up to the level of the striæ medullares. The lower part is in front of the central canal of the medulla close to the median plane in that part of the central grey matter which is continuous with the basal part of the anterior grey column of the spinal cord. The upper part is in the grey matter in the floor of the fourth ventricle, subjacent to the medial part of the surface area named the **hypoglossal triangle** (see p. 887). Within the nucleus the axons of the cells arrange themselves in converging bundles of fine fibres and leave through the front of the nucleus as the rootlets of the nerve. The nerve-bundles thus formed traverse the entire antero-posterior thickness of the medulla oblongata to emerge on the surface in linear order between the olive and the pyramid.

In the substance of the medulla oblongata the rootlets of the hypoglossal pass between the olivary nucleus and the medial accessory olivary nucleus, and many of them on their way to the surface pierce the ventral lamina of the olivary nucleus. After they emerge they at first collect to form a series of definite bundles like the anterior nerve-roots of three or four spinal nerves (Fig. 813). These subsequently unite to form two trunks which always pierce the dura mater separately, and the trunks then unite to form the single hypoglossal nerve. This arrangement is an expression of the composite nature of the hypoglossal nerve, for developmentally it is formed by the fusion of three or four segmental nerves.

No decussation between the nerves of opposite sides takes place in the medulla oblongata, but commissural fibres pass between the two nuclei (Kölliker). Further,

numerous cortico-nuclear fibres from the opposite side enter the nucleus and end in connexion with its cells. The nucleus is thus brought into connexion with the motor area of the cerebral cortex of the opposite side.

Accessory Nerve.—The accessory nerve also is a motor nerve, and it arises by a spinal and a cranial root.

The fibres of the **spinal root** emerge as a vertical row of bundles through the side of the spinal cord from the level of the fifth cervical nerve upwards; they unite to form a stem that ascends between the anterior and posterior roots of the cervical nerves and enters the skull through the foramen magnum. The root-fibres take origin in a column of cells situated in the anterior grey column close to its lateral margin and immediately behind the nerve-cells which give rise to the fibres of the anterior roots of the upper five cervical nerves. The cells of the accessory nucleus are large, multipolar, and in every respect similar to the motor cells of the spinal nerves. The axons from these cells leave the posterior surface of the nucleus in converging groups to form the root-bundles of the nerve. These, in the first place, proceed straight backwards in the anterior grey column. Reaching the bay between the two columns of grey matter, they turn sharply laterally into the white matter and traverse the lateral white column to gain their points of exit from the cord. At the decussation of the pyramids additional rootlets proceed from the detached head of the anterior grey column.

It should be noted that many of the fibres which take origin from the lower part of the spinal nucleus do not at once emerge on the surface of the spinal cord, but ascend for some distance in the white matter alongside the base of the anterior grey column. These fibres constitute the *intraspinal root* of the accessory nerve.

The fibres of the **cranial root** arise in the medulla oblongata. As they proceed laterally from their nucleus they cross in front of the spinal tract of the trigeminal nerve; this distinguishes them from the fibres of the vagus, for the vagal fibres pass through the tract or behind it. The nucleus of origin of the cranial rootlets is the **nucleus ambiguus**, which, at a higher level, gives motor fibres to the vagus and glosso-pharyngeal nerves.

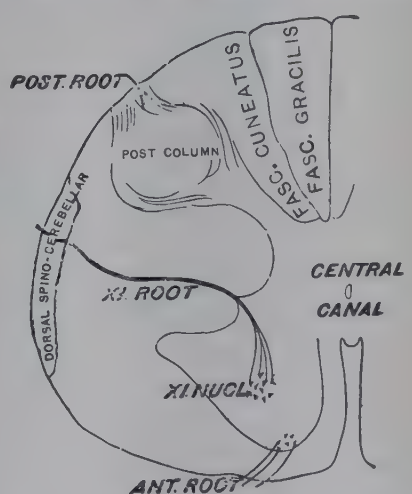


Fig. 814.—Diagram of Spinal Origin of Accessory Nerve. (After Bruce, 1892.)

The part of the accessory nerve which takes origin in the spinal cord supplies the sterno-mastoid and trapezius muscles. The cranial portion joins the vagus, and through the recurrent laryngeal nerves it supplies all the intrinsic muscles of the larynx except the crico-thyroid (see p. 1040).

Collaterals and fibres of the opposite lateral cerebro-spinal tract end in connexion with the cells of origin of the accessory nerve, and thus bring its nucleus into connexion with the motor area of the cerebral cortex.

Vagus and Glosso-Pharyngeal Nerves.—The vagus and glosso-pharyngeal nerves have similar connexions with the brain, and they may therefore be studied together. The greater part of both nerves is composed of afferent fibres which arise outside the brain-stem from ganglionic cells placed in relation to the nerve-trunks. Both nerves possess efferent fibres also, which spring from two special nuclei of origin situated within the medulla oblongata and termed respectively the **dorsal** or **splanchnic nucleus** and the **nucleus ambiguus**, which is a **branchial nucleus**. The afferent ganglionic fibres of the vagus and glosso-pharyngeal enter the brain by a series of roots which penetrate the medulla oblongata along the front of the inferior cerebellar peduncle. Within the medulla oblongata they separate into two sets, viz., a series of bundles (composed chiefly of vagus fibres, *i.e.*, afferent splanchnic) which end in grey matter closely related to the dorsal nucleus of the vagus and glosso-pharyngeal nerves, and another series of bundles (composed chiefly of glosso-pharyngeal fibres, *i.e.*, taste-fibres) which join a conspicuous longitudinal tract of fibres called the **tractus solitarius**.

The **dorsal nucleus** (Figs. 774, p. 891, and 779, p. 895) of the vagus and glosso-pharyngeal nerves contains motor cells which give origin to efferent fibres.

Immediately lateral to it is a slender column of grey matter (sometimes called the "dorsal sensory nucleus of the vagus") in which terminate afferent fibres of the vagus, and possibly also of the glosso-pharyngeal nerve. The dorsal nucleus proper (*i.e.*, the motor nucleus) is almost as long as the nucleus of the hypoglossal nerve, with which it is closely related. Above, it reaches as high as the striæ medullares, whilst its inferior end falls slightly short of that of the hypoglossal nucleus. In specimens stained by the Weigert-Pal method the two nuclei offer a marked contrast. The hypoglossal nucleus has a dark hue, owing to the enormous

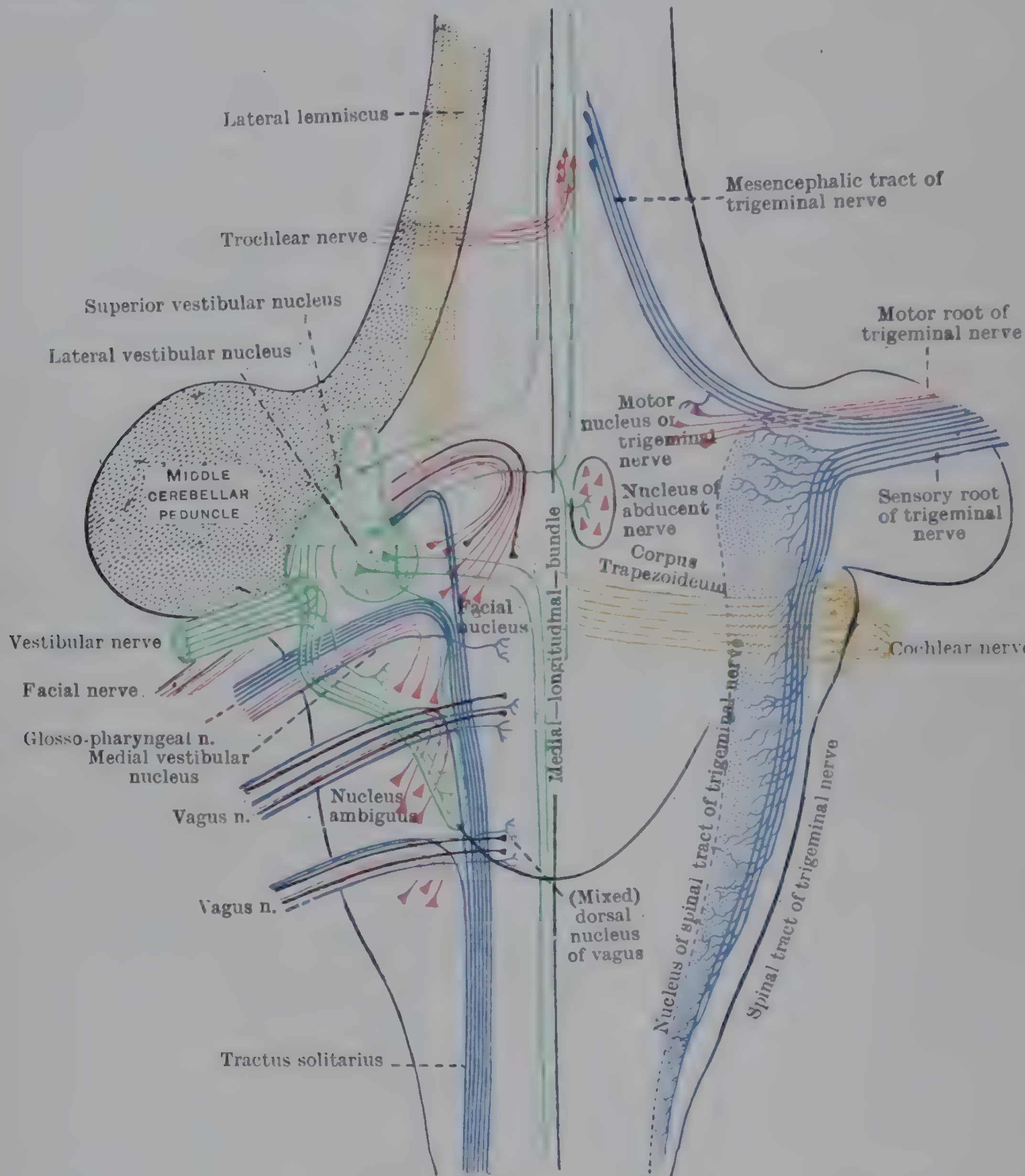


FIG. 815.—DIAGRAM OF DEEP CONNEXIONS OF VAGUS, GLOSSO-PHARYNGEAL, AUDITORY, FACIAL, ABDUCENT, AND TRIGEMINAL NERVES.

numbers of fine fibres which twine in and out among its cells; the vago-glossopharyngeal dorsal nucleus is pale, from the scarcity of such fibres within it. Its cells, like those of all splanchnic efferent nuclei, are much smaller than the cells of the nucleus ambiguus. In the lower half of the medulla oblongata the dorsal vago-glossopharyngeal nucleus lies in the central grey matter lateral to the central canal and immediately behind the hypoglossal nucleus; in the upper part it lies in the grey matter of the floor of the fourth ventricle immediately to the lateral side of the hypoglossal nucleus and subjacent to the vagal triangle (see p. 887).

All the fibres which arise from the dorsal splanchnic nucleus are very fine, and in sections of the vagus nerve can readily be distinguished from the coarser fibres which come from the nucleus ambiguus, and also from the medium-sized sensory fibres, which spring from the ganglia placed on the nerves. The fine fibres

from the dorsal nucleus are distributed (indirectly, *i.e.*, after being interrupted in a peripheral ganglion) to the involuntary striated muscle of the œsophagus, and the plain muscle of the œsophagus, stomach, and respiratory system.

The **nucleus ambiguus** (Figs. 774, 779, 815) gives origin to the branchial motor fibres of the glosso-pharyngeal, vagus and accessory nerves. It has already been noted that the motor fibres of the accessory nerve which arise in the nucleus eventually join the vagus nerve and are distributed with its branches. All of the fibres that pass into the glosso-pharyngeal nerve end in the stylo-pharyngeus muscle and the superior constrictor muscle of the pharynx; the vagal branches are distributed to the muscles of the soft palate (except the tensor palati), to the muscles of the pharynx (except the stylo-pharyngeus), and to the crico-thyroid muscle. The cells of the nucleus ambiguus are large, multipolar, and similar in every respect to the large cells in the anterior grey column of the spinal cord. They are arranged in a slender column seen best in the upper half of the medulla oblongata. There the nucleus can easily be detected, in transverse sections, as a small area of compact grey matter in the formatio reticularis grisea, midway between the dorsal accessory olive and the nucleus of the spinal tract of the trigeminal nerve. It therefore lies more deeply in the substance of the medulla oblongata than the dorsal vago-glosso-pharyngeal nucleus. It can be traced downwards as low as the level of the sensory decussation, and upwards as high as the level of entrance of the cochlear nerve. The axons of its cells emerge from the dorsal aspect of the nucleus, and in the first instance pass backwards towards the floor of the fourth ventricle; then, bending suddenly laterally and forwards, they join the afferent roots of the vagus and the glosso-pharyngeal nerves, and emerge from the brain in company with them. The origin of the cardiac fibres of the vagus is not certainly known; there is some evidence that they arise, not from the dorsal splanchnic efferent nucleus, but from a group of slightly larger cells alongside the nucleus ambiguus.

Sensory Nuclei of Glosso-Pharyngeal and Vagus (Splanchnic and Gustatory Components).—The cells in the column of grey matter, lateral to the dorsal (motor) nucleus, which acts as a *nucleus of termination* are spindle-shaped in form and similar to those found in the posterior grey column in the spinal cord. The greater number of the afferent fibres of the vagus nerve, and a small proportion of the afferent fibres of the glosso-pharyngeal nerve, end around these cells in fine terminal arborizations. A small part of the upper portion of the nucleus may be said to belong to the glosso-pharyngeal nerve and the remainder to the vagus nerve.

The **tractus solitarius** (Figs. 773, p. 889; 774, p. 891; and 779, p. 895) is a cylindrical bundle of longitudinal fibres which forms a very conspicuous object in transverse sections through the medulla oblongata. It begins at the upper end of the medulla oblongata and can be traced downwards through its whole length. The relations of the tractus solitarius are not the same in all parts of its course. It lies immediately to the lateral side of the dorsal vago-glossopharyngeal nucleus—rather in front of it in the upper part of the medulla, and behind it in the lower part. Throughout its entire length it is intimately associated with a column of gelatinous grey substance, called the **nucleus of the tractus solitarius**, which is its nucleus of termination. Most of the fibres of the tractus solitarius are derived from the glosso-pharyngeal nerve; only a few of the afferent fibres of the vagus enter it, but fibres of the sensory root of the facial also enter it at its upper extremity. As the fibres of the three nerves join the fasciculus they immediately turn downwards, and at different levels they come to an end in the associated nucleus.

As the afferent rootlets of the vagus and the glosso-pharyngeal nerves traverse the substance of the medulla oblongata in a backward and medial direction to reach the tractus solitarius and the dorsal nucleus of termination, they pass through the spinal tract of the trigeminal nerve and the nucleus of that tract. As the afferent root of the vagus passes through the spinal tract and its nucleus (which is somatic sensory in nature), it gives off to that nucleus its own somatic sensory branches, the peripheral ends of which constitute the *auricular branch*, distributed to the skin on the back of the auricle. The other afferent fibres in the glosso-pharyngeal and vagus nerves include taste-fibres, sensory fibres from the pharynx, larynx, and other parts of the respiratory and alimentary systems, and other splanchnic afferent fibres. Although

there is no sharp demarcation between the terminal nuclei of these various components, it is probable that the taste-fibres proceed to the nucleus of the tractus solitarius, the splanchnic afferent fibres to the dorsal nucleus, and the somatic afferent fibres to the nucleus of the spinal trigeminal tract.

Auditory Nerve.—As this is a nerve of special sense it will be left for consideration after the rest of this series.

Facial Nerve (Figs. 815 and 816).—The facial nerve is a mixed nerve with two separate roots—sensory and motor.

The **motor root** is so much the larger that the term **facial nerve** is often applied to it alone. It emerges through the lower border of the pons a little medial to the auditory nerve. The **sensory root** is a very slender cord that lies between the auditory nerve and the motor root—but nearer the former than the latter (Fig. 813)—and it sinks into the upper end of the medulla oblongata. The two roots run alongside the auditory nerve from the pons to the internal auditory meatus.

The fibres of the sensory root arise in the temporal bone from the cells of the ganglion of the facial nerve. These, like the cells of a spinal ganglion, are unipolar—the single process in each case dividing into a peripheral and a central branch. The group of peripheral fibres is represented partly by the greater superficial petrosal nerve and chorda tympani nerve. The central fibres form the sensory root; they penetrate the brain, and, passing either through or behind the spinal tract of the trigeminal nerve, they finally reach the upper part of the column of grey matter in connexion with the tractus solitarius, and in that they end. The sensory root has therefore the same terminal connexions as the glossopharyngeal nerve.

The motor nucleus of the facial nerve contains elements serially homologous with both the nucleus ambiguus and the dorsal vago-glossopharyngeal nucleus. It is composed partly of the larger cells characteristic of the former and the smaller cells distinctive of the latter. The axons of the larger cells innervate the striated muscles of the face, whereas the splanchnic fibres from the smaller cells pass to the sphenopalatine, otic, and submandibular ganglia (as their preganglionic fibres), and are concerned with the regulation of the secretory activity of the large salivary glands and other glands around the mouth; these secretory fibres of the seventh nerve leave the brain with its sensory root which is therefore not composed wholly of afferent fibres.

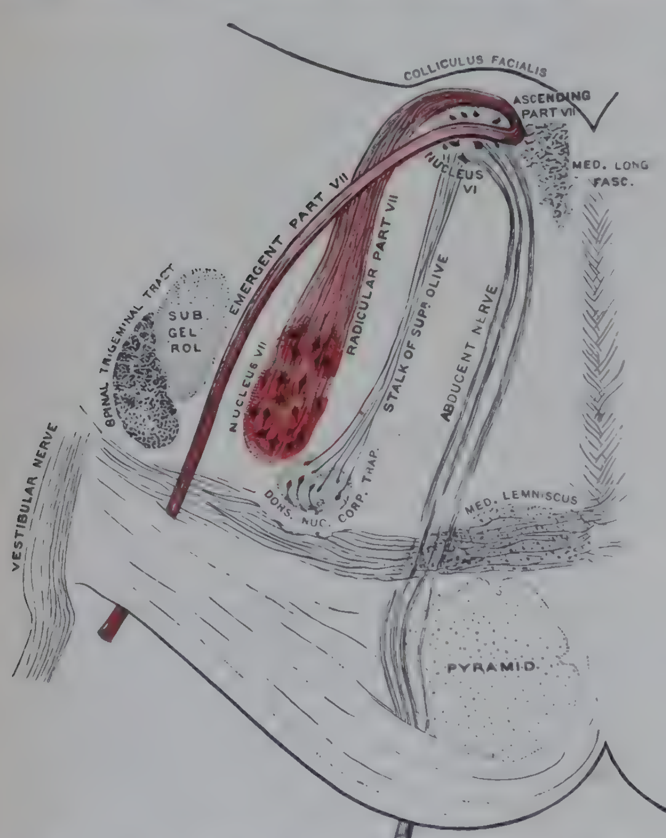


Fig. 816.—Diagram of Intrapontine Course of Facial Nerve.

SUB. GEL. ROL. refers to the nucleus of the spinal trigeminal tract.

The facial nucleus is situated close to the place where the nerve emerges from the brain, but the nerve does not at once pass to the point of exit. It pursues a long and devious path within the pons before it finally reaches the surface. This intrapontine part of the nerve may be divided into three parts, viz.: (1) a radicular part, (2) an ascending portion, and (3) an emergent part.

The **radicular part of the facial nerve** (Fig. 816) is composed of a large number of fine, loosely arranged bundles of fibres which issue from the lateral and dorsal aspect of the nucleus and proceed backwards and slightly medially through the pons. Reaching the floor of the fourth ventricle they curve medially,

and the bundles which lie highest up sweep over the lower part of the nucleus of the sixth nerve. Close to the median plane they turn sharply upwards and are collected into a solid nerve-bundle. This **ascending part** (Figs. 815 and 816) proceeds upwards immediately beneath the ependyma of the ventricular floor on the dorsal surface of the medial longitudinal bundle, and along the medial side of the abducent nucleus for a distance of about five millimetres; it then bends laterally, and curves a second time over the dorsal surface of the abducent nucleus, and this bend bulges the floor of the ventricle, producing the **colliculus facialis** (Fig. 816 and Fig. 770, p. 886). The nerve having thus made a curved loop over the dorsal aspect of the abducent nucleus, its **emergent part** now begins (Figs. 815, 816). This part takes an oblique course laterally, forwards and downwards to its place of exit at the lower border of the pons; and, on its way, it passes between its own nucleus and the spinal tract of the trigeminal nerve.

Ending in the facial nucleus, in fine terminal arborizations around its cells, there are: (1) many cortico-nuclear fibres from the pyramidal tract of each side; (2) fibres from the spinal tract of the fifth nerve; (3) fibres from the corpus trapezoideum, etc. The nucleus is thus brought into connexion with the motor area of the cerebral cortex, with the trigeminal nerve (the sensory nerve of the face), and with the auditory nerve.

The peculiar course of the efferent fibres of the facial nerve within the pons is the result of a migration of the motor nucleus which has occurred during embryonic (and also during evolutionary) development. In the embryo the facial nucleus develops alongside the abducent nucleus. The latter, controlling one of the eye-muscles, receives most of its afferent impulses from the medial longitudinal bundle (descending from the optic centres in the superior corpus quadrigeminum), and therefore it remains alongside the medial longitudinal bundle and perhaps moves slightly upwards, *i.e.*, towards the mid-brain. The facial nucleus, however, receives most of its stimuli from the nucleus of the spinal tract of the trigeminal nerve and from cortico-nuclear fibres, and therefore, as the walls of the metencephalon thicken during their growth, this nucleus comes to occupy a position between the trigeminal nucleus and the pyramidal tract (Fig. 816), and so migrates along a course which remains mapped out by its emerging fibres.

Abducent Nerve (Figs. 781 and 816).—The abducent nerve is a small motor nerve which emerges from the brain at the lower border of the pons above the lateral border of the pyramid of the medulla oblongata. It is the nerve of supply to the lateral rectus muscle of the eyeball. Its **nucleus** of origin is a small oval mass of grey matter, containing large multipolar cells, which lies in the lower part of the pons, close to the median plane and immediately subjacent to the grey matter of the floor of the fourth ventricle. Its position can be easily indicated on the ventricular floor, seeing that it is placed subjacent to the facial colliculus and immediately above the level of the striæ medullares. Its peculiar and intimate relation to the intrapontine portion of the facial nerve has already been indicated.

The axons of the multipolar cells of the nucleus emerge from the medial side of the nucleus in several bundles which proceed through the whole dorso-ventral thickness of the pons towards the place of exit. As they pass forwards they incline downwards and slightly laterally. In the dorsal part of the pons they proceed forwards on the medial side of the dorsal nucleus of the corpus trapezoideum, whilst in the basilar part of the pons they keep for the most part to the lateral side of the pyramidal bundles, although several of the nerve-rootlets pierce these on their way to the surface.

It appears probable that certain of the axons of the cells of the abducent nucleus enter the medial longitudinal fasciculus and proceed upwards in it to end in the oculomotor nucleus of the opposite side. Fibres and collaterals from the basis pedunculi enter the nucleus, and, ending around the cells, bring the nucleus into connexion with the motor area of the cerebral cortex. A slender bundle of fibres connects it with the dorsal trapezoid nucleus, and is called the *pedicle* of that nucleus (named "stalk of sup^{r}. olive" in Fig. 816).

Trigeminal Nerve.—The trigeminal nerve strikes its roots deeply into the brain and establishes a connexion with it which extends from the upper part of

the mid-brain to the level of the second cervical nerve. No other cranial nerve presents so extensive a connexion (Fig. 815). It has two roots—a large afferent or sensory root and a small efferent or motor root; both roots appear close together on the surface of the pons, rather nearer its upper than its lower border, and in the same line as the facial, and glosso-pharyngeal and vagus nerves (Fig. 813).

The **sensory root** is composed of fibres which arise outside the brain from the cells of the trigeminal ganglion. They end within the brain in a tadpole-shaped nucleus, the swollen body of which is situated in the pons and is termed the main sensory nucleus of the trigeminal nerve: the tail is a long column of grey matter which is directly continuous below with the substantia gelatinosa of the spinal cord.

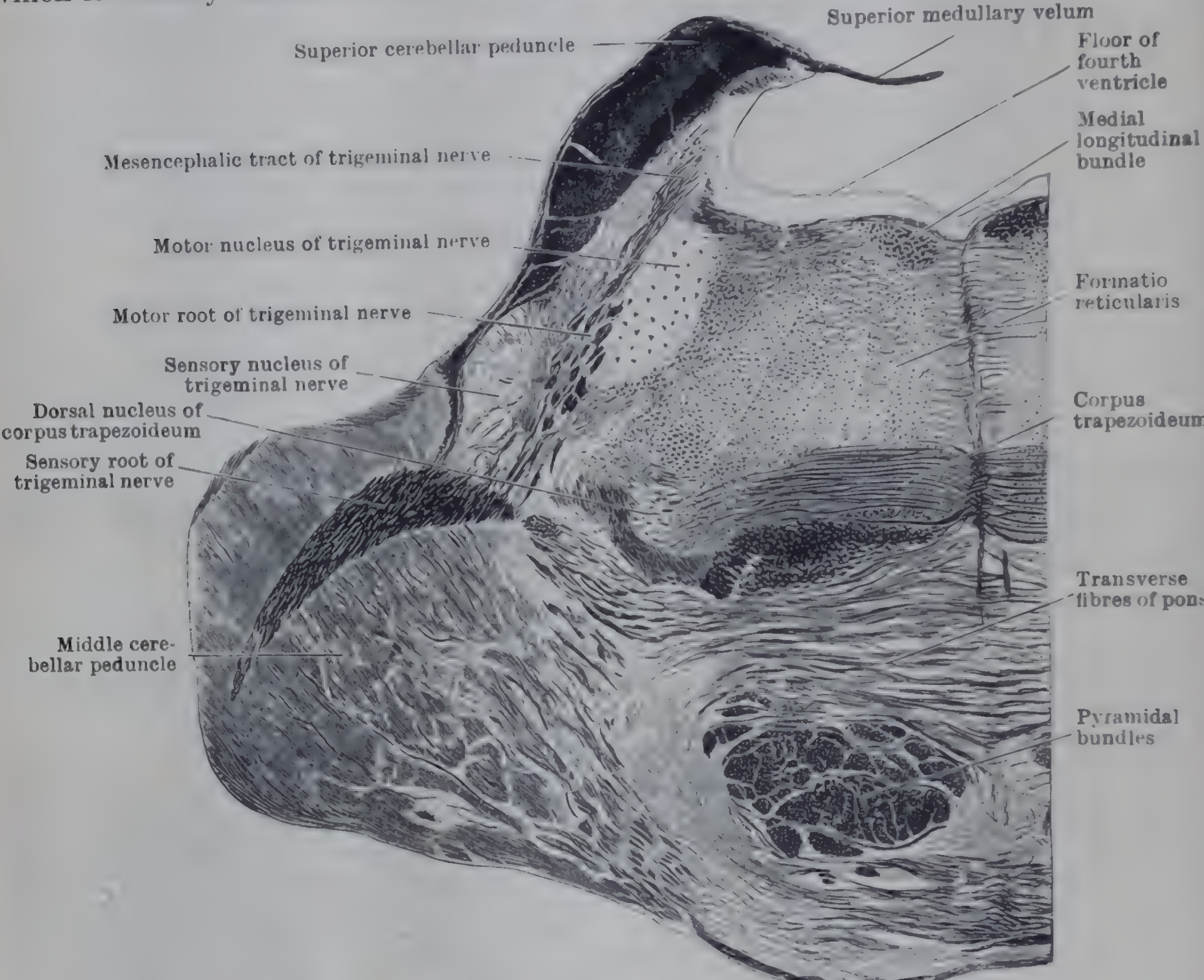


FIG. 817.—SECTION THROUGH PONS AT LEVEL OF NUCLEI OF TRIGEMINAL NERVE.

The **main sensory nucleus** (Fig. 817) is an oval mass of grey matter placed half-way up the pons in the lateral part of its dorsal portion. It lies close to the surface immediately subjacent to the submerged margin of the superior cerebellar peduncle. It is directly continuous with the substantia gelatinosa, and may be regarded as being merely its enlarged upper end.

The fibres of the sensory root, on reaching the sensory nucleus, divide (in the same way as the fibres of the entering posterior roots of the spinal nerves) into ascending and descending branches (Fig. 815). The ascending fibres are short, and almost immediately enter the main sensory nucleus and end within it; the descending fibres turn sharply downwards and form the **spinal tract**. This tract descends on the lateral side of the nucleus in which its fibres terminate—the **nucleus of the spinal tract of the fifth nerve**. Fibres constantly leave it to enter the nucleus, so that the farther the spinal tract proceeds the smaller does it become, until, in the upper part of the spinal cord, about the level of the first or second spinal nerve, it disappears altogether.

The spinal tract of the trigeminal nerve is a conspicuous object in sections through the pons and medulla oblongata. In the pons it traverses the dorsal part—first between the

emergent part of the facial nerve and the vestibular nerve, and then, lower down, between the inferior cerebellar peduncle and the nucleus of the facial nerve (Fig. 781). In cross-sections it presents a well-defined semilunar or curved piriform outline. In the upper part of the medulla oblongata it lies on the front of the inferior peduncle, and is therefore nearer the surface at this level (Fig. 779, p. 895); here, it is traversed and broken up into bundles by the olivo-cerebellar fibres and the roots of the glosso-pharyngeal and vagus nerves. Finally, it comes to the surface and its fibres are spread over the area on the side of the medulla oblongata known as the **tubercle of the fifth nerve.** (Fig. 778, p. 894).

The **motor root of the trigeminal nerve** is distributed chiefly to the muscles of mastication, and derives its fibres from the motor nucleus.

The **motor nucleus** (Fig. 817) lies in the lateral part of the dorsal division of the pons, close to the medial side of the main sensory nucleus, but slightly nearer the floor of the fourth ventricle. It is serially homologous with the motor nuclei of the branchial group, namely, the facial nucleus and the nucleus ambiguus. It does not become displaced so far forwards as these nuclei, because its chief source of sensory impulses—the terminal nucleus of the trigeminal afferent fibres—is placed alongside it, and there is no need for any definite migration (Fig. 815).

The **mesencephalic tract of the fifth nerve** takes origin from a column of loosely arranged pear-shaped unipolar cells placed in the extreme lateral part of the grey matter around the aqueduct. As this tract is traced downwards it gradually increases in size by the accession of new fibres, and it is crescentic in transverse section (Figs. 783, p. 900; 784, p. 901; and 785, p. 902). In the lower part of the mid-brain it lies on the medial side of the superior cerebellar peduncle; and the trochlear nerve, on its way to the surface, runs downwards in the concavity of its medial side. In the upper part of the pons it continues its course downwards on the lateral and deep aspect of the grey matter in the floor of the fourth ventricle. Finally, reaching the level of the nuclei of the trigeminal nerve, the fibres of the mesencephalic tract turn forwards and run in close association with the *motor root.* Experimental observations have shown fairly conclusively that the mesencephalic tract is made up of sensory fibres derived from the dental and palatine nerves.

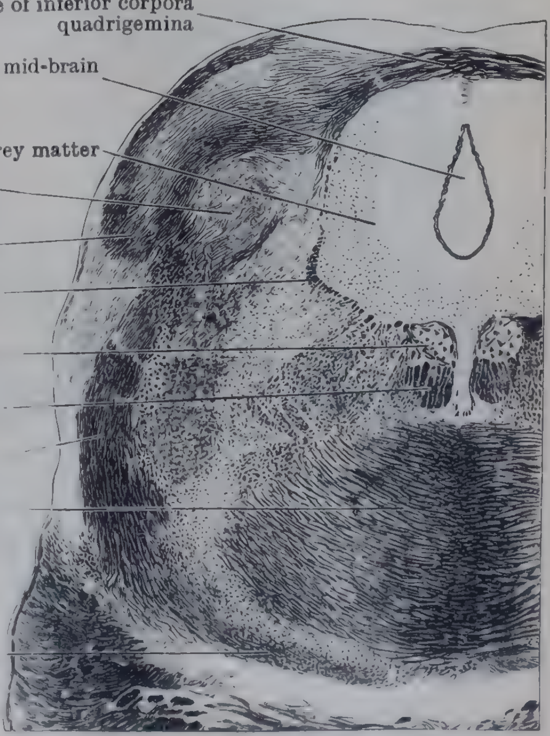


Fig. 818.—Section through Inferior Corpus Quadrigeminum and Tegmentum of Mid-Brain at Level of Middle Part of Trochlear Nucleus.

The reason why the afferent nature of the tract was not suspected until recent times is no doubt the fact that its fibres arise, not in some ganglion outside the central nervous system, like other afferent nerves, but from cells inside the mid-brain. The neural crest in the mesencephalic region must presumably have been drawn into the neural tube during development and given rise to this sensory nucleus of origin (*not* a terminal nucleus) within the central nervous system.

Trochlear Nerve.—The trochlear nerve supplies the superior oblique muscle of the eyeball. It emerges through the back of the brain-stem, at the upper part of the superior medullary velum, immediately below the lower border of the inferior corpus quadrigeminum (Fig. 799, p. 912). Its **nucleus** is a small oval mass of cells, placed in the ventral part of the central grey matter, at the level

of the upper part of the inferior corpus quadrigeminum. The close association of this nucleus with the medial longitudinal bundle has already been referred to. It is sunk deeply in a bay which is hollowed out on the dorsal and medial aspect of the tract. The nerve has a course of some length within the mid-brain. The axons of the cells leave the lateral aspect of the nucleus, and curve backwards and laterally in the central grey matter until they reach the medial surface of the mesencephalic tract of the trigeminal nerve. There they are gathered together into one or two round bundles, which, bending sharply, turn downwards at a right angle and descend on the medial side of the trigeminal tract. When the region below the inferior corpus quadrigeminum is reached, the nerve makes another sharp bend. This time it turns medially, enters the upper end of the superior medullary velum, and here decussates with its fellow of the opposite side. Having thus crossed the median plane, the trochlear nerve emerges at the medial border of the superior cerebellar peduncle. The course of the trochlear nerve in the central grey matter may be traced by examination in the order given of Fig. 818, Fig. 819, Fig. 785, p. 902, and Fig. 799, p. 912.

Oculomotor Nerve.—The oculomotor nerve supplies the levator palpebræ superioris, all the extrinsic muscles of the eyeball (with the exception of the superior oblique and the lateral rectus) and also two muscles within the eyeball, viz., the sphincter pupillæ and the ciliary muscle. The **nucleus** of origin is in the ventral part of the central grey matter subjacent to the superior corpus quadrigeminum (Fig. 806, p. 919). In length it measures from 5 to 6 mm. Its relation to the medial longitudinal fasciculus (Fig. 806) is even more intimate than that of the trochlear nucleus. It is closely applied to the dorsal and medial aspect of this strand; many of its cells occupy a position in the intervals between the nerve-bundles of the tract, and some are seen even in front of it. The axons of the cells leave the nucleus in numerous bundles which describe a series of curves as they proceed forwards through the medial longitudinal fasciculus, the tegmentum, red nucleus, and medial margin of the substantia nigra, to emerge finally from the brain-stem along the bottom of the medial sulcus of the mid-brain.

Fig. 819.—Section through Inferior Corpus Quadrigeminum and Tegmentum of Mid-Brain at Level of Lower Part of Trochlear Nucleus.

The oculomotor nucleus is made up of two main components—a large-celled somatic element which supplies extrinsic ocular muscles, and a small-celled visceral element which innervates intrinsic muscles. The somatic element is arranged as a longitudinal column of cells on each side of the median plane. In the upper part of the nucleus there is also a median group of cells which is probably concerned with the innervation of the medial rectus muscle; hence it is sometimes called the "nucleus of convergence". The lateral columns are often seen in transverse section to be subdivided into more or less well-defined and rather variable clusters of cells, but the significance of these groups is uncertain. It is generally supposed that they bear some relation to the several branches of the oculomotor nerve and the muscles which they supply, but there is considerable divergence of opinion regarding the topographical representation of these muscles. In the accompanying diagram (Fig. 820) one interpretation of this topographical

representation is shown, but in actual histological preparations it is not possible to define such groups anatomically.

On the basis of clinical observation, there is reason to believe that the cells from which the superior rectus and levator palpebræ superioris are innervated are situated dorsally, for tumours which exert pressure on the region of the oculomotor nucleus from above commonly lead to a paralysis of these muscles first. There is also indirect evidence that the cells which are concerned with the innervation of the inferior rectus muscle are situated in the ventral part of the oculomotor nucleus.

Whilst the majority of the fibres in an oculomotor nerve arise from the cell-groups on its own side of the median plane, it has been satisfactorily established that a certain proportion of its fibres are derived from the nucleus of the opposite side, thus forming a crossed connexion and giving rise to a median decussation. The whole oculomotor nucleus, and particularly that part which is concerned with the innervation of the medial rectus muscle, is connected, through the medial longitudinal fasciculus, with the abducent nucleus, from which proceeds the nerve of supply for the lateral rectus muscle. The harmonious action of the medial and lateral recti in producing the conjugate movements of the eyeballs is thus explained.

The oculomotor nucleus is connected: (1) with the occipital part of the cerebral cortex by fibres which reach it through the optic radiation; (2) with the vestibular, trochlear, and abducent nuclei (and probably with other nuclei) by fibres which come to it through the medial longitudinal fasciculus; (3) possibly with the facial nerve by fibres which pass out from it into the medial longitudinal fasciculus (p. 896); (4) with the fibres which convey retinal impulses indirectly through the pretectal nucleus and the superior corpus quadrigeminum.

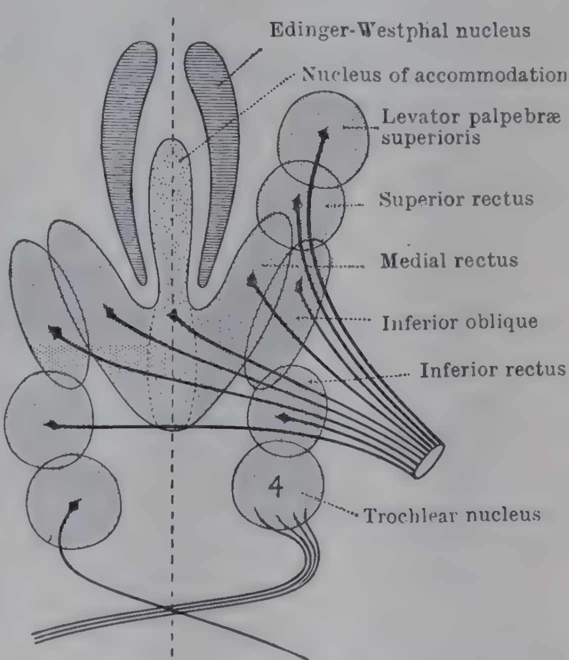


Fig. 820.—Diagram of the Oculomotor and Trochlear Nuclei. (After Brouwer, 1918.)

It is important to recognize that although the main part of the oculomotor nucleus belongs to the somatic group, which also includes the trochlear, abducent, and hypoglossal nuclei, it includes also a representative (the Edinger-Westphal group of small cells) of the column of general splanchnic efferent nuclei (parasympathetic) in series with those of the facial, glosso-pharyngeal, and vagus nerves. Its axons pass out with the other fibres of the oculomotor nerve and enter the ciliary ganglion, where they end in relationship with the cells that innervate the ciliary muscle and the sphincter pupillæ. The third, fourth, and sixth cranial nerves, which supply motor fibres to the extrinsic muscles of the eye, contain also proprioceptive afferent fibres, but their termination in the brain-stem is uncertain.

Auditory Nerve.—The **eighth cranial nerve** is a thick composite bundle that enters the brain at the lower border of the pons. Its fibres spring from bipolar ganglionic cells within the internal ear or its immediate neighbourhood (see section dealing with the Organs of Sense). One group of them forms the **spiral ganglion**, the peripheral branches of which are distributed to the spiral organ in the cochlea: another group constitutes the **vestibular ganglion**, which distributes fibres to the ampullæ of the semicircular ducts, the utricle, and the saccule. Although the central processes of the cells in the two ganglia accompany one another and are known collectively as the auditory nerve, they probably remain distinct throughout, in their mode of termination in the brain as well as in their peripheral distribution. Reaching the brain, the auditory nerve divides into two parts, viz.,

the cochlear nerve and the vestibular nerve, which have different connexions, corresponding to their distinct functions. At the pons, the two nerves embrace the inferior cerebellar peduncle—the vestibular nerve entering the pons on the medial side of the peduncle, whilst a large part of the cochlear nerve sweeps round its lateral surface. Special nuclei of termination require to be studied in connection with each of the two divisions.

The **cochlear nerve** is composed of finer fibres than the vestibular nerve, and they acquire their medullary sheaths at a later period. It is the true nerve of hearing, and its fibres end in two nuclei which are intimately related to the inferior cerebellar peduncle. One of them, called the **dorsal cochlear nucleus**, is a piriform mass placed on the back of the inferior peduncle—between it and the flocculus. The other, termed the **ventral cochlear nucleus**, is placed on the antero-lateral aspect of this peduncle in the interval between the dorsal part of the cochlear nerve and the vestibular nerve, after they have separated from each other. The fibres of the cochlear nerve enter these two nuclei and end around

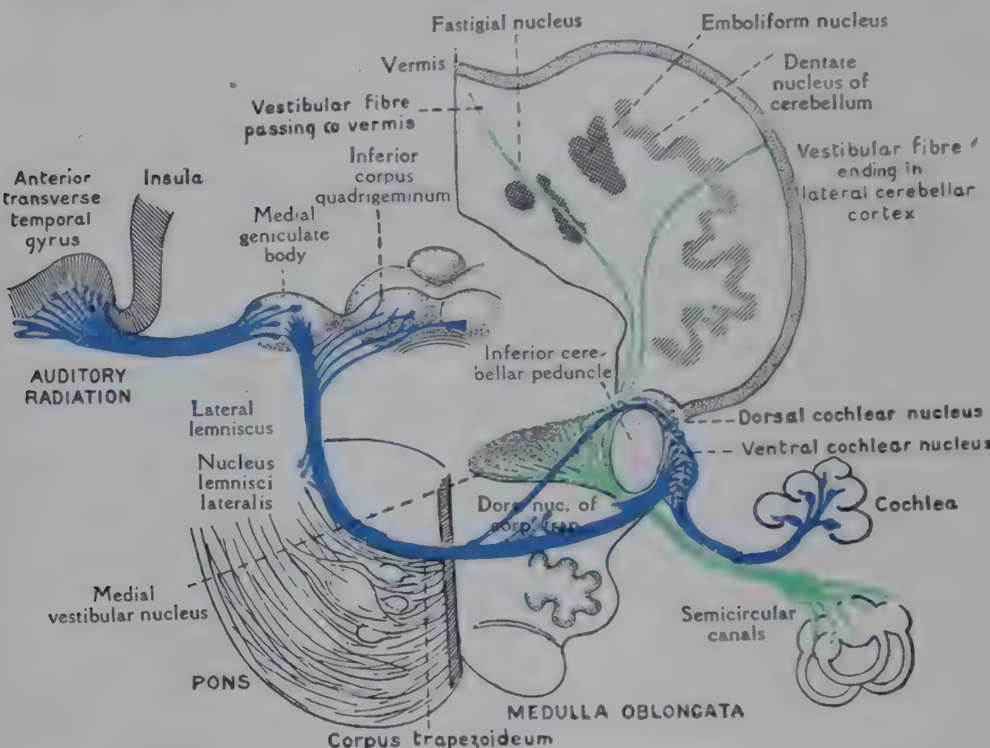


FIG. 821.—CENTRAL CONNEXIONS OF COCHLEAR AND VESTIBULAR NERVES.
Vestibular fibres, *green*. Cochlear fibres, *blue*.

the cells in arborizations which are characterized by their fineness and their intricate arrangement.

The **vestibular nerve** enters the brain at a slightly higher level than the cochlear nerve. It proceeds backwards through the pons between the inferior cerebellar peduncle, which lies on its lateral side, and the spinal tract of the trigeminal nerve, which is placed on its medial side. Its fibres end in a series of terminal nuclei—medial, lateral, superior, and inferior—and in the cerebellar cortex.

The **medial nucleus** (Figs. 781, p. 898; and 821) is the principal one. It is a large diffuse nuclear mass which lies in the floor of the fourth ventricle subjacent to the vestibular area (Fig. 770, p. 886). It is situated, therefore, in both the pons and the medulla oblongata to the lateral side of the foveæ. In transverse section it is prismatic in outline, and its surface is crossed by the striæ medullares.

When the vestibular nerve enters the brain on the medial side of the inferior peduncle, its fibres bifurcate to form ascending and descending branches. The latter pass downwards in separate bundles and form the **descending tract of the vestibular nerve** (Figs. 781, p. 898; 779, p. 895; and 815, p. 928). This proceeds through the lower part of the pons into the medulla oblongata, in which it may be traced as far as the level of the sensory decussation. The **inferior nucleus** is

associated with the descending tract; it is a column of grey matter containing sparsely strewn nerve-cells around which the fibres end in fine arborizations.

Some of the ascending fibres end in the **lateral nucleus.** This nucleus is composed of a number of large and conspicuous multipolar nerve-cells scattered amidst the bundles of the vestibular nerve. As it is traced upwards the nucleus gradually inclines backwards, and finally it occupies a place in the side-wall of the fourth ventricle. It attains its greatest size at the level of the emerging part of the facial nerve, and this upper part is termed the **superior nucleus.** Other ascending fibres pass without interruption into the cerebellum to terminate in

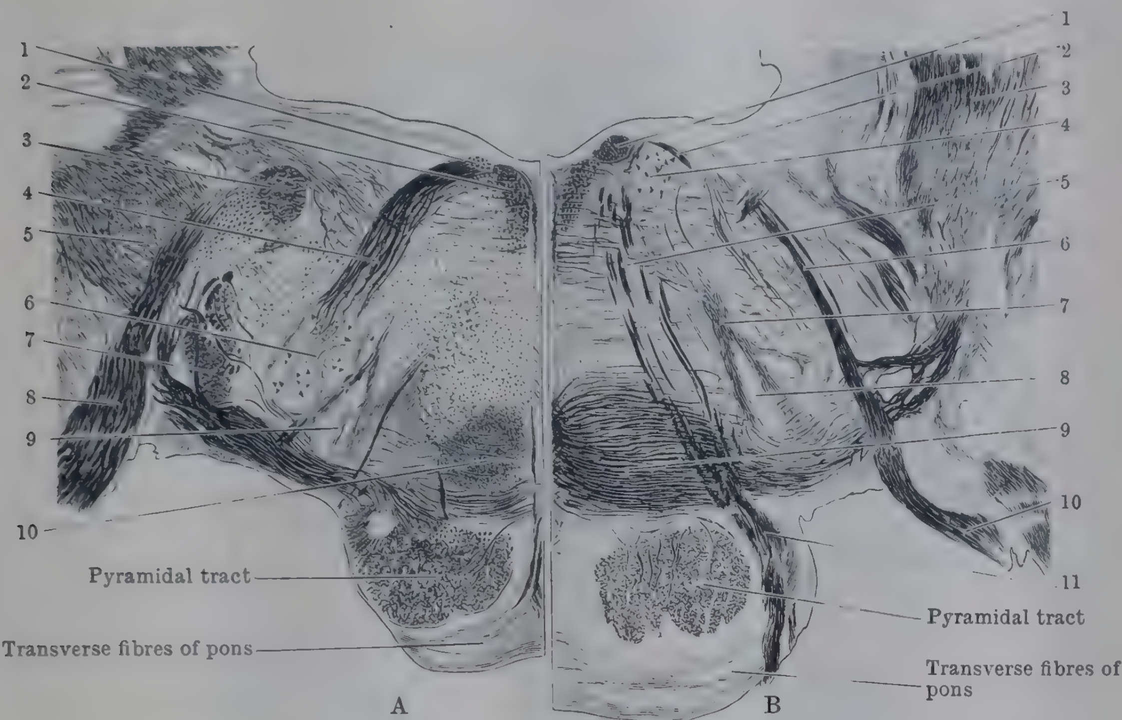


FIG. 822.—TWO SECTIONS THROUGH PONS.

The left side of the drawing is taken from a section at a level slightly inferior to the section from which the right side is taken.

A

1. Ascending part of facial nerve.
2. Medial longitudinal bundle.
3. Descending tract of vestibular nerve.
4. Radicular fibres of facial nerve.
5. Inferior cerebellar peduncle.
6. Facial nucleus.
7. Spinal tract of trigeminal nerve.
8. Vestibular nerve.
9. Dorsal nucleus of corpus trapezoideum.
10. Medial lemniscus.

B

1. Ascending part of facial nerve.
2. Emergent part of facial nerve.
3. Inferior cerebellar peduncle.
4. Nucleus of abducent nerve.
5. Abducent nerve.
6. Emergent part of facial nerve.
7. Peduncle of dorsal nucleus of corpus trapezoideum.
8. Dorsal nucleus of corpus trapezoideum.
9. Corpus trapezoideum.
10. Facial nerve.
11. Abducent nerve.

the cortex of the anterior and posterior lobes. In their course many of these fibres pass through the nucleus fastigii, and many writers describe them as terminating in this nucleus; but, according to Ramón y Cajal, they merely traverse it on their way to the cerebellar cortex.

From the lateral nucleus a strand of fibres passes medially to reach the medial longitudinal bundle, of which it forms one of the most important constituents. Some of these fibres pass upwards to the nuclei of the oculomotor, trochlear, and abducent nerves and form the basis for reflex movements of the eye which are produced by vestibular stimuli; others downwards, probably to the nucleus of the accessory nerve, which is concerned in regulating the movements of the head. Other fibres arise from the lateral nucleus and pass directly to the spinal cord without passing through the medial longitudinal bundle; they form the **vestibulo-spinal tract**, which passes downwards in the anterior white column and distributes fibres to the various motor nuclei in the anterior grey column of the spinal cord (Fig. 755, p. 868).

The **superior nucleus** also emits a group of fibres which pass directly to the mid-brain, chiefly to the oculomotor and trochlear nuclei.

Central Connexions of the Cochlear Nerve.—The cochlear nuclei are brought into connexion with the inferior corpus quadrigeminum and the medial geniculate body of the opposite side by the fibres of the corpus trapezoideum and the lateral lemniscus.

The fibres of the cochlear nerve end in the cochlear nuclei. From the cells of these nuclei two tracts arise, viz., a **ventral tract**, the fibres of which form the corpus trapezoideum, and a **dorsal tract** which lies near the floor of the fourth ventricle.

The **corpus trapezoideum** (Figs. 781 and 817) is formed of the axons of the cells of the ventral cochlear nucleus, as well as the axons of certain of the cells of the dorsal nucleus. In the midst of the corpus trapezoideum are lodged large cells which are known

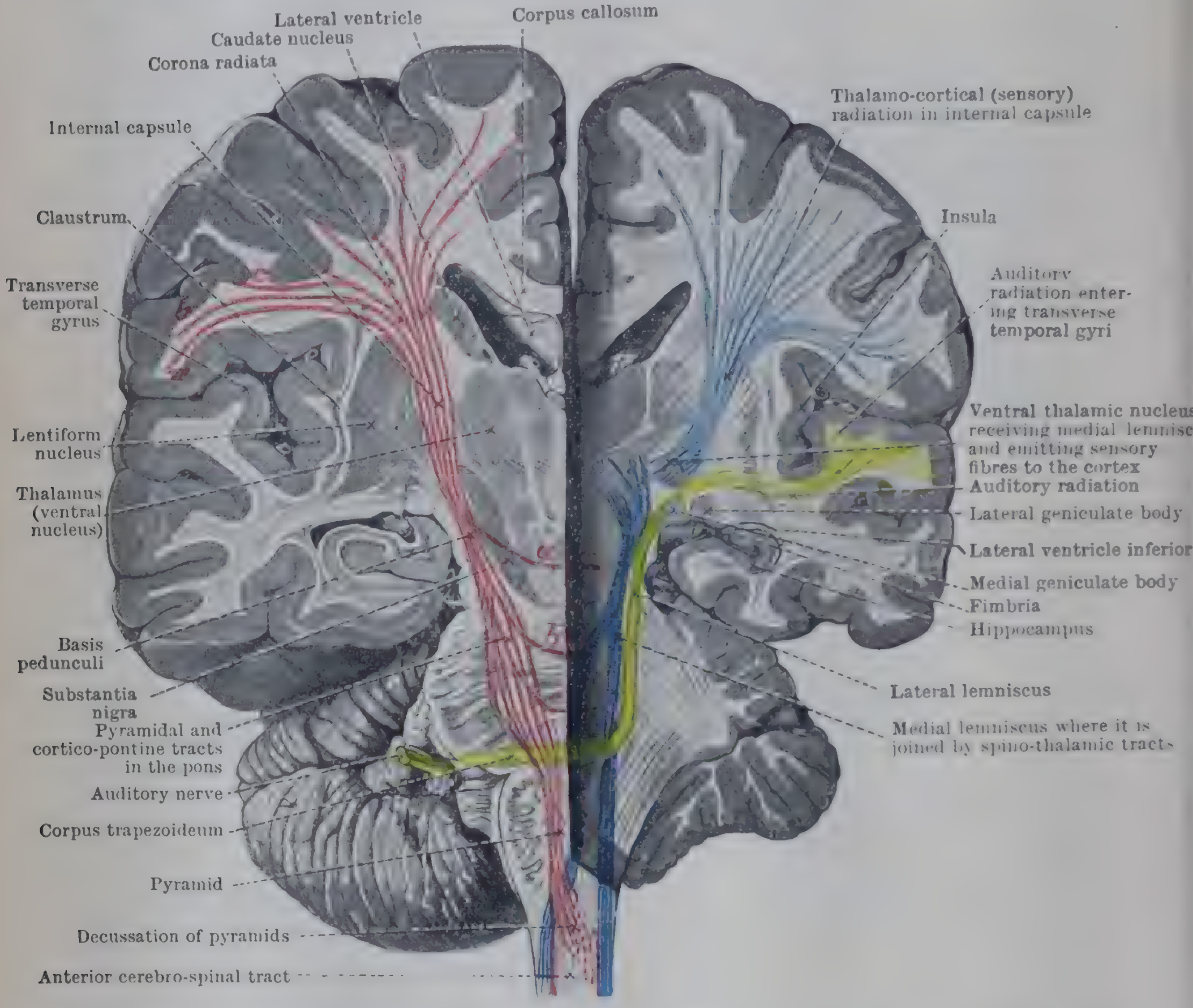


FIG. 823.—CORONAL SECTIONS OF BRAIN TO SHOW THE WHOLE OF THE CENTRAL AUDITORY PATH.
The left half of the brain (right side of the figure) is cut on a plane posterior to that of the right. Motor fibres, *red* (*a*, *b*, *c*, cortico-nuclear fibres). Sensory fibres, *blue*. Auditory fibres, *yellow*.

as the *ventral nucleus of the corpus trapezoideum*, and these give off axons which join the strand with which they are associated. Many of the fibres of the corpus trapezoideum end in a small mass of grey matter called the **dorsal nucleus of the corpus trapezoideum** which is placed immediately behind the trapezoid body. Most of the trapezial fibres cross the median plane and decussate with the corresponding fibres of the opposite side. Reaching the opposite dorsal trapezoid nucleus, more fibres leave the trapezoid body, and almost immediately after that the strand bends upwards and forms the **lateral lemniscus** (Figs. 784, p. 901; 785, p. 902). But still another nucleus is interposed in its path, viz., the **nucleus of the lateral lemniscus**. There some fibres are dropped, whilst from the nuclear cells others are acquired, and the lateral lemniscus then proceeds upwards until it reaches the inferior corpus quadrigeminum and the medial geniculate body, in which its fibres end.

The connexion between the cochlear nuclei and the inferior quadrigeminal body is not altogether with that of the opposite side, as the foregoing description and the diagram (Fig. 821) would lead one to infer. Some fibres pass directly to the inferior

corpus quadrigeminum of the same side, and some also reach the corresponding medial geniculate body.

From the medial geniculate body there proceeds a tract to an area of cerebral cortex in the upper surface of the temporal lobe (within the lips of the lateral sulcus of the cerebral hemisphere) which is marked by small convolutions called the transverse temporal gyri. The whole nervous apparatus of hearing is thus linked on to the cerebral cortex, and the successive neurons which build up the entire chain are therefore: (1) in the cochlea of the internal ear the bipolar cells of the spiral ganglion emit axons that terminate in the brain; (2) from the nerve-cells of the cochlear nuclei fibres arise and for the most part cross to the lateral lemniscus of the opposite side, proceeding to (3) the medial geniculate body, from which fibres pass to the cerebral cortex.

All the axons of the cells of the dorsal trapezoid nucleus do not join the trapezoid strand. Many pass backwards in a group called the **pedicle of the dorsal trapezoid nucleus** to end in the nucleus of the abducent nerve (Fig. 816, p. 930), and, through the medial longitudinal bundle, in the nuclei of the trochlear and oculomotor nerves. In this way the organ of hearing is brought into connexion with the nuclei through which the movements of the eye are controlled.

PROSENCEPHALON OR FORE-BRAIN

The fore-brain vesicle in the embryo is subdivided, more or less arbitrarily, into two parts—an anterior termed the **telencephalon**, and a posterior called the **diencephalon**, which forms the greater part of the walls of the third ventricle. The extreme anterior part of the third ventricle belongs to the telencephalon; it includes the layer of grey matter, known as the **lamina terminalis**, which forms the anterior extremity of the primitive neural tube (Fig. 829).

Development of Parts derived from Fore-Brain

The lateral wall of the telencephalon grows out on each side to form a diverticulum which ultimately constitutes the cerebral hemisphere, and thus, from a very early period, the primitive position of that part of the side-wall is indicated by the interventricular foramen—an aperture of communication between the cavity of the cerebral hemisphere and the third ventricle (Fig. 836).

The lateral wall of the diencephalon undergoes a thickening, the main part of which forms the thalamus. It arises as a large oval swelling which gradually approaches its fellow of the opposite side, and thus diminishes the width of the third ventricle. Finally, the two bodies sometimes come into contact in the median plane and cohere over an area corresponding to the interthalamic connexus. This may occur about the end of the second month.

On the posterior part of the thalamic thickening there appear on the surface two small elevations—the lateral and medial geniculate bodies. With the expansion of the thalamus as a whole these bodies become pushed farther back. It thus comes about that in the adult brain the medial geniculate body seems to hold a position on the lateral aspect of the mid-brain, whilst the lateral geniculate body, viewed from the surface, appears on the lower surface of the posterior pole of the main part of the thalamus.

Above the thalamus, a smaller thickening of the lateral wall of the diencephalon appears close to the roof of the third ventricle. This is the epithalamus. From it are developed the pineal body, its peduncle, and the habenular region. These parts are relatively much more evident in the embryonic brain than in the adult. The pineal body appears to be developed as a diverticulum of the posterior part of the roof of the diencephalon, but in reality it is a derivative of the alar lamina. Viewed from the dorsal aspect of the brain-tube, this diverticulum shows, in the first instance, as a rounded elevation, from each side of which a broad ridge runs forwards. The ridge becomes the stria habenularis, whilst in the region of its junction with the pineal elevation the trigonum habenulæ takes shape. The pineal diverticulum ultimately becomes solid, but a small portion of the original cavity is retained as the pineal recess of the third ventricle.

The floor of the diencephalon contributes to the formation of the hypothalamus. This is separated from the thalamic swelling by a sulcus—the hypothalamic sulcus—which is still to be recognized in the adult brain. The hypothalamus shows several elevations from which are derived the mamillary bodies, the tuber cinereum, and the cerebral part of the hypophysis. In front of the tuber cinereum are seen the optic chiasma and the optic recess. The anterior wall of the recess is formed by the lamina terminalis. The mamillary body forms, in the first instance, a relatively large ventral bulging of the floor of the brain-tube. As development goes on, this bulging becomes relatively small, and about the fourth month the single projection

becomes divided into a pair of tubercles. The infundibulum and the posterior or cerebral lobe of the hypophysis are developed as a hollow downgrowth of the floor of the third ventricle (Fig. 836). A portion of the original cavity is retained in the upper part of the infundibulum, and constitutes the infundibular recess in the floor of the third ventricle.

The **optic nerve** is formed by the growth of fibres backwards from the retina in the wall of the original optic stalk, whilst the chiasma takes form by the passage of fibres across the median plane in front of the infundibulum and behind the optic recess. These fibres are derived from the optic nerve. The optic recess of the third ventricle marks the spot where the optic vesicle was originally attached to the inferior and lateral part of the fore-brain, and in the adult it therefore represents a portion of the primitive cavity of the tubular stalk of the optic vesicle. In the course of development the optic nerve-fibres, which appear in the stalk of the optic vesicle to form the optic nerve, seek an attachment much farther back, and through the optic tract they are even carried as far as the mid-brain.

The **roof of the fore-brain** remains thin, and does not proceed to the development of nervous elements, although its posterior part becomes invaded by nervous tissue to form the pineal body and the posterior commissure. In front of these structures the roof of the fore-brain remains ependymal and constitutes the roof of the third ventricle. Along each side of the median plane it becomes invaginated into the third ventricle to form the choroid plexus (Figs. 829, 838). The posterior commissure appears as a transverse thickening at the bottom of the groove which lies in the roof of the early brain-tube below the pineal diverticulum.

Parts derived from Diencephalon

Under this heading we have to consider: (1) the **thalamus**; (2) the **epithalamus**, which comprises the pineal body and the habenular region; and (3) the **hypothalamus.**

Thalamus.—The thalamus is the principal structure in this section of the brain

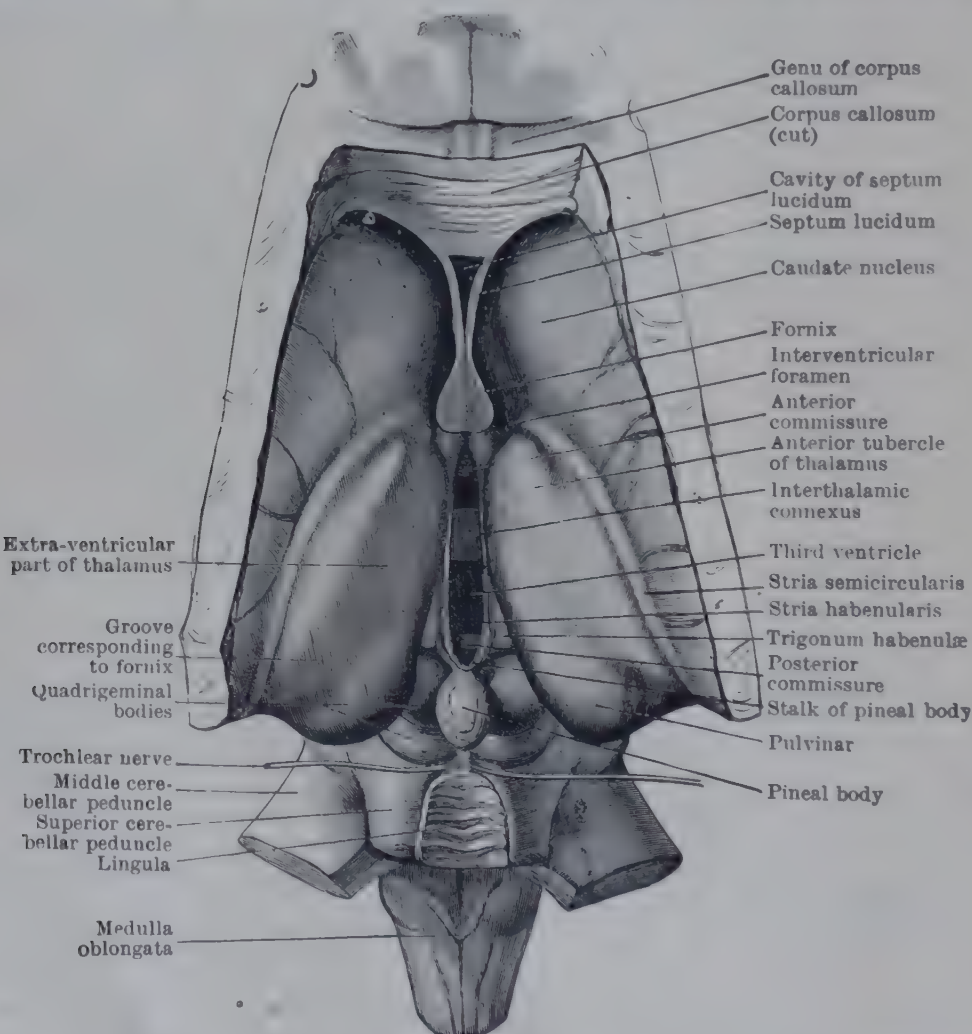


Fig. 824.—Thalami and the Parts of the Brain around them.

(Fig. 824). It is a large, ovoid mass of grey matter which lies obliquely across the path of the cerebral peduncle (Fig. 826). The anterior end of the thalamus lies close to the median plane, and is separated from the corresponding part of the

opposite side by a very narrow interval. The posterior ends of the thalami are larger, and they are farther apart, being separated by a fairly wide interval in which the corpora quadrigemina are seen.

The two thalami, in their anterior two-thirds, lie close together, one on each side of the deep, median cleft called the third ventricle of the brain. The inferior and lateral surfaces are in apposition with, and indeed, directly connected with, adjacent parts of the brain, and on that account it is customary to study them by means of sections through the brain. The superior and medial surfaces face towards ventricular cavities and are mainly free.

The *lateral surface* of the thalamus is applied to a thick layer of white matter, interposed between it and the lentiform nucleus, called the **internal capsule** and composed mainly of fibres passing to and from the cerebral cortex ; a large proportion of these fibres descend to form the basis pedunculi. From the entire extent of the lateral surface of the thalamus large numbers of fibres stream out and enter the internal capsule, to reach the cerebral cortex. They constitute what are termed the **thalamic radiations**. As the fibres leave the thalamus over the whole of its lateral surface they form a very distinct reticulated stratum which is termed the **external medullary lamina.**

The *inferior surface* of the thalamus rests on the hypothalamus. From the latter region many fibres enter the most medial part of the thalamus on its inferior surface, whilst other fibres leave this surface of the thalamus and sweep laterally to take part in the thalamic radiations.

The *superior surface* of the thalamus is free. Laterally it is bounded by a groove which runs antero-posteriorly along the floor of the lateral ventricle of the brain and intervenes between the thalamus and the caudate nucleus. In this groove is placed a slender band of longitudinal fibres termed the **stria semicircularis**, and also the thalamo-striate vein. Medially, the superior surface is separated from the medial surface in its anterior half by a sharp ledge of the ependyma of the third ventricle raised up by a subjacent longitudinal strand of fibres called the **stria habenularis.** When these two structures—the ependymal ridge and the subjacent stria—are traced backwards, they are seen to turn medially and become continuous with the stalk of the pineal body. Behind the portion of the stria which turns medially towards the pineal body a small depressed triangular area situated in front of the superior corpus quadrigeminum—the **trigonum habenulæ**—forms a very definite medial boundary for the posterior part of the superior surface of the thalamus.

The superior surface of the thalamus is slightly convex, and it is of a whitish colour, owing to the presence of a thin superficial covering of nerve-fibres termed the **stratum zonale**. It is divided into two areas by a faint oblique groove which is an impression caused by the edge of the fornix. The two areas which are thus mapped out are very differently related to the ventricles of the brain, and also to the parts which lie above the thalamus. The *lateral area*, which includes the anterior end of the thalamus, forms a part of the floor of the lateral ventricle ; it is covered with ependyma and is overlapped by the choroid plexus of this ventricle. Along the line of the groove the ependymal lining of the lateral ventricle is reflected over the choroid plexus. The *medial area*, which includes the posterior end of the thalamus, intervenes between the lateral and third ventricles of the brain, and takes no part in the formation of the walls of either. It is covered by a fold of pia mater, termed the tela chorioidea of the third ventricle, above which is the fornix, and these two structures intervene between the thalamus and the corpus callosum (Fig. 829, and Fig. 855, p. 971).

The *anterior end* of the thalamus bulges up into the lateral ventricle, forming an elevation which is called the **anterior tubercle of the thalamus**, and it is separated from the anterior column of the fornix by the interventricular foramen. The ependymal roof of the passage between the two interventricular foramina is, on each side, continuous with an ependymal strip that extends along the upper limit of the medial wall of the thalamus behind the foramen. These ependymal strips in the medial wall of the lateral ventricle and in the roof of the third ventricle between them are invaginated by the vascular pia to form a continuous sulcus in

the ependymal area of the brain-wall called the **choroid fissure.** The vascular pia mater covered by the ependymal brain-wall is called the **choroid plexus** (Figs. 829, 837, and 838).

The *posterior end* of the thalamus is very prominent and forms a rather sharp, rounded projection which overhangs the brachia of the corpora quadrigemina. This prominence is called the **pulvinar**. On the lateral part of the lower surface of the pulvinar there is a small bulging called the **lateral geniculate body**; most of the fibres of the optic tract end in it.

The *medial surfaces* of the anterior parts of the two thalami are placed close together, and are covered by the lining ependyma of the third ventricle. A band of grey matter, termed the **interthalamic connexus**, crosses the third ventricle and joins the two thalami together.

Intrinsic Structure and Connexions of Thalamus.—In its early development the thalamus consists of a relatively homogeneous mass of cells in the wall of the third ventricle. It then undergoes a rapid differentiation and becomes divided into a number of separate nuclear elements which are to be distinguished not only by their topographical position but also by their fibre-connexions and the arrangement and appearance of their cells. Some of these thalamic nuclei can be readily defined on macroscopic inspection of unstained sections cut through the thalamus, for they consist of circumscribed areas of grey matter outlined by thin medullary laminæ of white matter (Fig. 826). They are as follows: ventral nucleus, lateral nucleus, the pulvinar, anterior nucleus, medial nucleus, centre-median nucleus, and the lateral and medial geniculate bodies. (Le Gros Clark, 1936; Walker, 1938.)

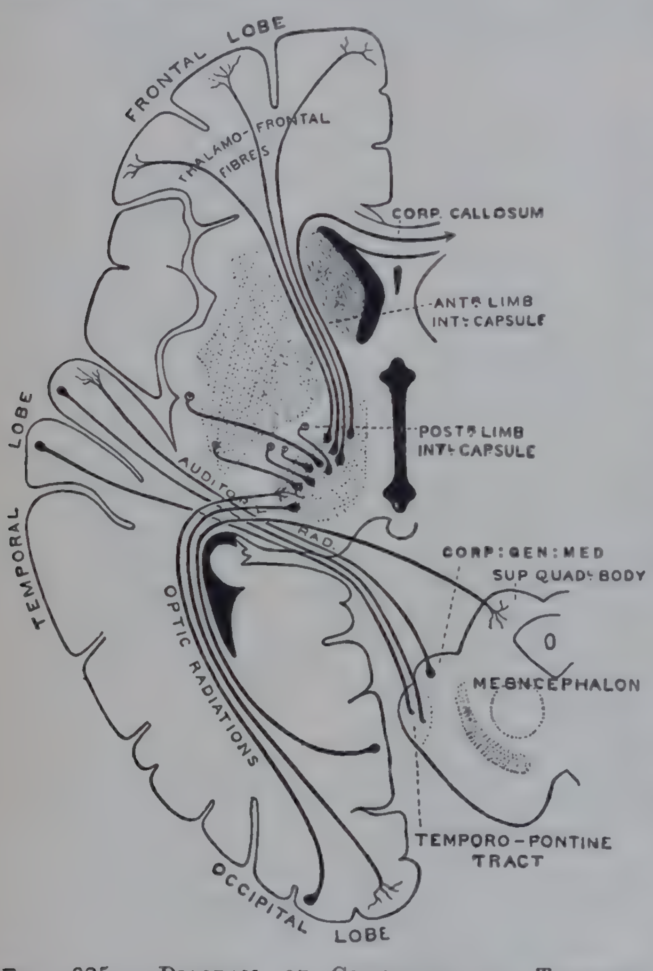


Fig. 825.—Diagram of Connexions of Thalamus with Cerebral Cortex, and of Cortex with Mid-Brain.

The **ventral nucleus** of the thalamus is very indistinctly demarcated from the lateral nucleus. Indeed, the two elements are commonly included under the common term *ventro-lateral nucleus.* The ventral nucleus, however, is distinguished by the fact that it is the terminal station of two systems of fibres which reach it from lower levels of the central nervous system, the lemniscus-system and dentato-thalamic fibres from the cerebellum. The posterior part of the ventral nucleus receives the lemniscus-fibres, and these consist of the medial lemniscus, the spino-thalamic tracts ("spinal lemniscus"), and the secondary trigeminal fibres ("trigeminal lemniscus"). It is therefore a terminal centre for proprioceptive and exteroceptive sensory impulses derived from all parts of the body, and it may appropriately be termed the "lemniscus-nucleus". From its cells a mass of thalamo-cortical fibres takes origin through which these sensory impulses are relayed on to the sensory area of the cerebral cortex, which lies behind the central sulcus. It may be noted that the different regions of the body acquire quite a definite topographical representation within the "lemniscus-nucleus", for sensory impulses from the lower limb terminate in its most lateral part, those from the upper limb in an intermediate position, and those from the head and face region in the most medial portion. Consequently, it is possible for

a small localized pathological lesion in the thalamus to give rise to sensory disturbances in one part of the body only.

The anterior part of the ventral nucleus receives terminal fibres from the dentate nucleus of the cerebellum, and projects on to the motor area of the cerebral cortex in front of the central sulcus. It is therefore a relay centre through which the motor area is brought into functional relation with the opposite half of the cerebellum.

In lower mammals it has been found by experiment that the extreme anterior end of the ventral nucleus appears to receive neither fibres of the lemniscus nor dentato-thalamic fibres, and its connexions remain obscure.

The **lateral nucleus** extends along the upper and lateral part of the thalamus, reaching to the ventricular surface. So far as is known, it receives no fibres from the lower levels of the brain and its afferent connexions are probably derived entirely from other nuclear elements of the thalamus. Its efferent connexions are almost entirely with the parietal lobe of the cerebral hemisphere behind the sensory area of the cortex, but its anterior part probably sends fibres to the cortex of the frontal lobe in front of the motor area. In other words, it is connected with the so-called "association areas" of the cerebral cortex.

The **pulvinar** is really a posterior extension of the lateral nucleus. Superficially it is conspicuous because it forms the prominent posterior pole of the thalamus which projects back in close relation to the superior corpus quadrigeminum of the mid-brain. Its afferent connexions are not known, but it projects on to those areas of the cortex which extend in front of the visual area.

The **anterior nucleus** can be located in the intact thalamus because it is responsible for raising up on the anterior part of its upper surface a small oval eminence—the anterior tubercle—which lies in the floor of the body of the lateral ventricle (Fig. 826). It is a very well-defined element in the human brain. Entering it from below is a sharply circumscribed tract of white fibres——the *mamillo-thalamic tract*—which arises in the mamillary body. Its cells give origin to thalamo-cortical fibres which are distributed to the whole length of the gyrus cinguli of the cerebral hemisphere. The functional significance of the anterior nucleus is still quite obscure, for nothing is yet known of the nature of the impulses conveyed by the mamillo-thalamic tract.

The **medial nucleus**, as seen in transverse section, is a rounded mass of grey matter lying at the upper surface of the thalamus close to the median plane (Fig. 826). Because of its dark colour, which is due to the relative absence of medullated nerve-fibres in its substance, it is a particularly well-defined element. The efferent connexions of the medial nucleus are entirely with the frontal areas of the cerebral cortex, which lie anterior to the motor and premotor areas, and it receives afferent fibres from the hypothalamus which ascend close to the side-wall of the third ventricle. It has been suggested, therefore, that the medial nucleus is essentially a relay mechanism through which the more primitive activities of the hypothalamus are brought into relation with the higher functional levels of the cerebral cortex.

The **centre-median nucleus** is found in the posterior part of the thalamus, lying between the medial nucleus above and the ventral nucleus below. It stands in marked contrast with the other main nuclei of the thalamus in that it has no connexions at all with the cerebral cortex. It is commonly regarded as an integrating mechanism through which other thalamic nuclei are interrelated, but there is no certain knowledge regarding its connexions.

The **geniculate bodies** are developmentally a part of the thalamus, and make their appearance as a differentiated portion of the mass of cells which contribute to the formation of the ventral nucleus. The **lateral geniculate body** is composed in the central region of its posterior two-thirds of a series of six grey laminæ separated by intervening laminæ of white matter. In suitably stained sections the grey laminæ can be seen to be made up of closely packed cells which receive the termination of the optic tract fibres. The latter enter the geniculate body mainly from in front and below, and spread out fanwise to reach the various grey laminæ.

The white laminæ are composed predominantly of axons of the cells of the grey laminæ. These collect together to form the optic radiation through which retinal impulses are ultimately projected on to the visual area of the occipital cortex. The more detailed connexions of the lateral geniculate body will be studied with the optic tract.

The **medial geniculate body** possesses none of the elaborate structure of the lateral geniculate body, for it is composed of an almost homogeneous mass of medium-sized cells. It receives auditory impulses (mainly, but not entirely, from the opposite side) which are conveyed to it by the lateral lemniscus, and its efferent connexions are entirely with the auditory area of the temporal cortex.

It will be observed that, with the exception of the centre-median nucleus, which has no cortical connexions, the greater part of the thalamus can simply be regarded as a nuclear mass interposed between various sensory tracts and the cerebral cortex. In other words, it is a relay station for the projection of these sensory impulses on to the cerebral cortex. It is of some importance to note also that the various cortical areas concerned are also related to the corresponding thalamic nuclei by descending cortico-thalamic fibres. At one time these were believed to provide an inhibitory mechanism whereby the activities of the thalamic centres are "damped down". However, it has been demonstrated by electro-physiological methods that the impulses which they convey actually increase these activities. It is probable that, through the cortico-thalamic fibres, the cerebral cortex is enabled to raise the sensitivity of the thalamic nuclei to afferent impulses reaching it by ascending sensory tracts. Thus the fibres may be regarded as forming part of a mechanism of sensory attention.

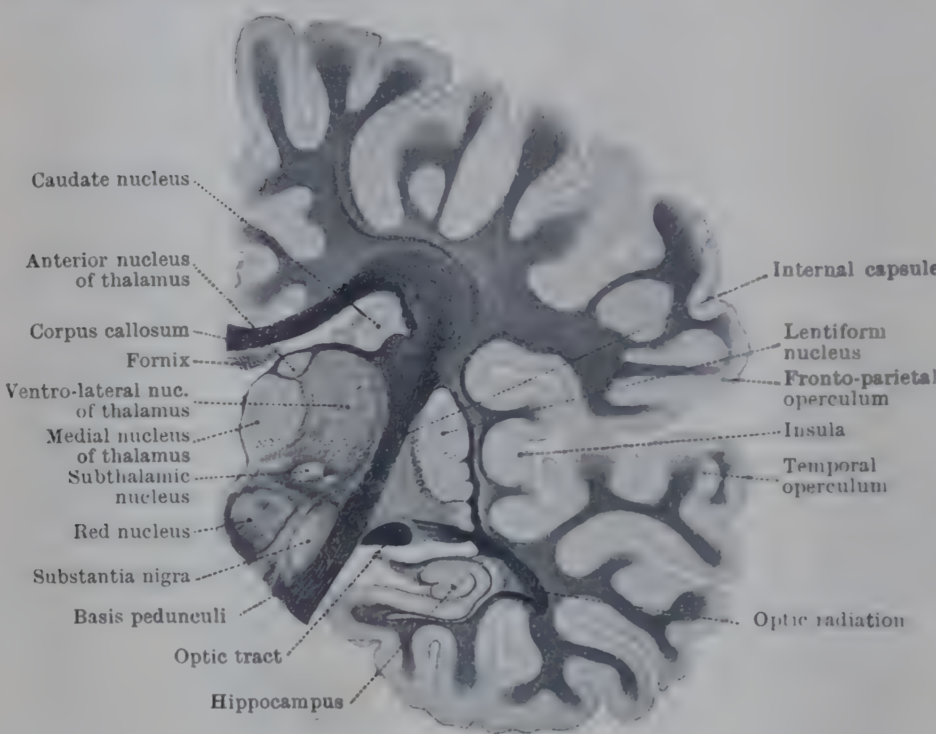


FIG. 826.—FRONTAL SECTION THROUGH CEREBRUM.

Subthalamic Region.—The tegmentum of the mid-brain is prolonged upwards and assumes a position below the posterior part of the thalamus. Here it becomes continuous with a region of the diencephalon which is called the *subthalamus.* This occupies a topographical position between the thalamus above and the cerebral peduncle below, while medially it is bounded by the hypothalamus. Broadly speaking, the subthalamus may be regarded as a structural and functional link between the basal nuclei of the forebrain and the tegmental region of the mid-brain. The **red nucleus** is a conspicuous object in sections through the upper extremity of the tegmentum (Fig. 826) and, gradually diminishing, it disappears before the level of the mamillary body is reached. Carried up around it are the same longitudinal tracts of fibres which have been studied already in relation to it in the mid-brain. Certain of these fibres, placed in immediate relation to the red nucleus, form a *capsule* for it. This capsule is partly derived from those fibres of the superior cerebellar peduncle which pass directly up into the thalamus and also partly from fibres which issue from the nucleus itself. The **medial lemniscus** takes up a position lateral to the red

PLATE LXXIII

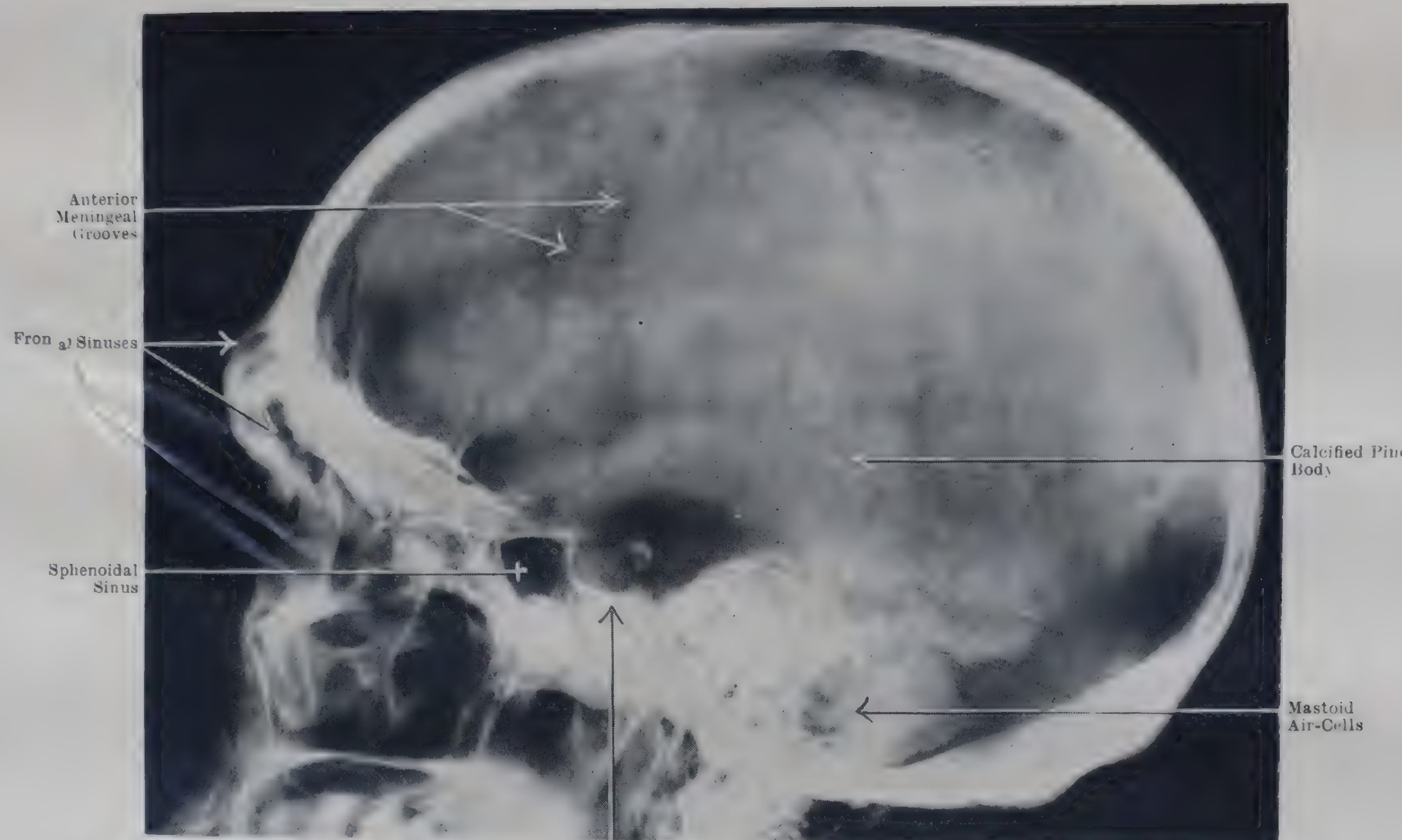


PLATE LXXIII.—LATERAL RADIOGRAPH OF HEAD OF MAN AGED 63, SHOWING HYPOPHYSIAL FOSSA AND CALCIFIED PINEAL BODY.

PLATE LXXIV

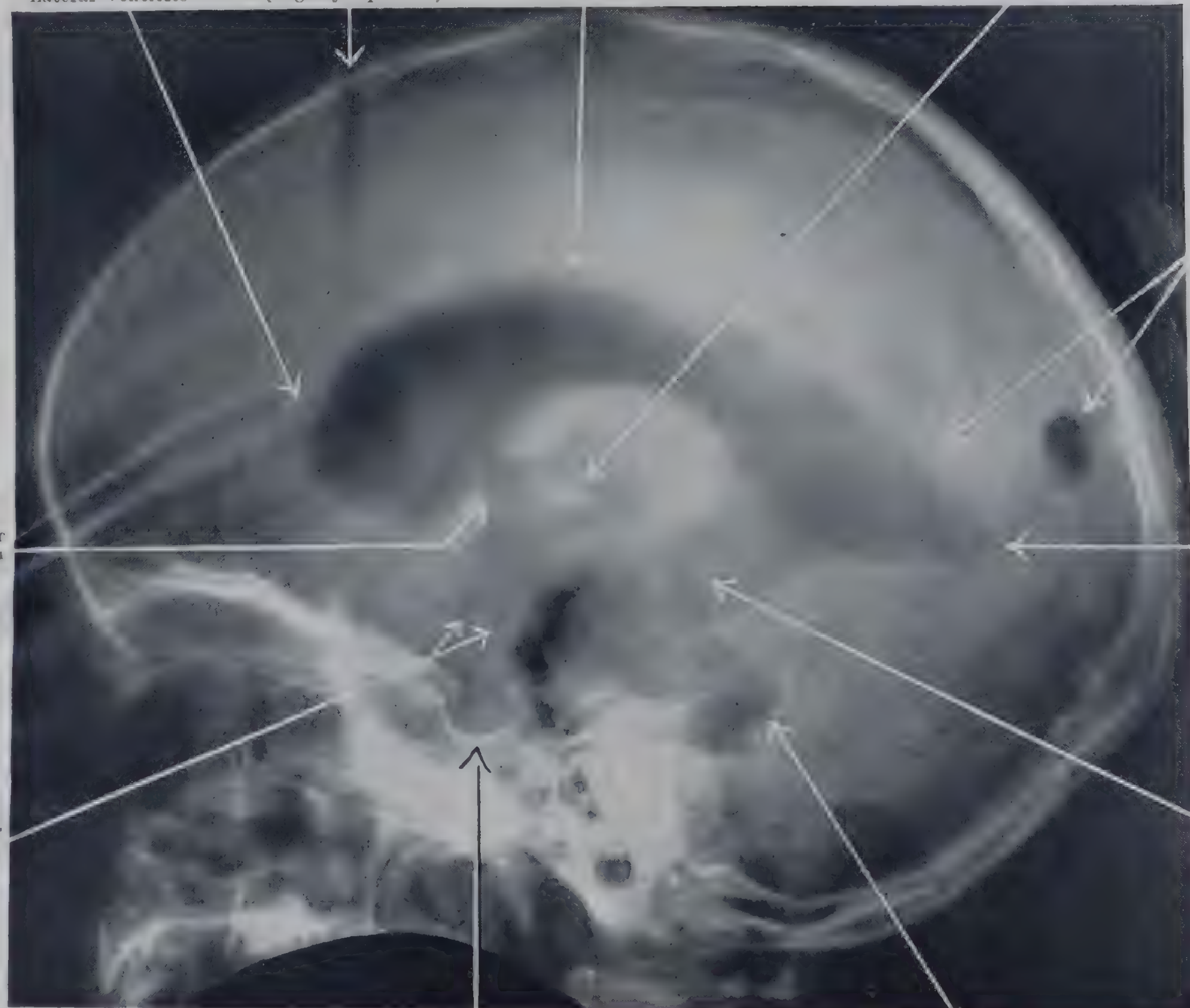


PLATE LXXIV.—LATERAL RADIOGRAPH OF LIVING HEAD OF CHILD AGED 4, AFTER DIRECT INJECTION OF OXYGEN INTO THE LATERAL VENTRICLES (Ventriculograph: Professor Norman M. Dott).

The oxygen-filled Ventricular System appears in the radiograph, like the air-filled sinuses, on account of its relative translucency to the X-Rays. The darker area is due to the overlap of the anterior horns of the two Lateral Ventricles; in this child the whole ventricular system was slightly distended, but the general form is well shown; compare with Plate LXXV, p. 960, for

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nucleus on a posterior plane. When the red nucleus comes to an end, these various fibres are continued onwards and form, in the position previously occupied by the nucleus, a very evident and dense mass of fibres. The fibres of the medial lemniscus and the superior cerebellar peduncle are prolonged upwards into the ventral part of the thalamus, where they end in connexion with the cells of the ventral nucleus.

The **substantia nigra** also is carried into the subthalamic region, where it maintains its original position dorsal to the basis pedunculi. As it is traced upwards, it is seen to diminish gradually in amount. It shrinks from the medial to the lateral side, and finally disappears when the level of the posterior part of the mamillary body is reached.

In coronal sections through the subthalamic region, the most conspicuous

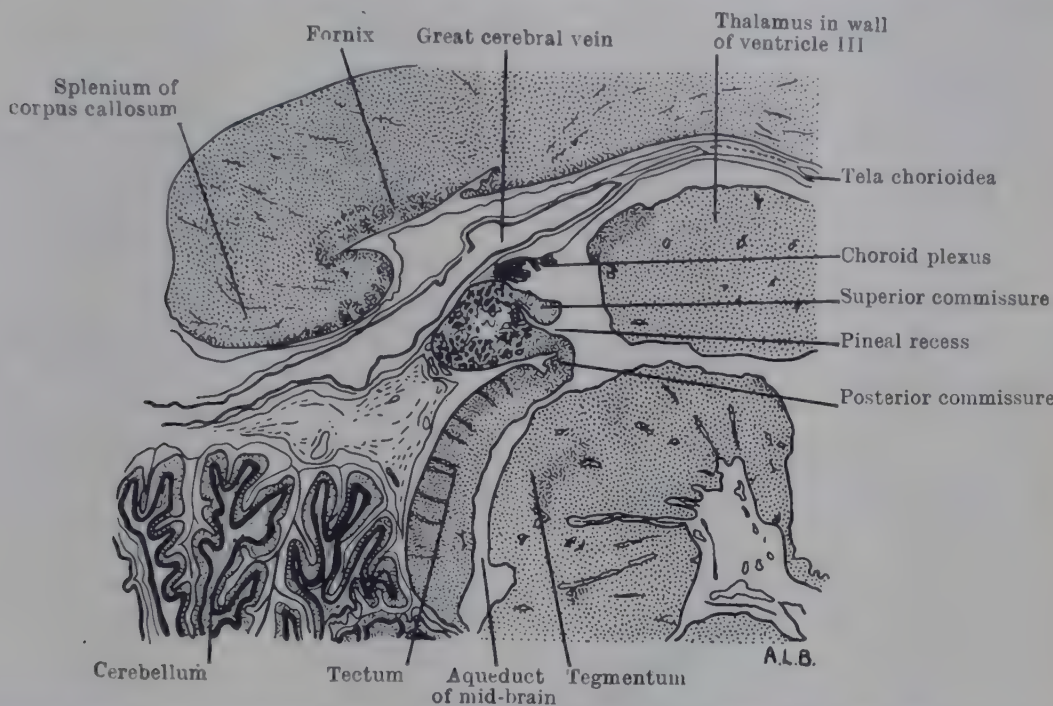

FIG. 827.—MEDIAN SECTION THROUGH THE PINEAL REGION OF A HUMAN BRAIN SHOWING THE RELATIONS OF THE PINEAL BODY. (After Gladstone & Wakeley, 1940.)

object which comes into view is the **subthalamic nucleus** (Fig. 826). It is a small brownish mass of grey matter, shaped like a biconvex lens, which makes its appearance behind the basis pedunculi immediately to the lateral side of the substantia nigra, and, enlarging rapidly in a medial direction, it takes the place of the diminishing substantia nigra. The subthalamic nucleus is made all the more evident by the fact that it is sharply defined by a thin capsule of white fibres. On its medial side these fibres proceed medially and form a very evident decussation across the median plane in the floor of the third ventricle, immediately above the posterior ends of the mamillary bodies. It receives fibres from the globus pallidus of the corpus striatum and emits fibres to the substantia nigra and the tegmentum.

Epithalamic Region.—In the roof of the third ventricle and at its attached margin are certain elements of the diencephalon which collectively form the *epithalamus*. These elements include the pineal body, the habenular commissure, the stria habenularis, and the trigonum habenulæ.

Pineal Body.—This is a small, reddish-brown, conical structure about 7-8 mm. in length with a blunted apex. Its base is attached by a pedicle or stalk to the posterior end of the roof of the third ventricle, and it lies in the groove between the two superior corpora quadrigemina and under cover of the splenium of the corpus callosum (Fig. 827). The stalk of the pineal body is hollowed out by a small recess from the cavity of the third ventricle. Superiorly, the stalk divides and each half curves forwards lateral to the median plane and appears to become continuous with the stria habenularis. Inferiorly, it becomes continuous with the posterior commissure (Fig. 714, p. 828).

The pineal body is composed mainly of a peculiar type of neuroglial tissue, the cells of which have an intimate relation to the capillaries of the vascular plexus which pervades it. These cells are characterized by long processes which extend for some distance in the connective tissue which surrounds the lobules into which the body is subdivided. Their function is not yet determined. It contains also a plexus of nerve-fibres, but it is probable that most of these accompany the blood-vessels which enter the gland. Other nerve-fibres can be seen to extend from the stria habenularis and the habenular nucleus into the pineal body by way of its stalk. There is some evidence that many of these (if not all) are aberrant fibres of the habenular commissure which enter the base of the gland on one side and leave it on the other. Lastly, a fine bundle of nerve-fibres has been described extending from the tip of the pineal body along the great cerebral vein to the floor of the straight sinus in the tentorium cerebelli. The significance of this fasciculus, which has been termed the *nervus conarii*, is not known. The pineal body commonly contains calcareous concretions (" brain sand ") which are sometimes clearly visible in radiographs (Pls. LXXIII, p. 944 and LXXIV, p. 945).

It is frequently stated that the pineal body is a vestigial structure—the remains of the pineal eye of lower vertebrates. This statement, however, is incorrect, for in lower vertebrates the pineal body may be found in association with a pineal eye. Clinical and experimental evidence has from time to time been advanced, which suggests that the pineal body is one of the endocrine glands and that it is related to the growth of the body and particularly the maturation of sexual characters. This evidence, however, is inconclusive, and the functions of the pineal body remain obscure. (See also p. 827, and the monograph by Gladstone & Wakeley, 1940.)

Trigonum Habenulæ.—The small, triangular, depressed area which receives this name lies immediately in front of the superior corpus quadrigeminum in the interval between the stalk of the pineal body and the posterior end of the thalamus (Fig. 824, p. 940). It marks the position of a small mass of nerve-cells which constitute the **habenular nucleus**. The axons of these cells emerge through the lower surface of the ganglion and form a bundle, called the **fasciculus retroflexus**, which takes a curved course downwards and forwards in the tegmentum of the mid-brain, close to the medial side of the red nucleus, and ends in the **interpeduncular nucleus** (p. 923).

The habenular nucleus is intimately connected also with the striæ habenulares and the dorsal part of the stalk of the pineal body.

As previously stated, the **stria habenularis**—a very evident band of white matter—lies on the thalamus at the junction of its medial and superior surfaces, subjacent to an ependymal ridge. When traced backwards, many of the fibres of the stria are observed to end amongst the cells of the habenular nucleus, whilst others are continued past the nucleus to enter the stalk of the pineal body, and, through it, to reach the habenular nucleus of the opposite side, in connexion with the cells of which they terminate. The stria habenularis, therefore, ends partly in the habenular nucleus of its own side and partly in the corresponding nucleus of the opposite side. The decussation of fibres across the median plane forms the dorsal part of the pineal stalk, and is termed the **habenular commissure**.

When the stria habenularis is traced in the opposite direction, it is noticed to split into dorsal and ventral parts near the anterior column of the fornix. The *dorsal part* arises from cells in the hippocampus: these fibres pass into the fornix and when they reach its anterior column they turn abruptly backwards to enter the stria habenularis. The *ventral part* springs from a collection of cells in the grey matter on the base of the brain close to the optic chiasma. The functional significance of the striæ habenulares is unknown.

Hypothalamus.—The part of the brain which forms the floor of the third ventricle, extending from the optic chiasma in front to the upper border of the pons behind, is called the hypothalamus. (Le Gros Clark, Beattie, Riddoch & Dott, 1938; Fulton, 1940.) It contains various elements of grey matter connected by numerous fibre-tracts with each other and with more distant parts of the brain. Viewed from the basal aspect, several features of the hypothalamus can be distinguished macroscopically. These are the *posterior perforated substance*, the *mamillary bodies*, and the *tuber cinereum*.

Posterior Perforated Substance.—This has already been mentioned on p. 878. It is perforated by a number of small vessels—the postero-medial central arteries—

which are derived from the posterior cerebral arteries close to their origin. It is situated at the posterior end of the hypothalamus and should probably be regarded as a part of it.

Mamillary Bodies.—These are a pair of round, white bodies, each about the size of a pea, which lie side by side in the interpeduncular fossa on the base of the brain, immediately in front of the posterior perforated substance.

Each mamillary body is coated on the outside by white matter derived from the anterior column of the fornix, and it contains, in its interior, a composite grey nucleus with numerous nerve-cells. Several important strands of fibres are connected with the mamillary body: (1) The anterior **column of the fornix** curves downwards in the side-wall of the third ventricle to reach the mamillary body in which its fibres end amidst the cells. (2) A bundle of fibres—the **mamillo-thalamic tract**—takes origin in the substance of each mamillary body and extends upwards into the thalamus to end in fine arborizations around the large cells in its anterior nucleus. (3) Another bundle of fibres—the **mamillo-tegmental tract**—takes form within the mamillary body and extends downwards in the grey matter of the floor of the third ventricle, to reach the tegmentum of the mid-brain. This tract is among the most ancient fibre-systems in the brain. Its functional significance, however, is not known.

Tuber Cinereum and Infundibulum.—The tuber cinereum is a small, slightly prominent field of grey matter which occupies the anterior part of the interpeduncular fossa between the mamillary bodies behind and the optic chiasma in front. From its anterior part the **infundibulum**, or stalk of the hypophysis, projects downwards and forwards to connect the base of the brain with the hypophysis. In its upper part the infundibulum is hollow—a small, funnel-shaped diverticulum of the cavity of the third ventricle being prolonged downwards into it.

Hypophysis Cerebri.—This is a small oval structure, flattened from above downwards and with its long axis directed transversely, which occupies the hypophysial fossa in the floor of the cranium. It has two lobes—a large anterior lobe and a smaller posterior lobe—which are closely applied the one to the other. The infundibulum is attached to the posterior lobe (see also p. 822).

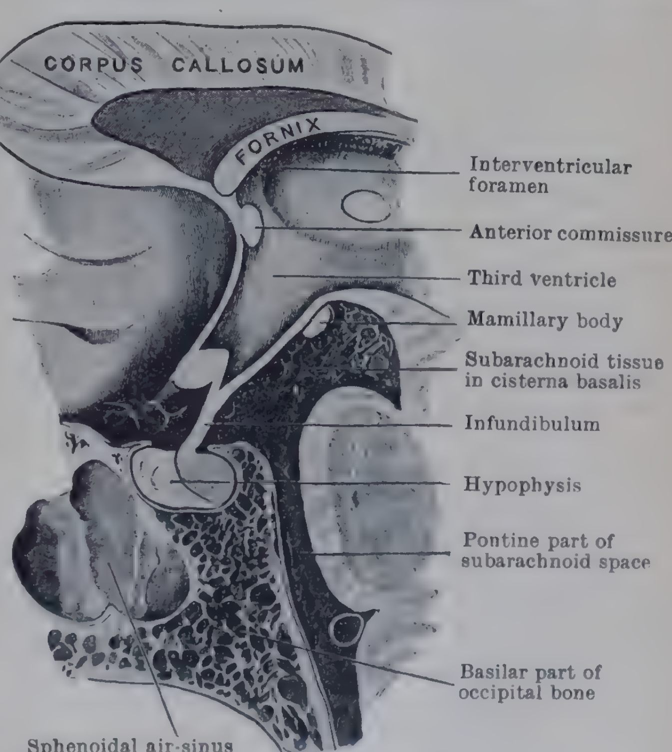

FIG. 828.—MEDIAN SECTION THROUGH THE HYPOPHYSIAL REGION.

The infundibulum and posterior lobe of the hypophysis are developed in the form of a hollow diverticulum which grows downwards from the floor of that part of the embryonic brain which afterwards forms the third ventricle. The original cavity of that diverticulum becomes obliterated, except in the upper part of the infundibulum. In structure, the posterior lobe of the hypophysis is chiefly composed of a peculiar type of neuroglial tissue with characteristic branched cells called "pituicytes". It is vascularized by a fine network of blood-vessels and receives a small but important tract of non-medullated nerve-fibres which has its origin in the hypothalamus. (See the Section on Ductless Glands, p. 824.)

The anterior lobe has quite a different origin—being derived from a tubular diverticulum which grows upwards from the primitive oral cavity. Its connexion with the latter (cranio-pharyngeal canal) is cut off in the course of embryonic development, and the diverticulum becomes encased within the cranial cavity in intimate association with the cerebral portion of the organ. Structurally, it consists of groups and columns of epithelial cells surrounded by capillary vessels.

The hypophysis is intimately connected with the hypothalamus by (1) blood-vessels which extend through the infundibulum and provide a vascular connexion between the sinusoids in the oral portion of the gland and the capillary network in the substance of the hypothalamus (see p. 824), and (2) by nerve-fibres that issue from the hypothalamus and pass into the nervous portion of the hypophysis. In the disease known as acromegaly, the hypophysis is usually greatly enlarged. The proximity of the hypophysis to the optic chiasma accounts for the frequent affection of the visual paths by tumours of the gland.

Intrinsic Structure of Hypothalamus.—Microscopical examination of different parts of the hypothalamus shows that it consists of a complicated series of cell-groups and fibre-tracts. It is not appropriate here to deal with these in detail, but a brief reference to

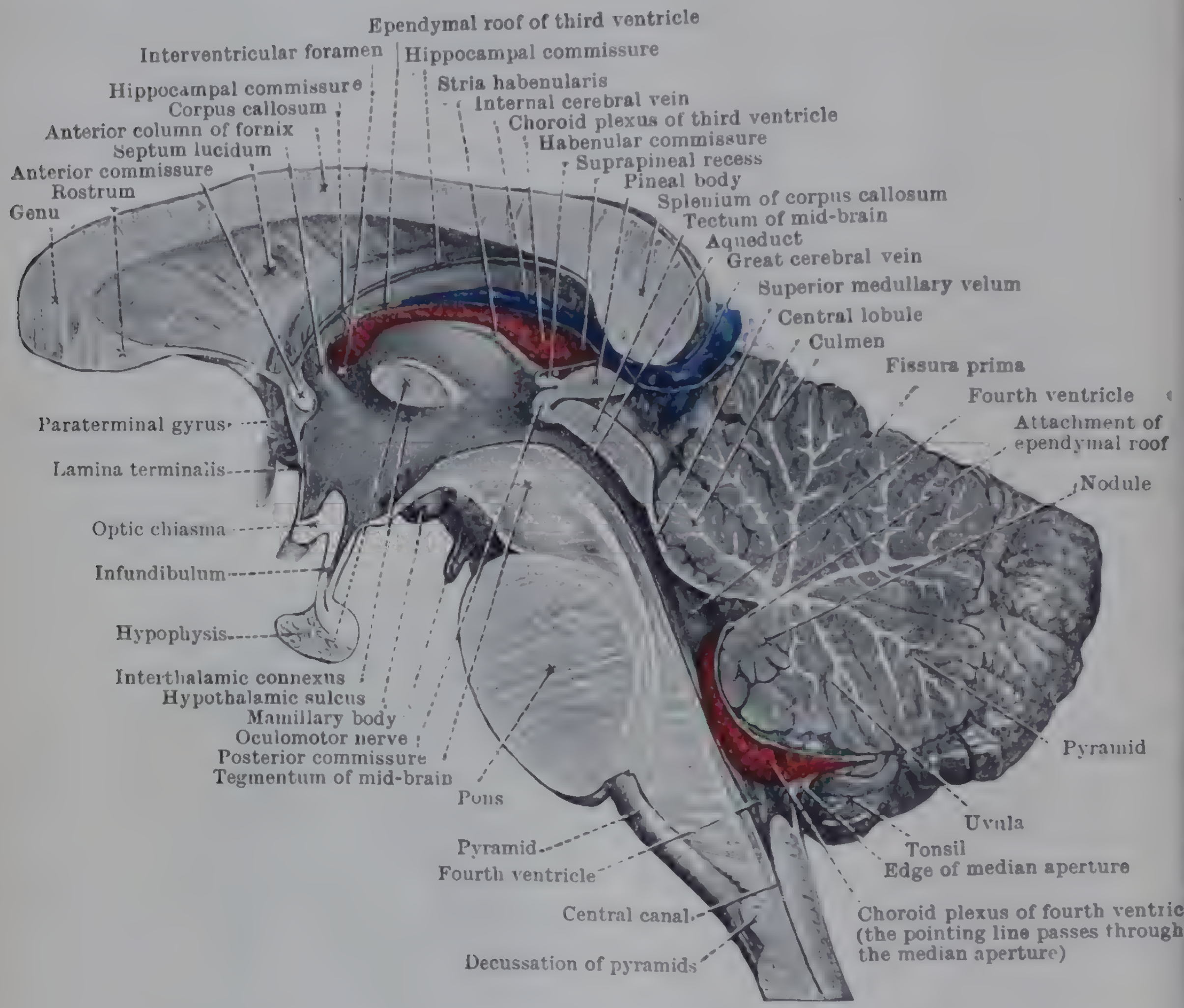

FIG. 829.—THE PARTS OF THE BRAIN CUT THROUGH IN A MEDIAN SECTION. The side-walls of the ventricular cavities also are shown.

them is desirable because of their functional importance. The hypothalamus is one of the most primitive parts of the fore-brain, and experimental and clinical evidence indicates that it is a regulatory centre for the control of the autonomic nervous activities of the body. Lesions of the hypothalamus are therefore often associated with vaso-motor, viscero-motor, and various metabolic disturbances. Anatomically, it is convenient to divide the hypothalamus into three regions antero-posteriorly. In front, in close relation to the optic chiasma, is the **pars optica hypothalami.** This contains two nuclei of closely packed, large nerve-cells—the *paraventricular nucleus* above and the *supra-optic nucleus* below. The latter straddles the optic chiasma on each side of the median plane, and it is this element which mainly gives rise to the tract of fibres which descends to the posterior lobe of the hypophysis—the supra-optico-hypophysial tract. Bilateral lesions of this tract are associated with diabetes insipidus. Behind the pars optica is the **pars tuberalis hypothalami.** This is represented on the base of the brain by the tuber cinereum; it contains several collections of small round cells; and on its surface a series of circumscribed cell-groups—the *nuclei tuberis*—may be responsible for raising up a number of small tubercles which are visible macroscopically. The posterior part of the hypothalamus is the **pars mamillaris hypo-**

thalami. It contains the *nuclei of the mamillary bodies*, together with some more diffuse collections of cells.

From most parts of the hypothalamus, but principally from the posterior region, fine, non-medullated fibres take origin and pass upwards and backwards in the side-wall of the third ventricle to reach a position in the mid-brain immediately in front of the aqueduct. This is the *periventricular system of fibres*, and it is the main efferent path through which the hypothalamus is brought into efferent relation with the splanchnic motor nuclei of the brain-stem, and possibly also with the spinal cord.

Third Ventricle.—The third ventricle is the narrow cleft between the two thalami. Its depth rapidly increases from behind forwards, and it extends from the pineal body behind to the lamina terminalis in front. Its *floor* is formed by the tuber cinereum and the mamillary bodies, and the posterior perforated substance (Figs. 828 and 829). It is interesting to note that the central grey matter which surrounds the aqueduct is directly continuous with the grey matter of the

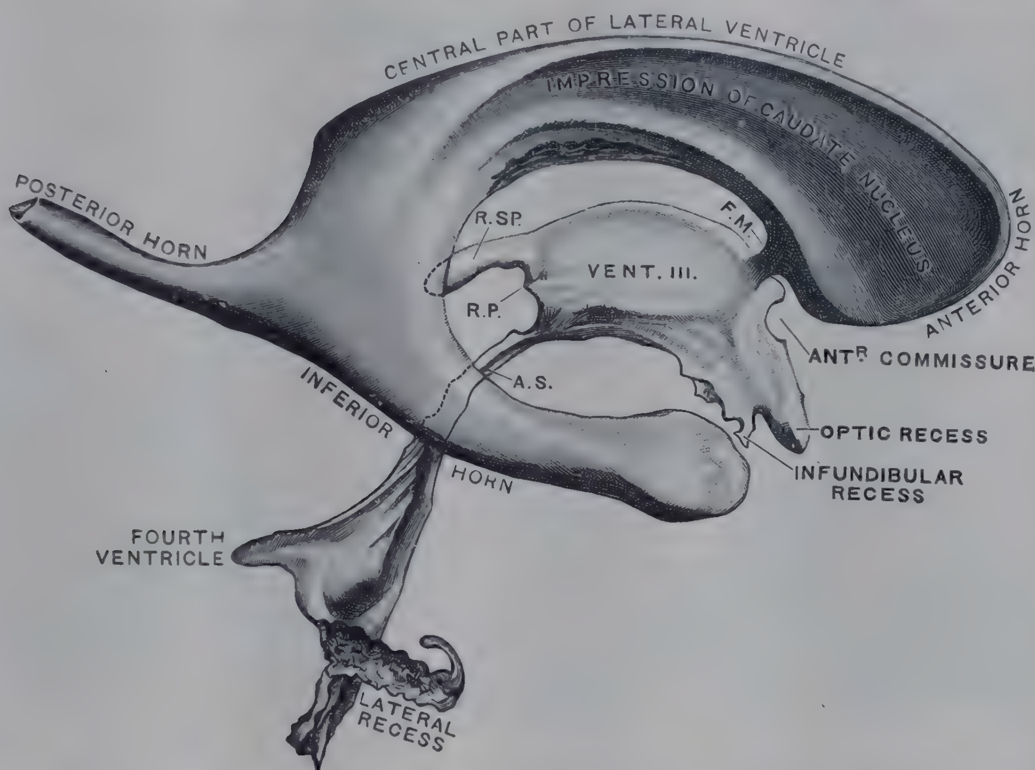

FIG. 830.—PROFILE VIEW OF A CAST OF THE VENTRICLES OF THE BRAIN. (From Retzius, 1900.)

R.SP. Suprapineal recess. A.S. Aqueduct.
R.P. Pineal recess. F.M. Interventricular foramen.

posterior perforated substance and tuber cinereum, and in this way it comes to the surface in the base of the brain. The optic chiasma crosses the floor in front and marks the place where the floor becomes continuous with the anterior wall. The *anterior wall* is formed by the lamina terminalis. This is a thin, delicate lamina which stretches from the optic chiasma in an upward direction to become connected with the rostrum of the corpus callosum. In the anterior part of the cleft between the two thalami, and immediately in front of the anterior columns of the fornix, a round bundle of fibres crosses the median plane in the lamina terminalis. This is the anterior commissure. The anterior commissure bulges into the ventricle from the anterior wall, but, of course, it is excluded from the cavity by the ventricular ependyma. It may be taken as indicating the place where the roof joins the anterior wall. The *roof* is merely the part of the ependymal lining that stretches across the median plane from one stria habenularis to the other. Applied to the upper surface of the ependymal roof is the fold of pia mater termed the tela chorioidea, and the roof is invaginated into the cavity along its whole length by two delicate choroid plexuses which hang down from the under surface of the fold one on each side of the mid-line. When the tela is removed the ependymal roof is torn away with it, leaving only the lines of attachment in the shape of the ridges that cover the striæ habenulares (Fig. 824).

Each *side-wall* of the third ventricle is formed for the greater part of its extent by the medial surface of the thalamus. A little in front of the middle of the ventricle the cavity is usually crossed by the *interthalamic connexus*, which links the thalami one with the other. It apparently has no functional significance, for in the human brain few, if any, fibres cross in it from one side to the other; it is also variable in size and form, and may be altogether absent. In front of the interthalamic connexus the anterior column of the fornix is seen curving downwards and backwards in the side-wall. At first it forms a prominent ridge, but it gradually

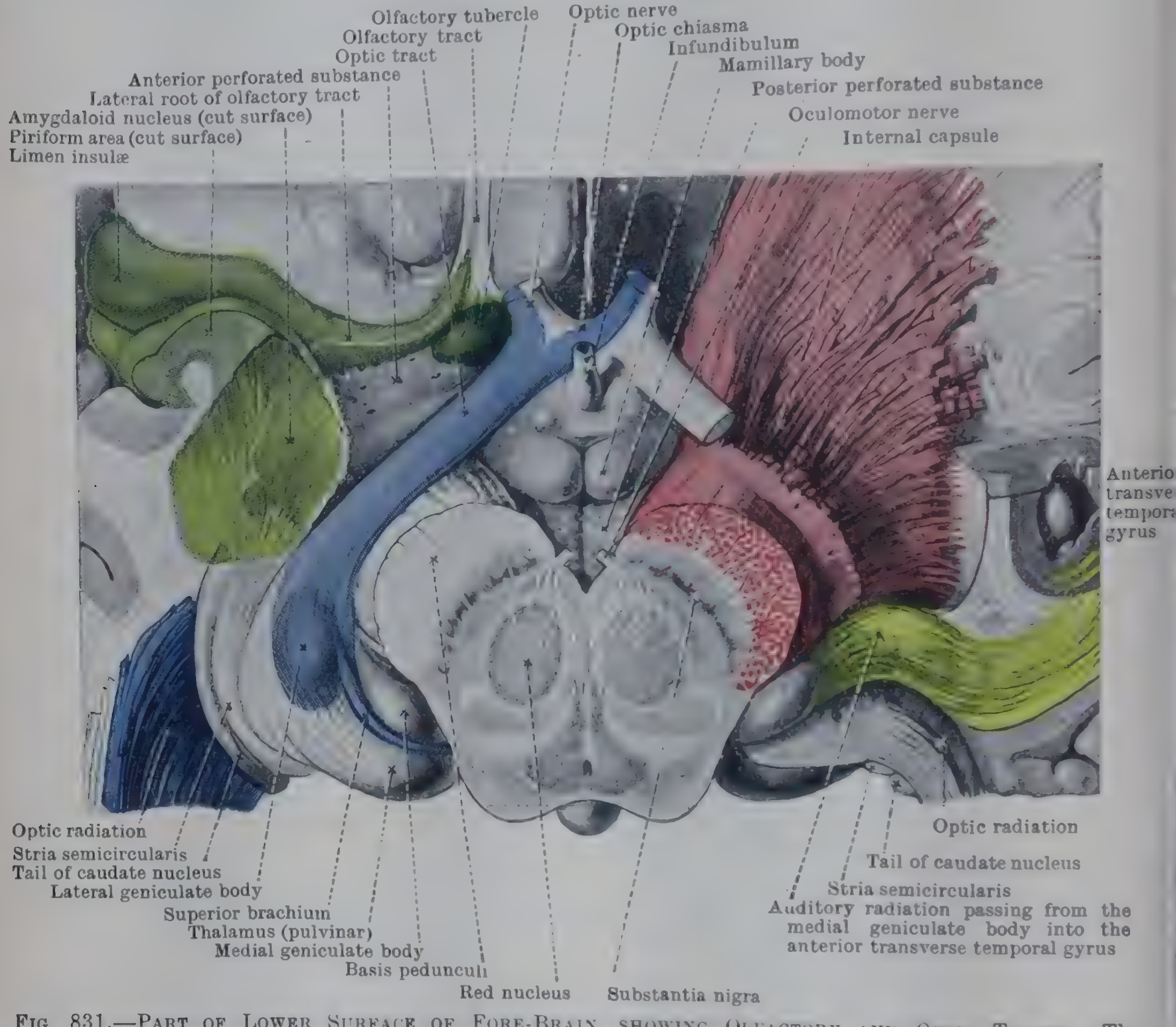

FIG. 831.—PART OF LOWER SURFACE OF FORE-BRAIN, SHOWING OLFACTORY AND OPTIC TRACTS. The mid-brain has been cut across. Olfactory area, *green*; optic fibres, *blue*; pyramidal tract and cortico-pontine fibres, *red*; auditory fibres, *yellow*.

subsides as the strand, on its way to end in the mamillary body, becomes more and more sunk in the grey matter on the side of the ventricle.

The third ventricle communicates with both of the lateral ventricles, and also with the fourth ventricle. The aqueduct of the mid-brain brings it into communication with the fourth ventricle. The opening of this aqueduct is at the posterior part of the floor, immediately below the posterior commissure. The **interventricular foramina**, which bring it into communication with the lateral ventricles, are at the upper and anterior parts of the side-walls; each leads laterally and slightly upwards between the anterior column of the fornix and the anterior end of the thalamus. They are very variable in width but usually are about one-eighth of an inch in diameter; and through them the ependymal lining of the three ventricles becomes continuous. From the foramen a broad shallow groove on the side-wall of the ventricle leads backwards towards the mouth of the aqueduct. It is termed the **hypothalamic sulcus**, and it serves to mark a topographical boundary between the thalamus above and the hypothalamus below.

The outline of the third ventricle, when viewed from the side in a median section through the brain (Fig. 829), or as it is exhibited in a plaster cast of the ventricular system of the brain (Fig. 830), is seen to be very irregular and to have several recesses. Thus, in the anterior part of the floor there is a funnel-shaped recess that leads down through the tuber cinereum into the infundibulum. Immediately in front of this *infundibular recess*, the *optic recess* passes downwards and forwards above the optic chiasma. Posteriorly there are two recesses in the roof of the third ventricle. One—the *pineal recess*—passes backwards for a short distance into the stalk of the pineal body. The second—the *suprapineal recess*—is carried backwards for a greater distance; it is a diverticulum of the ependymal roof, and is therefore difficult to demonstrate by macroscopic dissection.

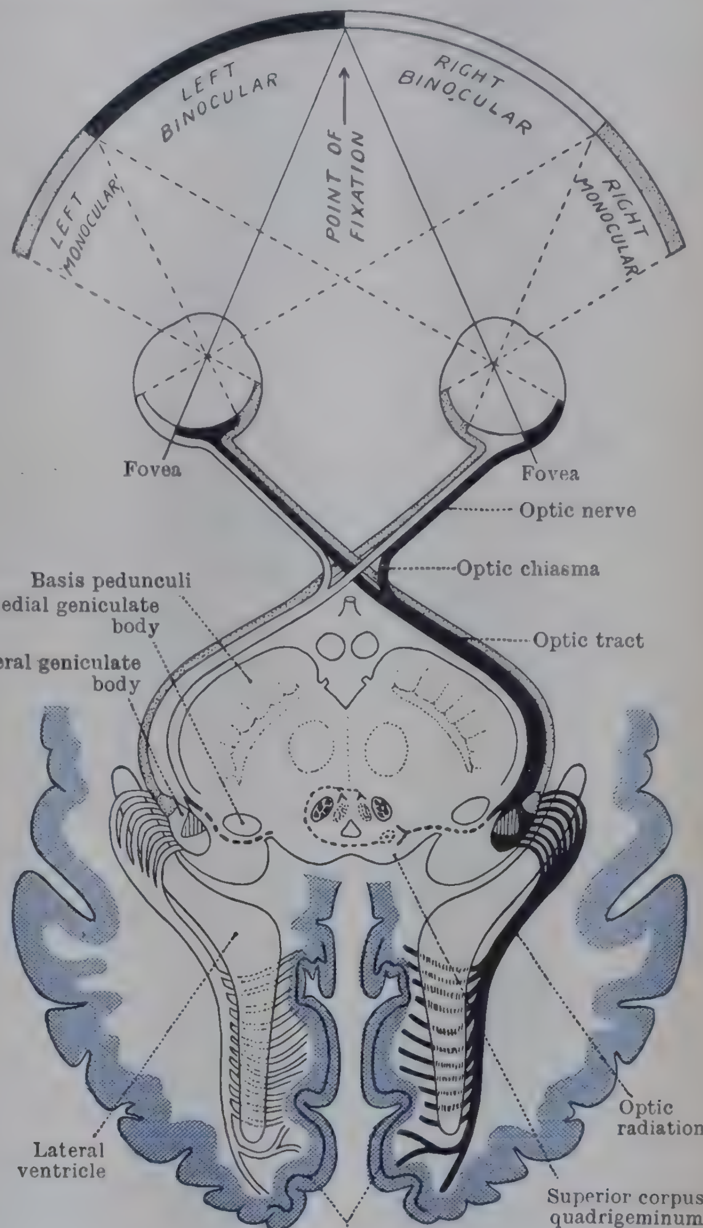

Fig. 833.—Composite Diagram to show the Projection of the Visual Field upon the Retinæ and the Relationship of Retinæ to Lateral Geniculate Bodies and Area Striata of Cerebral Hemispheres. The fibres from the maculæ, some crossed and some uncrossed, are not shown separately in the optic nerves and optic tracts, but their place of delivery in the lateral geniculate body—the intermediate part of its posterior two-thirds—is shown by hatching. The remainder of the posterior two-thirds receives the fibres from nonmacular regions of the binocular retinal field. The monocular retinal field is shown projecting into the anterior third of the lateral geniculate body. No attempt has been made in this figure to localize the delivery within the area striata of fibres from these different regions of the lateral geniculate body. (After Ivy Mackenzie (1934) and Winton & Bayliss (1948).)

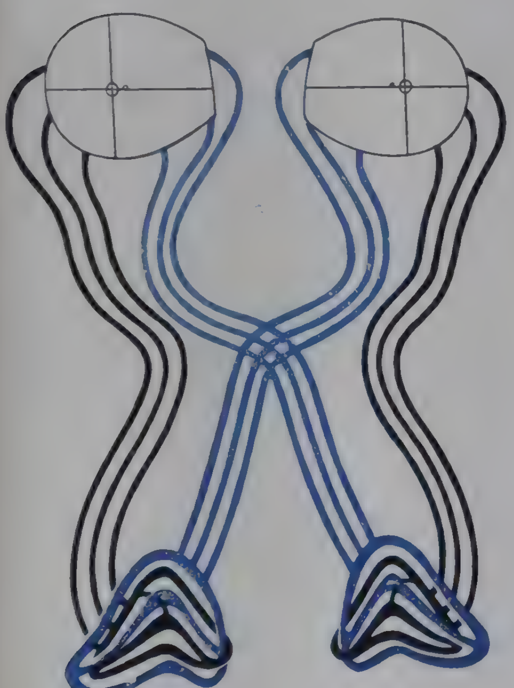

Fig. 832.—Diagram to show Relationship of Crossed and Uncrossed Fibres from Retinæ to Cell-Laminæ of Lateral Geniculate Bodies. The macular fibres, some of which are crossed and some uncrossed, are not shown separately. They are delivered to the cells that lie in the central region of the posterior two-thirds of the body, cf. Fig. 833. (From Ivy Mackenzie (1934), after Le Gros Clark.)

Cerebral Connexions of Optic Tract

At the optic chiasma the optic nerves are joined together and a partial decussation of fibres takes place. The fibres which arise in the medial or nasal half of each retina cross the median plane and join the optic tract of the opposite side. Those from the temporal half of the retina pass into the optic tract of the same side. Approximately two-thirds of the fibres in each optic tract are crossed, and

one-third uncrossed. Each optic tract forms a flattened band which proceeds backwards round the side of the cerebral peduncle, reaching the latter by passing backwards and laterally from the optic chiasma, between the anterior perforated substance and the tuber cinereum. In the neighbourhood of the geniculate bodies the tract appears to divide into two roots, viz., a lateral and a medial (Fig. 831), but only the former is really part of the tract. The so-called medial root can be traced to the medial geniculate body, and it consists of commissural fibres through which the two medial geniculate bodies and probably the inferior corpora quadrigemina are connected across the median plane. This commissure (the commissure of van Gudden) becomes secondarily incorporated in the optic chiasma and has nothing to do with visual functions.

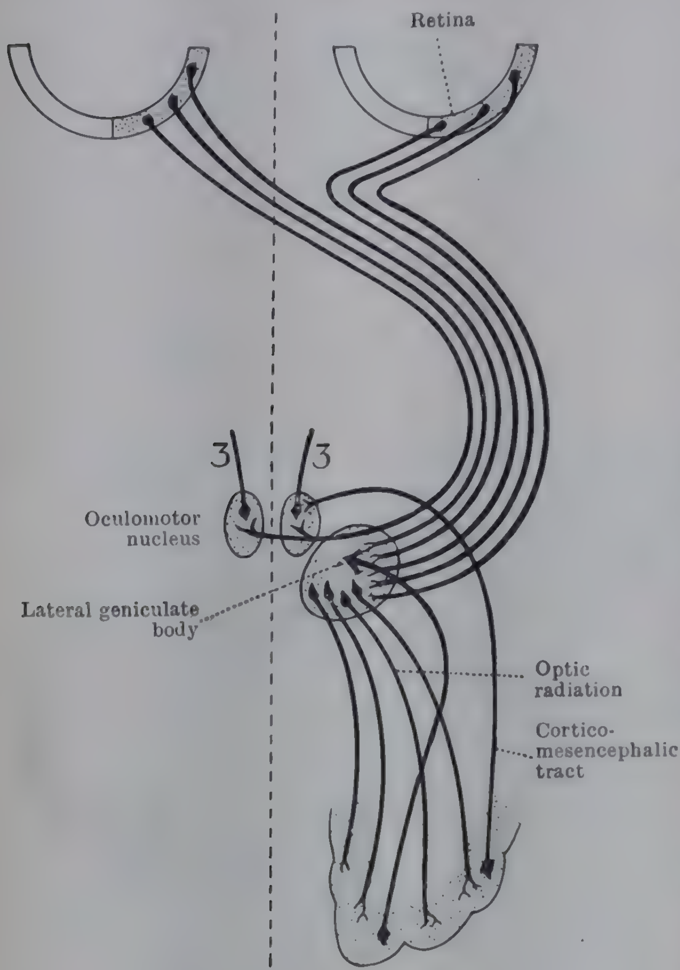

FIG. 834.—DIAGRAM OF CENTRAL CONNEXIONS OF OPTIC NERVE AND OPTIC TRACT.

Optic Tract.—It is important to recognize that each optic tract is composed of fibres from the temporal half of the ipsilateral retina and from the nasal half of the contralateral retina. It follows that section of one optic tract will result in a blindness in the nasal half of the field of vision of the ipsilateral eye and in the temporal half of the contralateral eye. This condition is called "homonymous hemianopia". Further, since the crossed fibres at first lie towards the medial side of the tract, pressure on the tract from the medial aspect (such as may arise from a tumour of the hypophysis) may give rise to a bilateral temporal hemianopia. Lastly, it should be noted that fibres from different areas of the retina retain a corresponding topographical localization in the optic tract, so that small circumscribed lesions in the latter may give rise to a circumscribed defect (*scotoma*) in the field of vision.

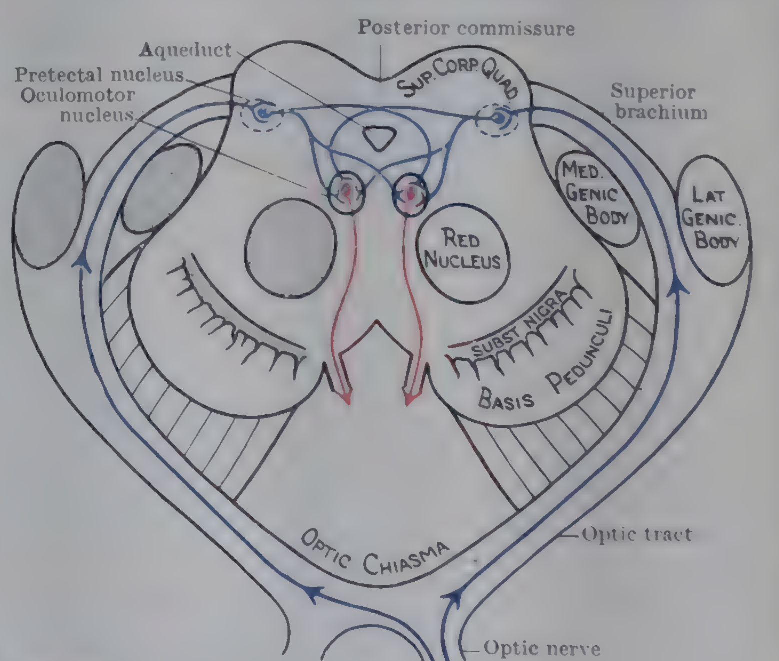

FIG. 835.—DIAGRAM OF SECTION THROUGH MID-BRAIN AND OPTIC CHIASMA SHOWING THE PATH OF PUPILLARY CONSTRICTOR FIBRES. (After Ranson & Magoun, 1933.)

By far the greater number of the fibres of the optic tract end in the lateral geniculate body, but some fibres proceed by way of the superior brachium to the mid-brain and end in the superficial layers of the superior corpus quadrigeminum and in the pretectal nucleus

(Fig. 835). The pretectal nucleus receives the pupillo-constrictor fibres of the optic tract and relays the retinal impulses on to the oculomotor nucleus (p. 919).

The mode of termination of the optic fibres in the lateral geniculate body is very precise. It has been noted that a considerable part of the nucleus consists of six well-defined cell-laminæ. Three of these receive the crossed fibres of the optic tract and three the uncrossed fibres. Moreover, it has been demonstrated that from each spot in the central area of the retina fibres pass to all three corresponding laminæ. It should be noted also that the topographical representation of each part of the retina in the lateral geniculate body is quite sharply defined. Thus, the upper half of the retina projects on to the medial half of the nucleus and the lower half of the retina on to the lateral half. The fibres from the macular area of the retina (related to central vision) are located in the medio-ventral part of the optic tract, and terminate in the central region of the posterior two thirds of the geniculate body.

Cortical Connexions of Optic Path.—The lateral geniculate body, the superior corpus quadrigeminum and the pretectal nucleus are termed the lower visual centres of the brain. The higher visual centre is in the cortex of the occipital lobe of the cerebral hemisphere, and this receives a conspicuous tract of fibres from the lateral geniculate body called the **optic radiation.** In other words, the lateral geniculate body is simply a relay station through which retinal impulses are projected on to the visual cortex. The optic radiation forms a wide, thin sheet of fibres which lies in the white matter of the posterior part of the cerebral hemisphere and passes back to the visual cortex in close relation to the posterior horn of the lateral ventricle. It is of some practical importance to recognize that in its course through the white matter of the cerebral hemisphere the optic radiation is in close topographical relation to the deep aspect of the temporal lobe. Consequently pathological lesions of the temporal lobe may be accompanied by visual defects. Mention should be made of a small fasciculus of fibres which leave the optic tract before it reaches the lateral geniculate body and pass into the subthalamus at the medial margin of the substantia nigra. This so-called "accessory optic tract" has been demonstrated experimentally in lower mammals and probably exists also in the human brain.

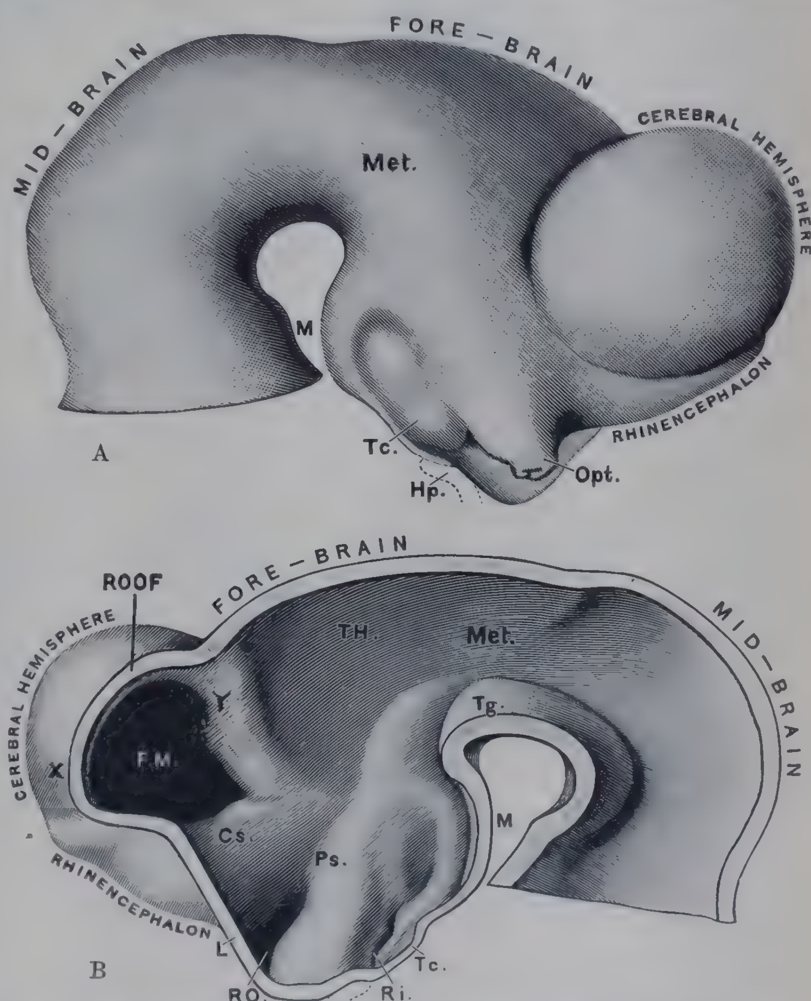

FIG. 836.—BRAIN OF HUMAN EMBRYO IN SEVENTH WEEK. (His, 1904.)

A. Brain from right side. B. Median section of same brain.

M, Mamillary eminence; Tc., Tuber cinereum; Hp., Hypophysis (hypophysial diverticulum from oral cavity); Opt., Optic stalk; TH., Thalamus; Tg., Tegmentum of mid-brain; Ps., Hypothalamus; Cs., Corpus striatum; F.M., Interventricular foramen; L, Lamina terminalis; RO., Optic recess; Ri., Infundibular recess; Met., Region of geniculate bodies; X, Junction of lamina terminalis and roof of fore-brain; Y, Posterior margin of interventricular foramen.

The visual cortex emits cortico-tectal fibres which descend to the superior corpus quadrigeminum.

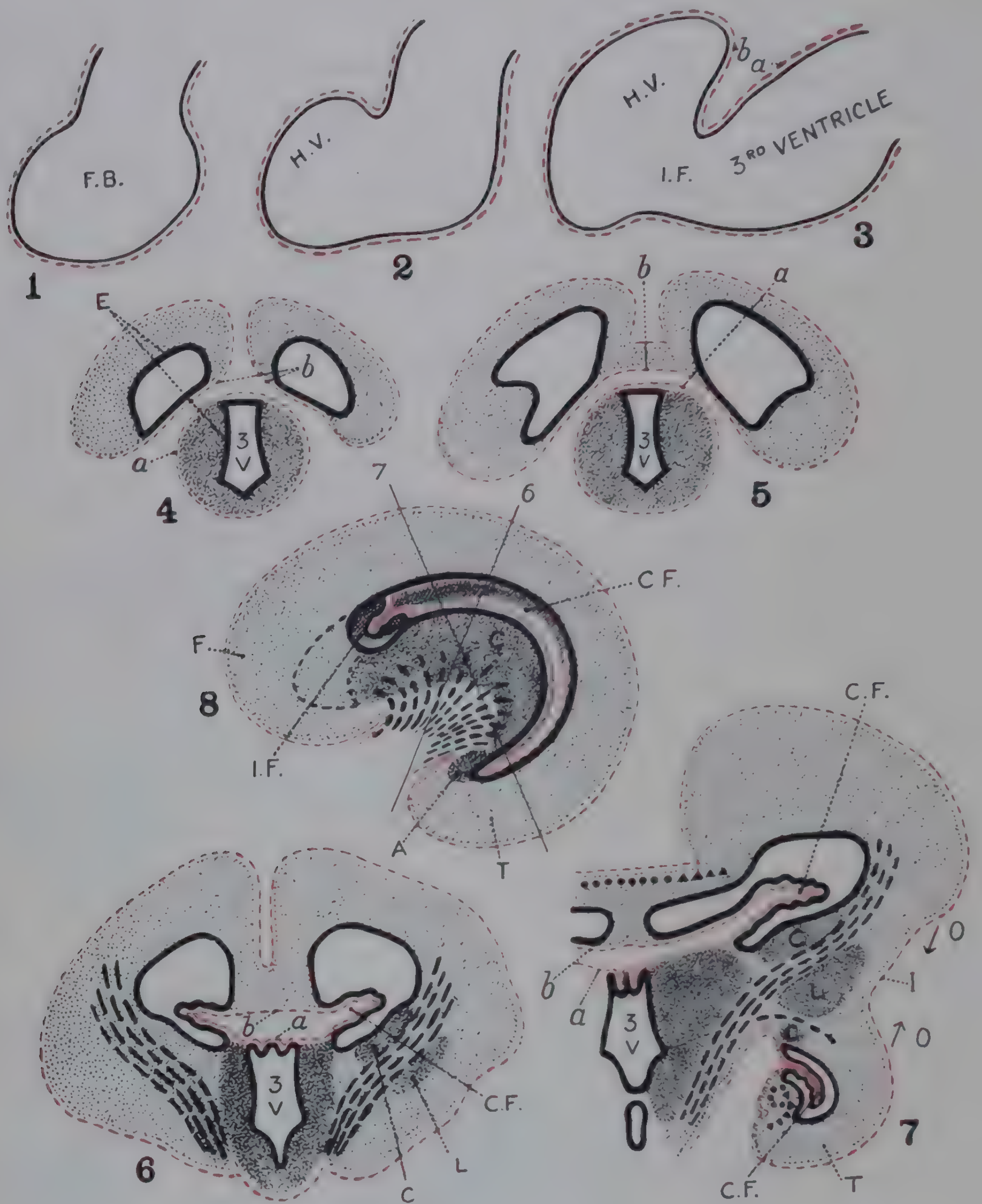

FIG. 837.—DIAGRAMS TO SHOW THE FORMATION OF THE TELA CHORIOIDEA AND ITS RELATION TO THE CHOROID FISSURE AND CHOROID PLEXUSES OF THE LATERAL AND THIRD VENTRICLES.

Adapted from figures in Frazer's *Manual of Embryology*.

In Fig. 1, the vascular tissue forming the primitive pia mater is shown as a broken red line surrounding the front end of the neural tube (F.B.). In Fig. 2, a developing cerebral hemisphere vesicle (H.V.) is seen carrying out over it a covering of pia mater continuous with that surrounding the original forebrain vesicle. Fig. 3 shows that the backward growth of the hemisphere leads to the formation of a double layer of pia mater interposed between it and the roof of the 3rd ventricle. This double layer of vascular pia mater is the tela chorioidea. "The layer '*b*' is derived from the original '*a*', so that any veins in '*b*' must run back to the roof of the interventricular foramen (I.F.) to enter one of the veins of '*a*' and so drain. The tela chorioidea, then, extends to the interventricular foramen because the upper layer was reflected at this point." (Frazer, 1940, p. 202.) But the layer '*b*' is carried out on each hemisphere vesicle (Fig. 4), and the two vesicles become connected by commissures (Fig. 5), and become fused also to the mid-line vesicle containing the 3rd ventricle so that the condition shown in Fig. 6 results. The plane of Fig. 6 is shown on Fig. 8 by a line labelled 6. The ependyma (E) lining the lateral ventricles and the 3rd ventricle is shown by a heavy black line, so that the strip of the medial wall of each hemisphere which consists only of ependyma and likewise the roof of the 3rd ventricle can be easily seen in Figs, 4, 5, 6, 7, 8. The inthrust of the ependymal region of the hemisphere wall is called the choroid fissure (C.F.) (see also description in text, pp. 941, 955). In Fig. 7 the choroid fissure is cut twice. A glance at Fig. 8, upon which the place of Fig. 7 is indicated by a line labelled 7, will show the reason for this.

C = caudate nucleus. O = opercula of insula. L = lentiform nucleus. F = frontal pole.
A = amygdaloid nucleus. T = temporal pole. I = insula.

PARTS DERIVED FROM TELENCEPHALON

Cerebral Hemispheres

The cerebral hemispheres form the largest part of the fully developed brain. When viewed from above they form an ovoid mass, the broader end of which is directed backwards, and the longest transverse diameter of which will be found in the vicinity of the parts which lie subjacent to the parietal eminences of the cranium. The massive, rounded character of the anterior or frontal end of each cerebral hemisphere is a leading human characteristic; but the posterior or occipital end is narrow and pointed, and is directed slightly downwards. The two cerebral hemispheres are separated from each other by a deep median cleft termed the longitudinal fissure.

Each cerebral hemisphere is formed from a small area of the extreme anterior end of the alar lamina, in the angle between the foremost part of the roof and the upper end of the lamina terminalis (Fig. 836 L), which becomes continuous with the roof (at the point marked X).

The rapid expansion of that area leads to the development of a lateral bulging containing a diverticulum of the third ventricle known as the lateral ventricle. This at first communicates with the third ventricle by means of a wide opening (F.M.)—the interventricular foramen—corresponding in size to the extent of the area of the side-wall that was bulged outwards to form the hemisphere vesicle. The thin, ependymal roof of the telencephalon takes no share in the formation of the two cerebral hemispheres, but it serves with the lamina terminalis (L) as a bond of union between them; it forms, also, the upper boundary of the interventricular foramen. At a later stage in development two folds become invaginated from the ependymal roof in the whole extent of the prosencephalon—both its telencephalic and diencephalic parts. In the greater part of their length these folds project into the third ventricle, and form its **choroid plexuses** (Fig. 829); but the anterior parts of the two choroidal folds, namely, those parts formed from the roof of the interventricular foramina (F.M.), become greatly enlarged and project each into the corresponding lateral ventricle. The furrow corresponding to this invagination of the roof is called the **choroid fissure** (p. 941). When the hemisphere vesicle first begins to expand, the thinner part of its wall, which is called the **pallium**, is freely continuous around the vertical caudal margin of the interventricular foramen (Fig. 836 Y) with the wall of the third ventricle.

But, as development proceeds, the wall of the prosencephalon becomes attenuated along the line of the choroid fissure, and eventually the pia mater of the choroid tela of the third ventricle extends laterally into the fissure to produce the **choroid plexus** of the lateral ventricle. It is obvious, therefore, that the choroid plexus of the lateral ventricle will become continuous with that of the third ventricle at the upper margin of the interventricular foramen, and that the choroid plexuses of the third and lateral ventricles all have a common origin from the same tela. Below and lateral to the choroid fissure the wall of the hemisphere remains in close contact with the thalamus. In this way the thalamus comes, in part, to face directly into the lateral ventricle, and the corpus striatum, developing in the floor of the cerebral hemisphere, acquires its close relationship with the thalamus (Fig. 838).

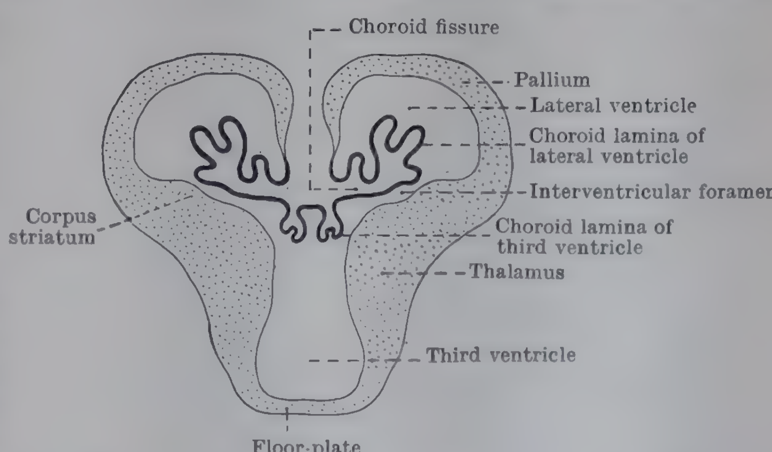

Fig. 838.—Diagram of Transverse Section through Fœtal Brain to show the Invagination of the Roof through each Interventricular Foramen.

At a very early stage in the development of the embryo, long before there is any sign of the hemisphere vesicles, the ectoderm on each side of the anterior neuropore (see p. 838) becomes thickened to form the **area olfactoria** (see Fig. 722 D, p. 838). Certain of the epithelial cells in this area become converted into bipolar sensory cells and these are specialized as receptors for certain kinds of air-borne chemical stimuli that awaken a consciousness of smell. These cells always remain *in situ* in the olfactory epithelium, just as sensory cells do in primitive invertebrates (Fig. 719, p. 835). But other nerve-cells seem to be derived from the area olfactoria which do not remain in the parent epithelium but become attached to the adjoining part of the neural tube. These cells form

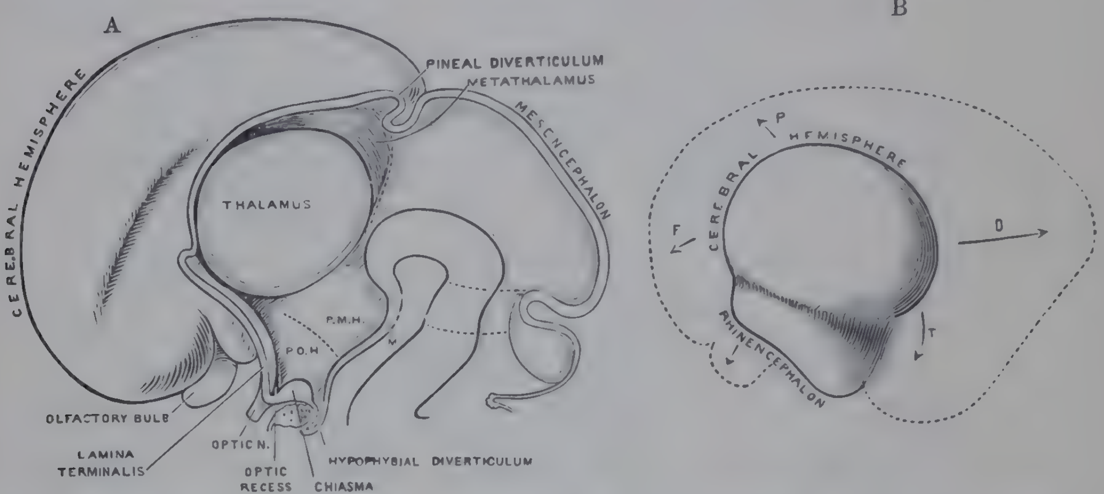

FIG. 839.—TWO DRAWINGS BY HIS, ILLUSTRATING THE DEVELOPMENT OF THE HUMAN BRAIN.

A. Median section of fœtal human brain in third month of development.
B. Schema showing directions in which the cerebral hemisphere expands during its growth.

P.M.H. Pars mamillaris of hypothalamus.
P.O.H. Pars optica and pars tuberalis of hypothalamus.
Metathalamus = Region of geniculate bodies.
M. Mamillary region.
F. Frontal lobe.
P. Parietal lobe.
O. Occipital lobe.
T. Temporal lobe.

the receptive organ for the impressions brought into the brain by the processes of the sensory cells in the olfactory epithelium; and the area of the neural tube to which it becomes attached is destined to become part of the cerebral hemisphere. At the end of the first month this portion of the hemisphere becomes drawn out as a hollow protrusion, the distal end of which is coated with a layer of grey matter and is known as the **olfactory bulb**; the rest forms a peduncle. In the course of its subsequent development in the human brain (though not in those of most mammals) the cavity in the bulb and peduncle becomes completely obliterated. The peduncle becomes so greatly elongated and attenuated that to the unaided eye it appears to be formed wholly of white nerve-fibres passing from the olfactory bulb to the hemisphere; hence it is called the **olfactory tract** (Figs. 831 and 841).

The cerebral hemisphere first appears in the form of a slight bulging on each side of the fore-brain, but it soon assumes large dimensions. At first it grows forwards and upwards (Fig. 839), and a distinct cleft, the floor of which is the roof-plate and lamina terminalis, appears between the two hemispheres: it is known as the **longitudinal fissure**. The separation of the two cerebral vesicles by the longitudinal fissure begins at the end of the first month, and the fissure becomes occupied by the mesodermal tissue which later on forms the **falx cerebri**. The cerebral hemisphere, in its further growth, is carried progressively backwards over the other parts of the developing brain. At the end of the third month it has covered the thalamus. A month later it reaches the corpora quadrigemina, and by the seventh month it has covered not only these, but also the entire upper surface of the cerebellum. From the latter it is separated by a mesodermal sheet which forms the basis of the **tentorium cerebelli**.

In the earlier stages of its development the cerebral hemisphere is a thin-walled vesicle with a relatively large cavity which represents the primitive condition of

the **lateral ventricle**. At first the vesicle is bean-shaped and the cavity is curved. As development proceeds, the posterior portion of the hemisphere grows backwards over the cerebellum in the shape of a hollow protrusion, and a distinct occipital lobe enclosing the posterior horn of the lateral ventricle is the result. This developmental stage begins about the fourth month.

Connexions of Olfactory Nerves

The olfactory nerves are the axons of the spindle-shaped bipolar cells situated in the olfactory mucous membrane (Fig. 840). These axons collect in the submucous layer to form small bundles which enter the cranial cavity through the foramina in the cribriform plate of the ethmoid bone. After forming an intricate plexus on the surface of the olfactory bulb, they enter it over the greater part of its surface, and each fibre breaks up into a tuft of terminal filaments. Towards these tufts dendrites proceed from large **mitral cells** placed in a deeper plane within the bulb, and each dendrite also breaks up into numerous terminal branches intertwined with those of the olfactory nerves. In this way a large number of globular bodies are formed, each consisting of the arborescent terminations of mitral dendrites and a large number of olfactory nerve-fibres. The globular bodies are called the **olfactory glomeruli**. Each mitral cell gives off several dendrites and one axon. It thus happens that a mitral cell, through its dendrite, stands in connexion with many olfactory nerve-fibres. The axon of the mitral cell passes upwards into the bulb, bends backwards, and runs in the olfactory tract towards the cerebral cortex.

The **olfactory bulb** is a small, flattened, elliptical mass of grey matter placed on the cribriform plate of the ethmoid bone. Its posterior end is attached to the rest of the cerebral hemisphere by the olfactory tract (Fig. 763)—a prismatic band of white substance placed in the olfactory sulcus on the orbital surface of the cerebral hemisphere. A short distance in front of the optic chiasma each olfactory tract becomes inserted into the hemisphere (Fig. 831). The swollen pyramidal-shaped attached end of the tract is called the **olfactory pyramid**. Immediately behind the pyramid a small obliquely placed ovoid area of grey matter—the **olfactory tubercle**—can sometimes be detected in the human brain; but in the brains of most mammals with a greater development of the organs of smell this swollen area is much more prominent and constant. In most human brains, however, it is difficult to distinguish it from a much more extensive area, situated behind it and to its lateral side, and named the **anterior perforated substance** (Fig. 831). Along the anterior margin of the perforated substance a very well-defined narrow band of nerve-fibres—the *lateral root of the olfactory tract*—proceeds backwards and laterally from the attached end of the olfactory tract. This is composed of axons of mitral cells proceeding to the hook-shaped part of the temporal lobe called the uncus.

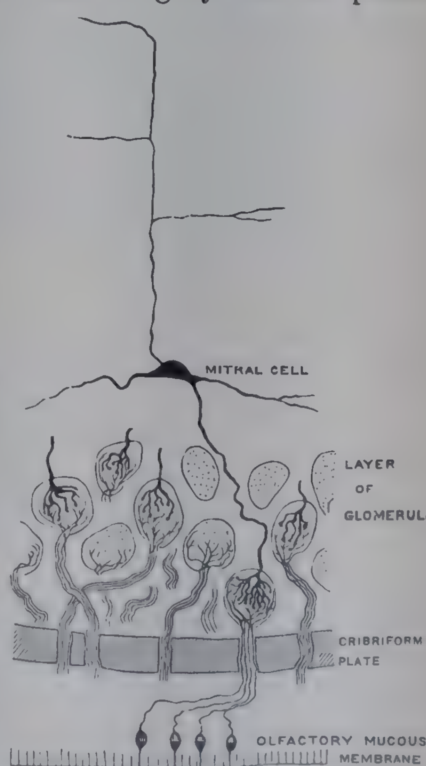

Fig. 840.—Diagram of Minute Structure of Olfactory Bulb.

The *uncus* forms the major part of a cortical layer of grey matter in which the lateral root of the olfactory tract ends. This area of cortex is termed the **piriform area** for the reason that in lower mammals it is distinctly pear-shaped.

The piriform area extends laterally in the deep valley between the orbital and temporal regions of the hemisphere; becoming slightly broader, and reaching what is known as the **insula** (of which it forms the **limen insulæ**), it becomes sharply bent upon itself (Figs. 831 and 841 C). It then passes medially and backwards, and emerges from the valley as a broad area on the under surface of the temporal

region (Fig. 841 C), where it enters into the formation of the uncus of the temporal lobe.

If the brain of almost any other mammal is examined (take the rabbit's as an example), the piriform area will be found to constitute relatively a much larger proportion of the cerebral hemisphere than it does in the human brain; and it is separated from the part of the hemisphere (**neopallium**) that lies above it by a longitudinal furrow called the **rhinal sulcus**. The enormous expansion of the neopallium in the human brain accentuates the flexure of the piriform area at the point x (Fig. 841), and at the point y the exuberant growth of neopallium relegates the swollen, posterior part of the piriform area on to the medial surface (Fig. 842), where the posterior part of the rhinal sulcus persists to

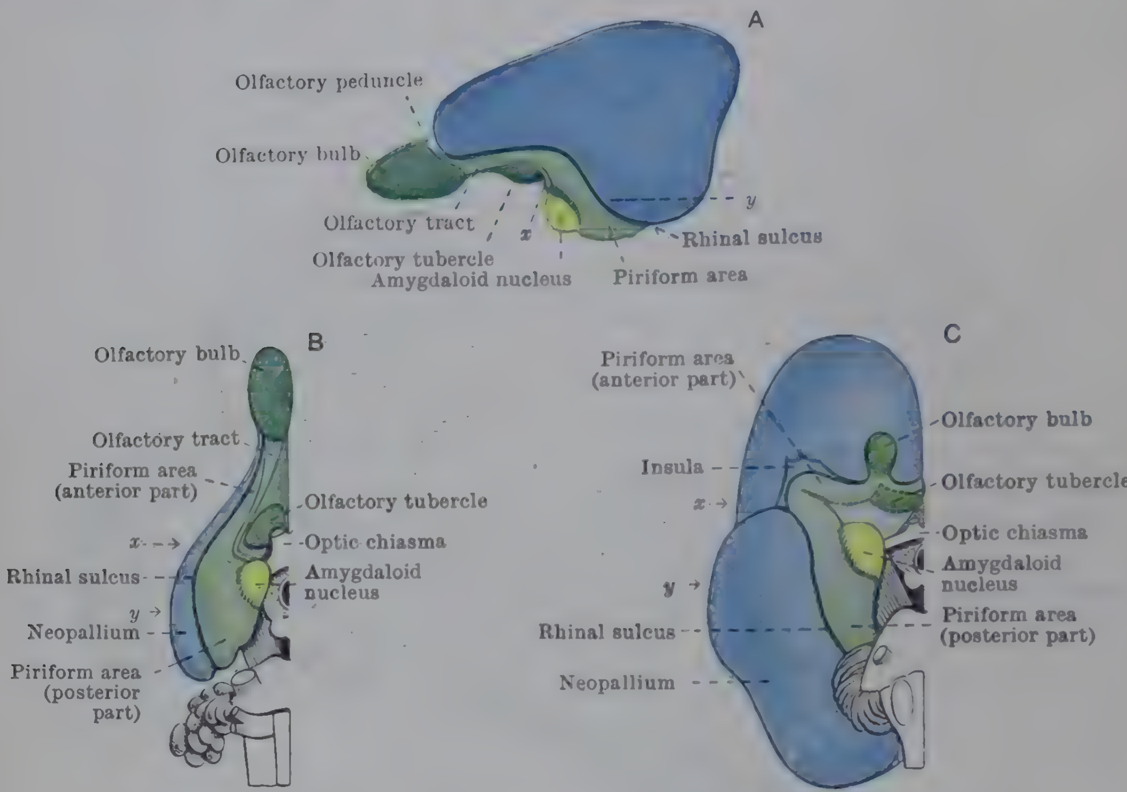

FIG. 841.—RELATION OF OLFACTORY PART OF HEMISPHERE TO NEOPALLIUM.

A. Lateral aspect of left cerebral hemisphere of rabbit. B. Inferior aspect of right half of rabbit's brain. C. Corresponding view of human fœtal brain at fifth month.

Olfactory areas, *green*; neopallium, *blue*.

It should be noted that the posterior part of the piriform area is not directly connected with the olfactory tract and is probably concerned with other than purely olfactory functions.

separate it from the neopallium. Strictly speaking, the olfactory tract fibres terminate directly only in the anterior part of the piriform area, and it is probable that the posterior piriform area is concerned with other than purely olfactory functions.

The surface of the piriform area often presents numerous small wart-like excrescences; and it is whitened by a thin layer of fibres prolonged backwards from the lateral root of the olfactory tract. By these fibres olfactory impulses are poured directly from the mitral cells of the bulb into the anterior piriform area. If we call the olfactory nerves the **primary olfactory neurons**, the fibres which pass from the bulb to the anterior piriform area would then be **secondary olfactory neurons**. Some of the olfactory tract fibres terminate in the olfactory tubercle at the anterior part of the anterior perforated substance and in certain elements of the amygdaloid nucleus; others pass up on to the medial surface of the cerebral hemisphere as the *medial root of the olfactory tract*, to terminate in a triangular mass of grey matter situated immediately in front of the lamina terminalis, and called the *paraterminal gyrus* (Fig. 842). There is reason to believe that the fibres of this medial root do not originate in the olfactory bulb, but probably arise from cells in a fine strip of grey matter which accompanies the main olfactory tract.

Hippocampal Formation

Extending back from the region of the uncus, and curving up to reach the under surface of the splenium of the corpus callosum, is a strap-like band of white matter, the *fimbria*. Immediately below this is a thin crinkled strip of cortex called the *dentate gyrus*, sunk deeply in the groove between the fimbria and the neighbouring convolution of the temporal lobe, the hippocampal gyrus (Fig. 842). The dentate gyrus, which is characterized in its structure by a compact layer of small granule cells, is developed along the margin of the pallium bordering the choroidal fissure where, in the fœtus, the choroid plexus becomes invaginated into the cavity of the lateral ventricle. Traced backwards, the gyrus is found to curve round below the splenium of the corpus callosum

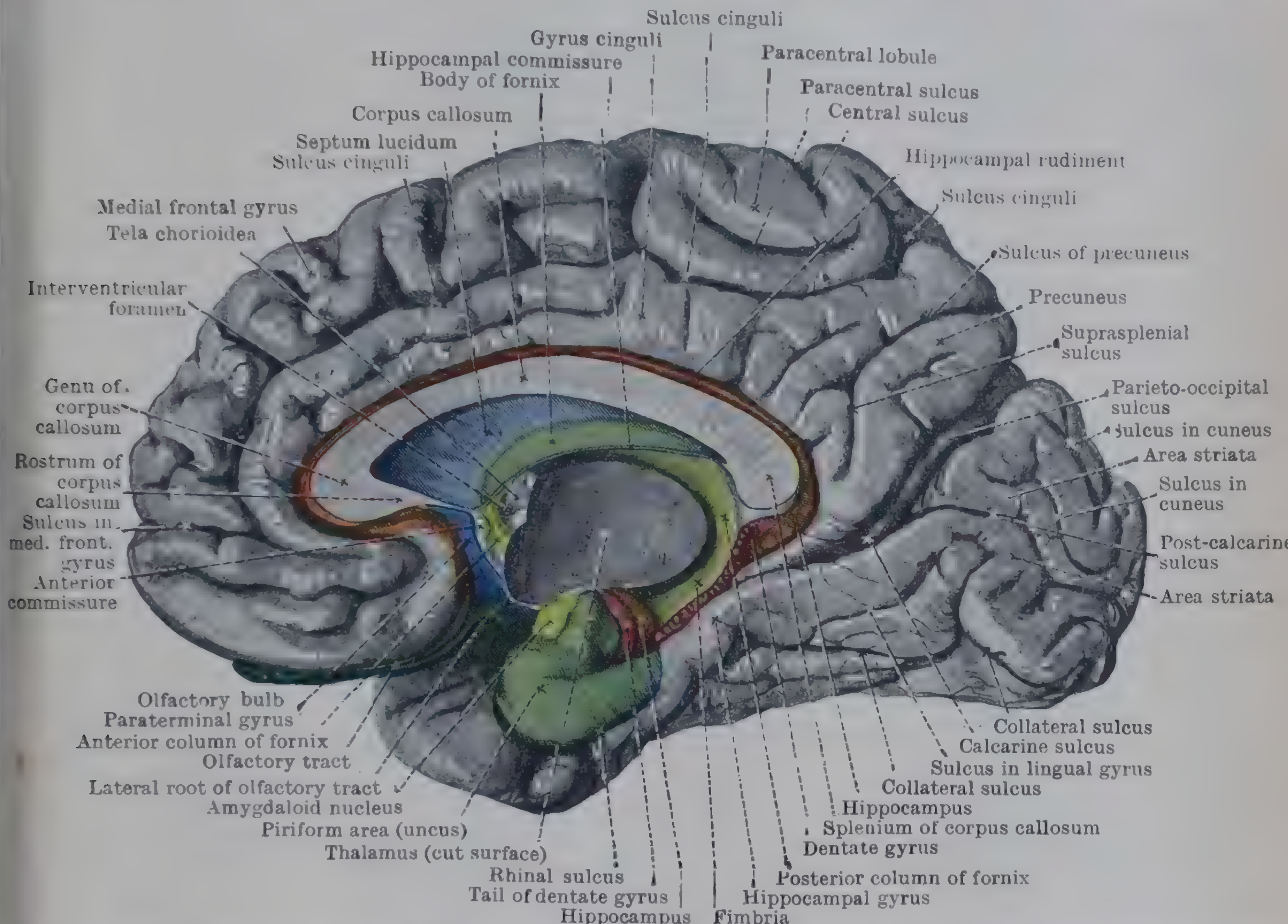

Fig. 842.—Medial Aspect of Right Cerebral Hemisphere, with the Main Olfactory Centres on the Base of the Brain coloured *Green*.

It should be noted that olfactory fibres end directly only in the anterior part of the piriform area.

to disappear from view on to its upper surface. Here it becomes continuous with a thin film of grey matter, the *indusium*, which is too attenuated to be discernible with the naked eye. At its anterior extremity, the dentate gyrus curves up on to the surface of the posterior part of the uncus, where it is called the " tail of the dentate gyrus " (Fig. 842). In lower mammals, in which the olfactory sense is powerfully developed, the dentate gyrus forms a broad and conspicuous convolution. It is a receptive area of the cortex in which terminate fibres (tertiary olfactory neurons) which arise in the anterior piriform area. The olfactory sense in Man is relatively poorly developed and, in association with this, the dentate gyrus has undergone a very considerable reduction. In some cases it is such a slender band of grey matter that it may not readily be distinguished on superficial examination.

The dentate gyrus is separated from the hippocampal gyrus by a shallow groove, the hippocampal fissure. Along the line of this fissure, during the course of embryological development, a broad band of cortex becomes sunk in from the surface and inrolled into the cavity of the descending horn of the lateral ventricle (Fig. 844). In the adult, it can be seen in the floor of the descending horn as a conspicuous elongated eminence (p. 967). This invaginated strip of cortex (which thus lies alongside the dentate

gyrus) is called the *hippocampus*; like the dentate gyrus it is continued anteriorly on to the surface of the uncus and posteriorly fades away into the indusium. The hippocampus and the dentate gyrus together comprise the **hippocampal formation**, and the indusium is to be regarded as an atrophied portion of this formation which has become stretched out into an exceedingly thin layer by the growth of the subjacent corpus callosum.

For many years the hippocampus has been regarded as an important component of the olfactory mechanism of the brain. However, while in lower vertebrates it appears to come under the dominating influence of the olfactory impulses which are conveyed to it by fibres from the dentate gyrus, this is certainly not its only, or even its most important connexion in mammals generally. In lower mammals, the hippocampus receives afferent fibres from two main sources—from the dentate gyrus (which relay olfactory impulses), and more numerous connexions from the neopallial cortex of the temporal lobe (which convey the resultants of neopallial activity as a whole). In the human brain the dentate gyrus, as already noted, has undergone very profound retrogressive changes, and the afferent connexions of the hippocampus are undoubtedly now received almost entirely from the cortex of the temporal lobe. It is not improbable, however, that the anterior extremity of the hippocampus, which is incorporated in the uncus, is still concerned mainly with the reception of olfactory impulses. But this forms a very small proportion of the whole hippocampus.

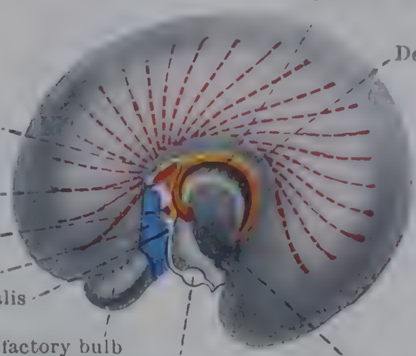

Fig. 843.—Medial Aspect of Right Cerebral Hemisphere of Human Fœtus of Fourth Month.

The broken red lines indicate the paths taken by callosal fibres in the neopallium to reach the upper end of the lamina terminalis.

The **fornix** is the efferent tract from the hippocampus (*a*) to the hippocampus in the other hemisphere, and (*b*) to the hypothalamus.

The axons of the cells of the hippocampus collect on its ventricular surface to form a white layer called the *alveus* (Fig. 844), the fibres of which converge towards the margin of the dentate gyrus, where they bend into a longitudinal direction (*i.e.*, parallel to the edge of the pallium and the choroid fissure) to form a prominent white marginal fringe called the **fimbria** (Fig. 844). The fibres of the fimbria pass first backwards and then upwards and forwards (Fig. 843), and come to lie in the roof of the third ventricle where a certain number of them cross the median plane into the fornix and the fimbria of the other hemisphere, so as to link together in functional association the two hippocampi. The crossing fibres are known as the **hippocampal commissure**.

Most of the fibres that run in the fimbria from the hippocampus to the fornix bend downwards in the anterior lip of the interventricular foramen to enter the thalamic region. They are collected into a vertical rounded column which is called the **anterior column of the fornix**; when it reaches the hypothalamus it bends backward to end in the mamillary body. From the mamillary body (as already noted) the mamillo-thalamic tract relays impulses to the anterior nucleus of the thalamus, and from here again other fibres pass to the gyrus cinguli on the medial aspect of the cerebral hemisphere. The functional significance of this projection-system remains quite obscure, for the nature of the impulses conducted in the first place to the mamillary body by the fornix is unknown.

In primitive vertebrates almost the whole of the cerebral cortex is made up of the piriform area and the hippocampal formation, and in these animals they appear to serve mainly olfactory functions. In the more highly organized brain of mammals, other senses than those of smell acquire a representation in the cortex of the cerebral hemisphere. A definite area of the pallium then becomes set apart to receive impressions of the tactile, visual, auditory, and other senses. This area is the **neopallium**. In the human brain it has grown to such an extent

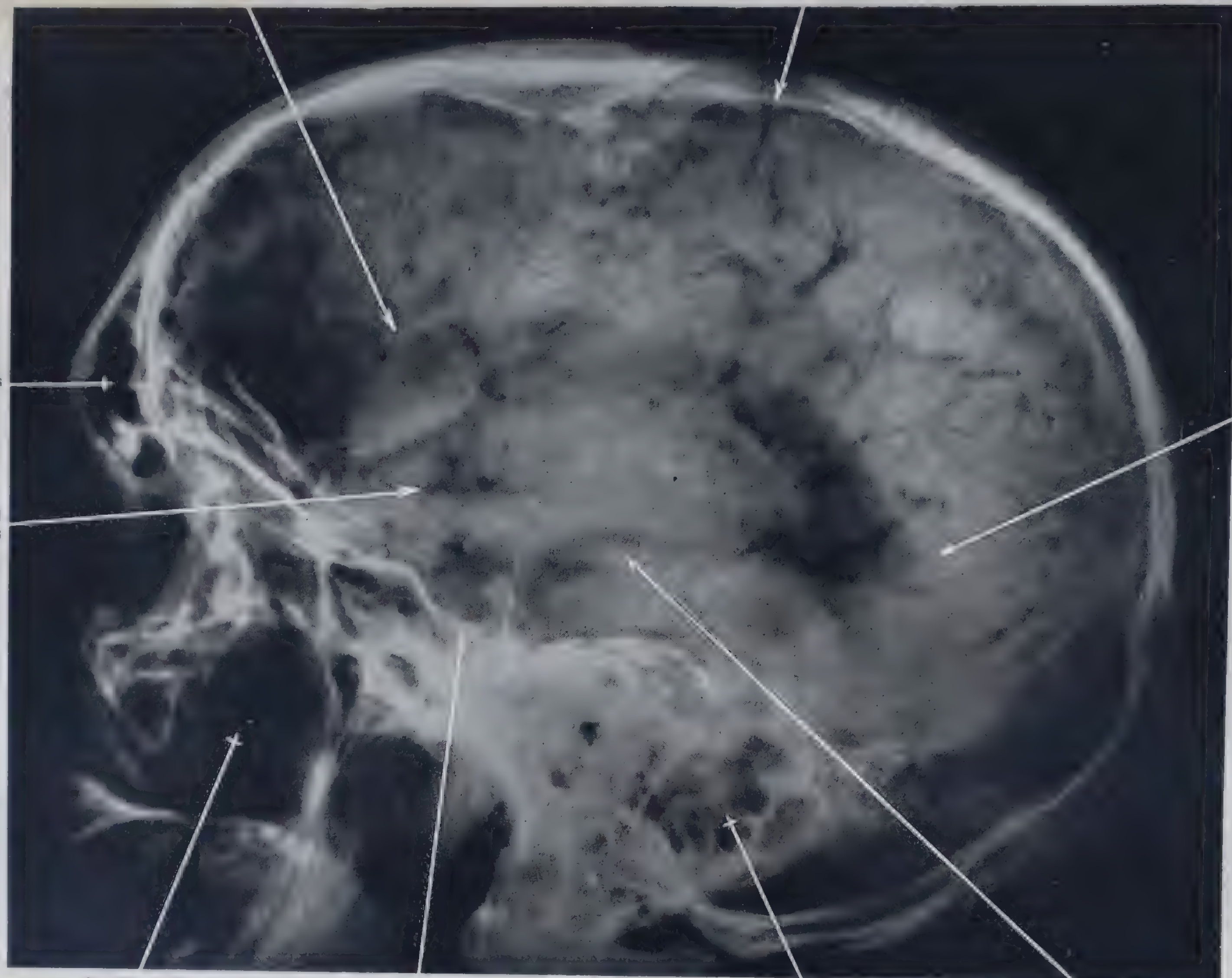

PLATE LXXV.—LATERAL RADIOGRAPH OF LIVING HEAD OF MAN AGED 24, AFTER INJECTION OF OXYGEN INTO THE SPINAL SUBARACHNOID SPACE BY LUMBAR PUNCTURE (Encephalograph : Professor Norman M. Dott).

The Sulci of the Cerebral Hemisphere appear in the radiograph on account of the relative translucency to the X-Rays of the oxygen-filled subarachnoid spaces. The oxygen has entered the Ventricular System also, and the form, size and position of a Lateral Ventricle are well shown. Compare with Plate LXXIV, p. 945, in which the Lateral Ventricles, directly injected, are more obvious but distended.

PLATE LXXVI

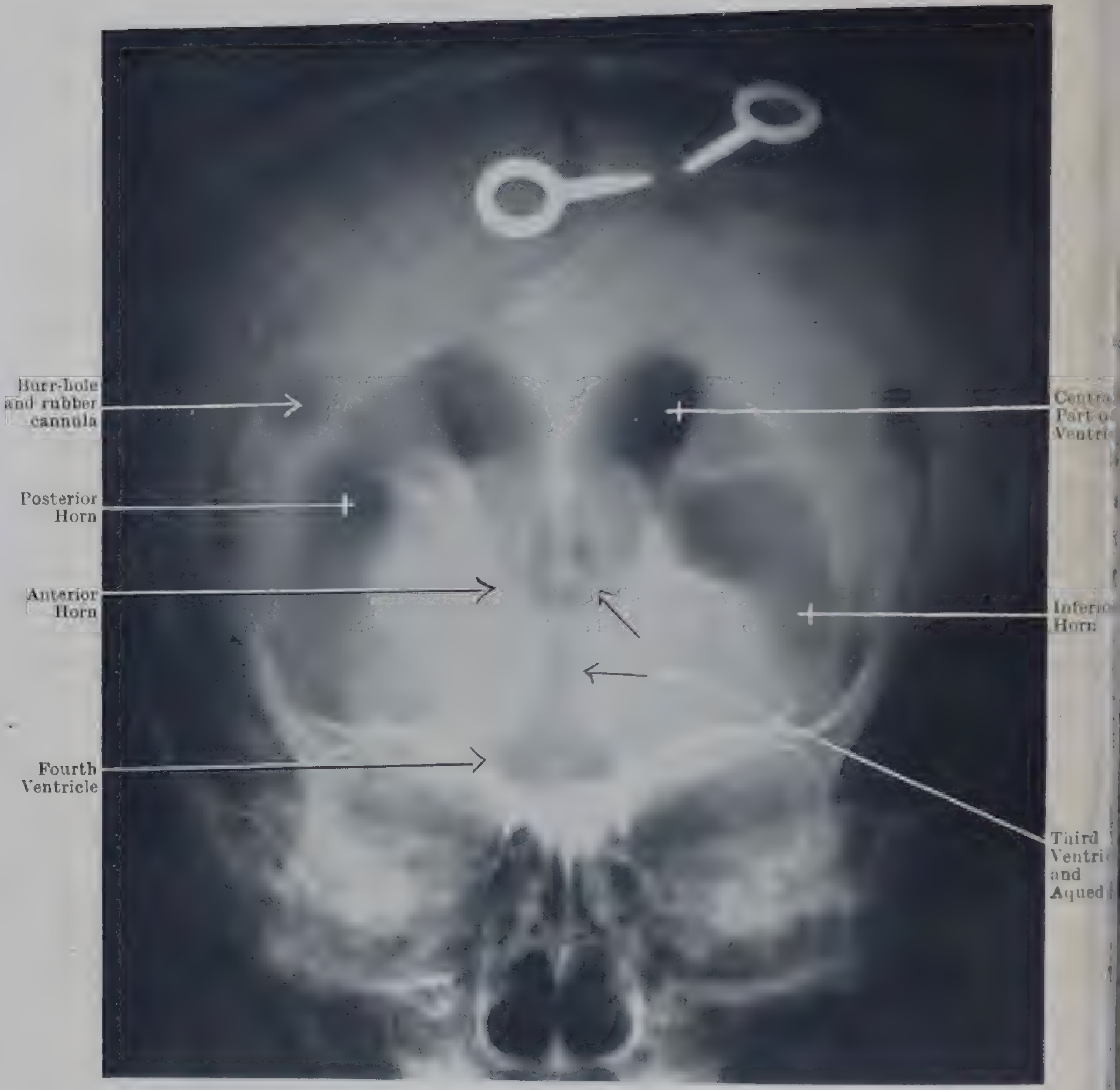

PLATE LXXVI.—ANTERO-POSTERIOR RADIOGRAPH OF LIVING HEAD OF CHILD AGED 4, AFTER DIRECT INJECTION OF OXYGEN INTO THE LATERAL VENTRICLES (Ventriculograph : Professor Norman M. Dott).

The ventricles were slightly distended. For lateral radiograph of the same head, see Plate LXXIV, p. 945.

that it forms almost the whole of the cerebral cortex, and the cerebral hemispheres come to form a mass far greater than the whole of the rest of the brain.

CEREBRAL COMMISSURES AND SEPTUM LUCIDUM

We have seen that certain fibres from the hippocampus cross from one hemisphere to the other, using the upper part of the lamina terminalis as a bridge across the median plane. But at an even earlier stage of development other fibres can

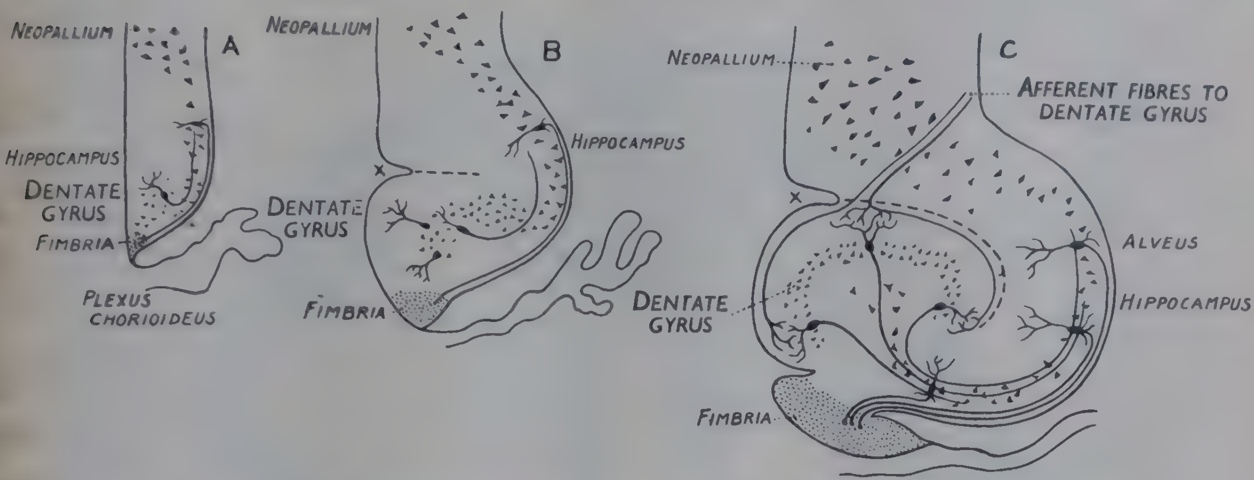

FIG. 844.—THREE STAGES IN THE DEVELOPMENT OF THE HIPPOCAMPAL FORMATION.
The position of the hippocampal fissure is marked X.

be detected at a slightly lower level in the lamina terminalis forming a bundle, of oval outline in sagittal section, called the **anterior commissure.** Its fibres come from the olfactory bulb, area piriformis, olfactory tubercle, and a small temporal area of neopallium. Dorsal to the hippocampal commissure, another commissure is

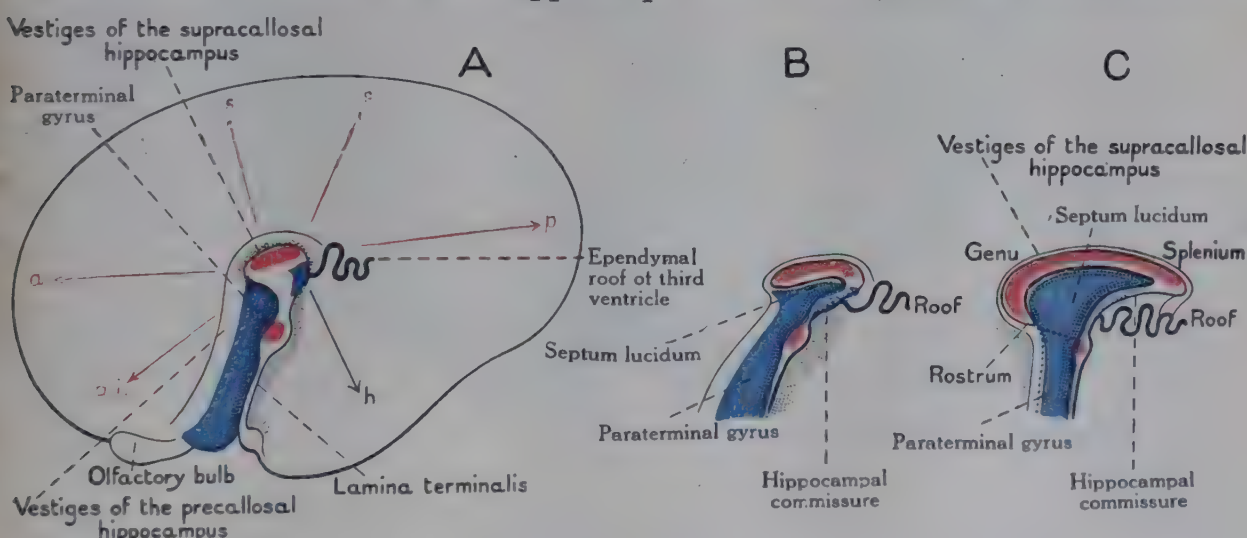

FIG. 845.—THREE STAGES IN THE DEVELOPMENT OF THE CORPUS CALLOSUM.

formed through which the neopallial part of the cortex of one side is connected by a bridge of transverse fibres with that of the other. This is the **corpus callosum.** As the corpus callosum elongates, it pushes its way forwards in the upper part of the paraterminal gyrus of each hemisphere, and as development proceeds a small area of the grey matter related to this gyrus becomes almost completely circumscribed by the corpus callosum and hippocampal commissure. As these commissural bands increase in size this area of grey matter becomes greatly stretched and expanded to form a thin translucent leaf—the **septum lucidum.** A narrow median cleft appears in the septum lucidum dividing it into a pair of laminæ; it is called the *cavity of the septum lucidum.*

As the posterior part of the corpus callosum pushes its way backwards, it

exerts traction on the fibres of the hippocampal commissure and this becomes enormously stretched so as to form a thin lamella (the floor of the cavity of the septum) stretching from a point just above the anterior commissure to the under surface of the swollen posterior end of the corpus callosum, which is called the **splenium** (Fig. 842). The whole of that part of the fornix which lies in the roof of the third ventricle is called the **body of the fornix**, while the part which connects the body with the fimbria of either side is the **posterior column of the fornix.**

The dentate gyrus appears as a notched band behind and below the fimbria;

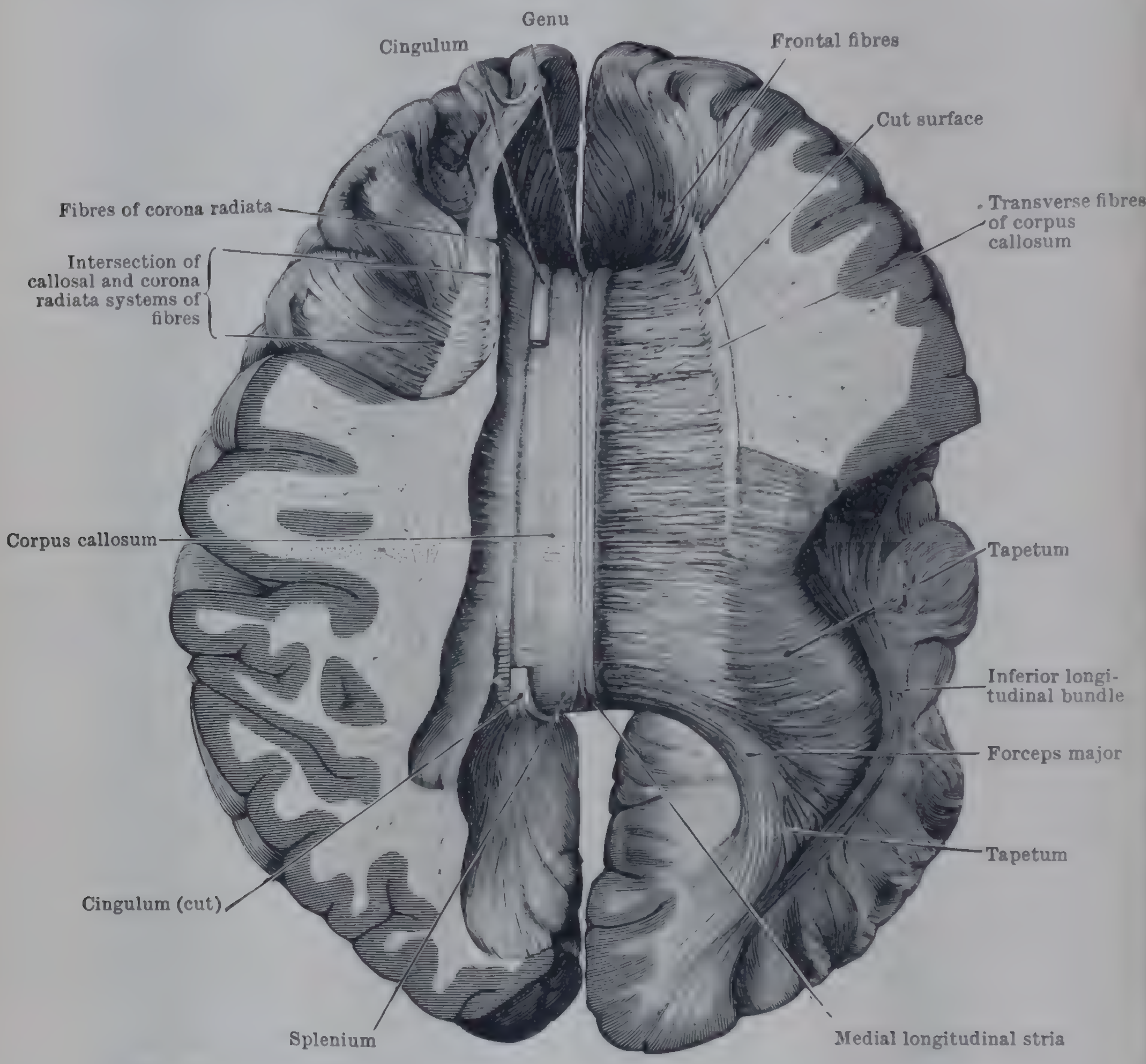

FIG. 846.—CORPUS CALLOSUM, EXPOSED FROM ABOVE AND RIGHT HALF DISSECTED.

its upper end passes on to the under surface of the splenium of the corpus callosum, where it tapers and appears to end; but a close inspection shows that the hippocampal formation is continued as a narrow band round the splenium and passes into a thin film of grey matter—**indusium griseum**—which is prolonged on to the upper surface of the corpus callosum. It proceeds forwards, becoming as a rule still more attenuated, and after surrounding the anterior end (**genu**) of the corpus callosum it passes downwards towards the olfactory pyramid along the line that separates the paraterminal gyrus from the neopallium. The indusium represents the atrophied remains of the anterior part of the hippocampal arc of the fœtal brain (Fig. 843). It is accompanied by longitudinal fibres—the **striæ longitudinales** of the corpus callosum (Figs. 842, 845, 850).

The anterior end of the dentate gyrus dips into a deep furrow in the uncus of the temporal lobe; here it becomes considerably reduced in diameter and then emerges (at right angles to its previous direction) to form the **tail of the dentate gyrus**. Immediately in front of the upper end of the tail of the dentate

gyrus a little knob of solid grey matter appears upon the surface in the middle of the uncus. This is the **amygdaloid nucleus** (Fig. 842).

Corpus Callosum.—The corpus callosum is the great neopallial commissure. It is placed nearer the anterior than the posterior end of the brain; it unites the medial surfaces of the hemispheres throughout very nearly a half of their antero-posterior length, and is highly arched from before backwards (Fig. 829).

The *superior surface* of the corpus callosum forms the bottom of the longitudinal fissure, and on each side of this it is separated from the gyrus cinguli by a slit called the *callosal sulcus*. The surface is covered with the **indusium griseum**, which is continuous at the bottom of the callosal sulcus with the cortex of each hemisphere. Two pairs of delicate longitudinal bands or striæ are embedded in the indusium. The **medial longitudinal stria** is the more strongly marked, and is separated from its fellow of the opposite side by a faint median furrow. The **lateral longitudinal stria** is under cover of the gyrus cinguli. The indusium, with the striæ, represents the vestigial remains of the hippocampus (see above). So thin is the indusium that the transverse direction pursued by the callosal fibres can be easily perceived through it.

The *two ends* of the corpus callosum are much thicker than the main part or **trunk**. The *posterior end*, which is full and rounded, lies over the mid-brain and extends backwards as far as the highest point of the cerebellum. It is called the **splenium**, and its lower part is bent forwards under the upper part, to the inferior surface of which it is closely applied. The *anterior end* is folded downwards and backwards on itself. It is termed the **genu**. The recurved inferior part of the genu rapidly thins as it passes backwards, and receives the name of the **rostrum**. The fine terminal edge of the rostrum becomes connected by means of a band of neuroglial tissue with the lamina terminalis on the front of the anterior commissure (Fig. 829 and dotted line in Fig. 845 C).

The *inferior surface* of the corpus callosum, on each side of the median plane, is coated with ependyma (Fig. 850, p. 967) and forms the roof of the anterior horn and the central part of the lateral ventricle. In the median plane, however, it is attached to subjacent parts, viz., to the septum lucidum in front and directly or indirectly (Fig. 829) to the body of the fornix behind (Fig. 850).

The transverse fibres of the corpus callosum, as they enter the white centre of the cerebral hemisphere, splay out to reach most parts of the cerebral cortex. These diverging fibres intersect those which form the *corona radiata*, that is, the fibres which extend between the internal capsule and the cerebral cortex (Figs. 854 and 855, p. 971). The more anterior of the fibres which compose the genu of the corpus callosum sweep forwards in a series of curves into the anterior region of each hemisphere, and the name **forceps minor** is given to the figure formed by these curving bundles. A large part of the splenium, forming a solid bundle termed the **forceps major**, bends suddenly and abruptly backwards into the occipital lobe (Fig. 846). Fibres from the trunk and upper part of the splenium, curving round the lateral ventricle, form a very definite stratum called the **tapetum**. It is a thin layer in the white centre of the hemisphere which constitutes the immediate roof and lateral wall of the posterior horn and the lateral wall of the inferior horn of the lateral ventricle. In coronal sections through the occipital and posterior temporal regions the tapetum stands out very distinctly (Fig. 846; see also Figs. 851, p. 967, and 853, p. 969).

Septum Lucidum (Fig. 829).—This is a thin vertical partition which intervenes between the two lateral ventricles. It is triangular in shape, and posteriorly it is prolonged backwards for a variable distance between the trunk of the corpus callosum and the fornix, to both of which it is attached. In front it occupies the gap behind the genu of the corpus callosum, whilst below, in the narrow interval between the posterior edge of the rostrum of the corpus callosum and the fornix, it is continuous, in early stages, with the paraterminal gyrus; but the subsequent development of the band of neuroglial tissue (see above) extending from the rostrum to the lamina terminalis breaks this continuity. The septum lucidum is composed of a pair of thin laminæ which are close together but separated (Fig. 848 Fig. 850, p. 967) by a cavity of variable size.

Lateral Ventricle

The cavity in the interior of the cerebral hemisphere is called the **lateral ventricle**. It is lined throughout with ependyma and is filled with cerebro-spinal fluid; it is of varying size, being reduced to a mere chink in places, *e.g.*, the posterior horn; and it communicates with the third ventricle of the brain by means of the **interventricular foramen** (Figs. 829, 849 and Pl. LXXIV, p. 945).

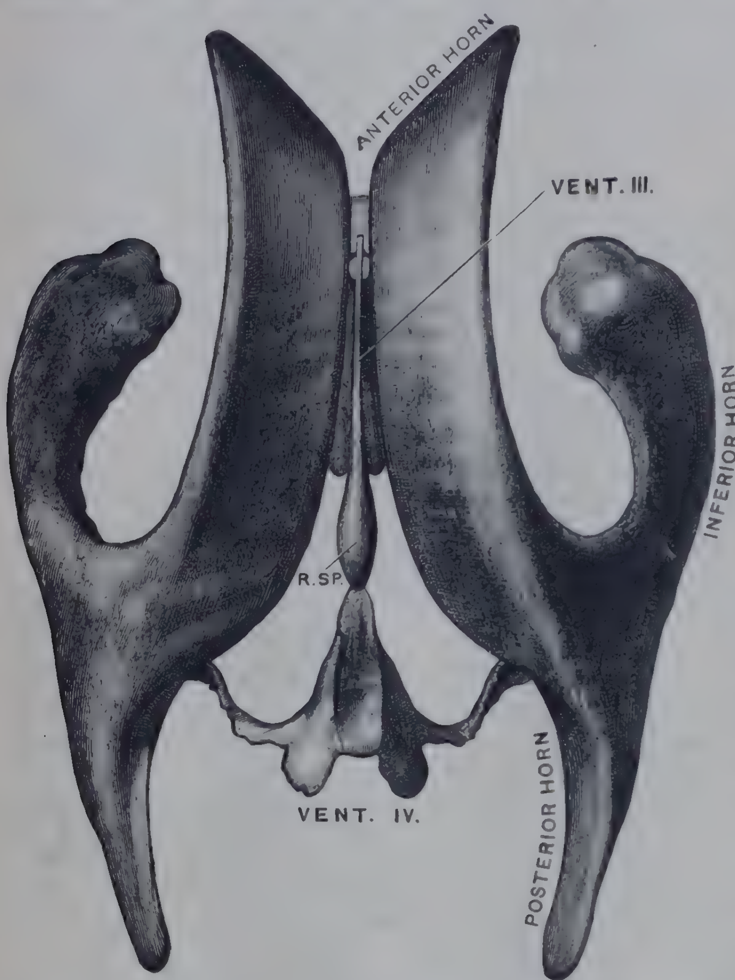

Fig. 847.—Drawing of Cast of Ventricular System of the Brain, seen from above. (After Retzius, 1900.)
Vent. III. Third ventricle. Vent. IV. Fourth ventricle.
R.SP. Suprapineal recess.

The highly irregular shape of the lateral ventricle can be best understood by the study of a cast of its interior (Figs. 830, p. 949, and 847). It is divisible into a central part and three horns,—anterior posterior, and inferior. The **anterior horn** is the part of the cavity in front of the interventricular foramen. The **central part** extends from the interventricular foramen to the splenium of the corpus callosum. At that level it is continuous with the posterior and inferior horns, which diverge from each other. The **posterior horn** curves backwards and medially into the occipital lobe. It is very variable in its length and capacity, for adhesions may occur between its walls. The **inferior horn** proceeds with a bold sweep round the posterior end of the thalamus, tunnels downwards and forwards in the temporal lobe, and then turns medially to end in the region of the uncus (Fig. 852).

The early fœtal lateral ventricle is very capacious and presents an arched form. Its parts correspond to the anterior horn, the central part and the inferior horn, and there is little or no demarcation between them. The posterior horn is a later production which grows backwards into the occipital lobe from the primitive cavity.

The **anterior horn** extends in a forward and lateral direction in the frontal lobe. When seen in coronal section (Fig. 848) it presents a triangular outline. It is bounded *in front* by the fibres of the genu of the corpus callosum; the *roof* is the trunk of the corpus callosum and the floor is the rostrum. The *medial wall*, which is vertical, is the septum lucidum; the *lateral wall* is sloping and presents a marked elevation or bulging, formed by the smooth, rounded head of the caudate nucleus.

The **central part** of the cavity also is *roofed* by the trunk of the corpus callosum. On the *medial side* it is bounded by the posterior part of the septum lucidum and by the line of contact between the corpus callosum and the body of the fornix. On the *lateral side* it is closed by the meeting of the floor and the roof of the cavity. On the *floor* a number of important objects may be recognized. From the lateral to the medial side they are met in the following order: (1) the body of the caudate nucleus; (2) a groove which extends obliquely from before backwards and laterally between the caudate nucleus and the thalamus, and in which are placed the thalamo-striate vein and a white band called the stria semicircularis; (3) a

portion of the upper surface of the thalamus; (4) the choroid plexus; (5) the sharp edge of the body of the fornix (Fig. 849).

The **caudate nucleus** narrows rapidly as it proceeds backwards on the lateral part of the floor of the lateral ventricle. The thalamo-striate vein is covered over with ependyma; it joins the internal cerebral vein close to the interventricular foramen. The connexions of the **stria semicircularis** will be dealt with later. The portion of the upper surface of the **thalamus** which appears in the floor of the ventricle is in great part hidden under the choroid plexus. The ependymal strip of the wall of the hemisphere, as it extends between the edge of the fornix and the upper surface of the thalamus, is invaginated at the choroid fissure into the central part of the lateral ventricle by the richly vascularized edge of the pial fold called the tela chorioidea. This vascular fringe with its ependymal covering is called the **choroid plexus**. In front it is continuous, in the interventricular foramen, with the choroid plexus of the third ventricle (Fig. 829 and Fig. 848), whilst, behind, it is carried into the inferior horn of the ventricle. Although the choroid plexus has all the appearance of lying free within the ventricle, it must be borne in mind that it is invested by the ependyma which represents a portion of the wall of the hemisphere and excludes it from the cavity. As elsewhere, the ependyma which covers the choroid plexus is modified to form a secretory epithelium concerned with the production of cerebro-spinal fluid.

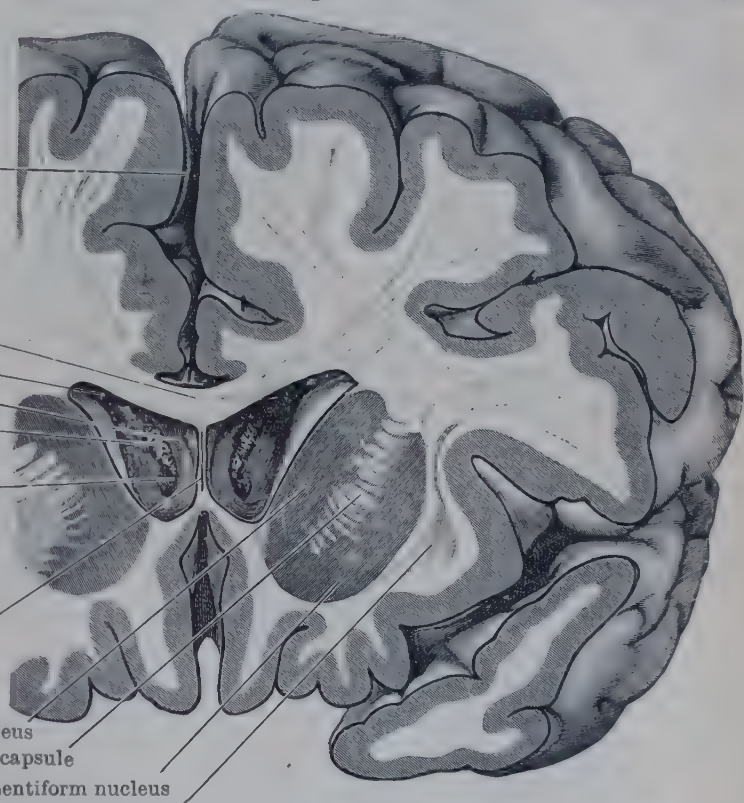

FIG. 848.—CORONAL SECTION THROUGH THE CEREBRAL HEMISPHERES. The section (viewed from the front) cuts the anterior horns of the lateral ventricles, through which the central part of the ventricles, the anterior columns of the fornix, and the interventricular foramina can be seen.

The **posterior horn** is an elongated diverticulum carried backwards into the occipital lobe from the posterior end of the ventricle. It tapers to a point and describes a gentle curve, the convexity of which is directed laterally. Its *roof* and *lateral wall* are formed by the tapetum of the corpus callosum. In coronal sections through the occipital lobe the tapetum is seen as a thin but distinct white layer immediately lateral to the ependyma and to the medial side of a much larger sheet of fibres, viz., the optic radiation.

On the *medial wall* two elongated curved elevations may be observed. The upper of them is termed the **bulb of the posterior horn**, and is produced by the forceps major. Below the bulb is the elevation known as the **calcar avis**. It varies greatly in size in different brains, and is caused by an infolding of the ventricular wall in correspondence with the calcarine sulcus on the exterior of the hemisphere. It may come into contact with and adhere to the lateral wall of the horn in a part or even the whole of its extent.

The calcar avis, which used to be called the "hippocampus minor", has a curious literary association. It is actually mentioned in Charles Kingsley's classical fairy-tale, *The Water-Babies* (chap. 5), where the author amusingly refers to it as the "hippopotamus major". The occasion

for this digression by Kingsley was the famous meeting of the British Association at Oxford in 1860 when a highly animated discussion took place on the subject of Man's descent from lower animals. Sir Richard Owen, the distinguished comparative anatomist, had contended that the hippocampus minor is a feature characteristic of the human brain whereby it is sharply distinguished from the ape's brain. Professor T. H. Huxley, however, had no difficulty in demonstrating the presence of the hippocampus minor in the brain of the chimpanzee, and thus provided a debating point which perhaps received a rather exaggerated emphasis in the ensuing controversy.

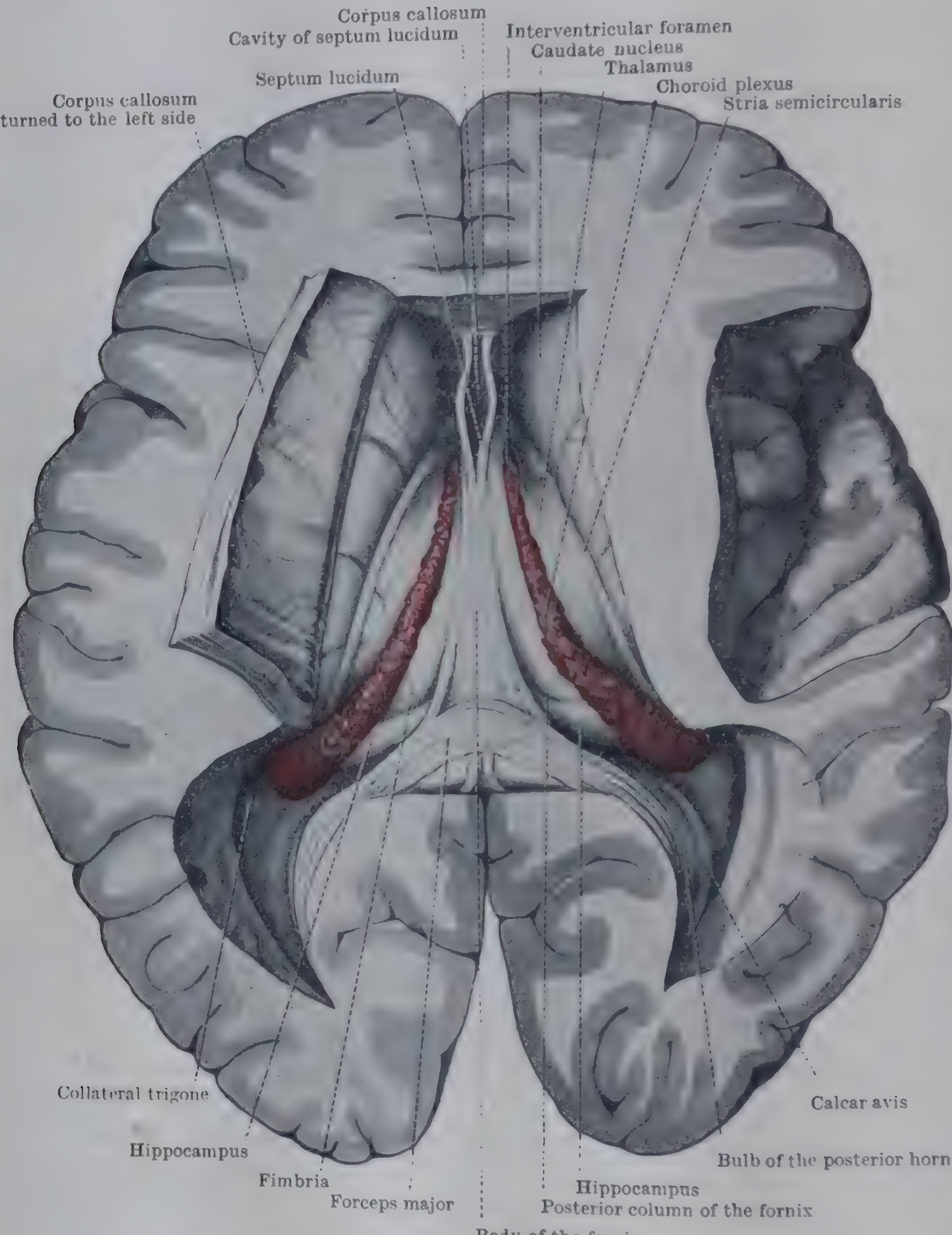

FIG. 849.—DISSECTION TO SHOW THE FORNIX AND LATERAL VENTRICLES.

The **inferior horn** is the continuation of the cavity into the temporal lobe. It is prolonged downwards and forwards behind the thalamus into the temporal lobe, in the centre of which it takes a curved course forwards and medially as far as the uncus.

In the angle between the diverging posterior and descending horns, and therefore between the calcar avis and the hippocampus as they diverge, the cavity presents an expansion of triangular shape, the floor of which is raised and is known as the **collateral trigone**. This eminence is raised up by the collateral sulcus which lies in immediate relation to it.

The *lateral wall* of the inferior horn is formed by the tapetum of the corpus

callosum. At the end of the horn, the *roof* presents a bulging produced by a collection of grey matter termed the **amygdaloid nucleus.** The **stria semicircularis** and the attenuated **tail of the caudate nucleus** are both prolonged into the inferior horn and are carried forwards in its roof to the amygdaloid nucleus. The ependymal *medial wall* of the descending horn is inthrust to form the temporal continua-

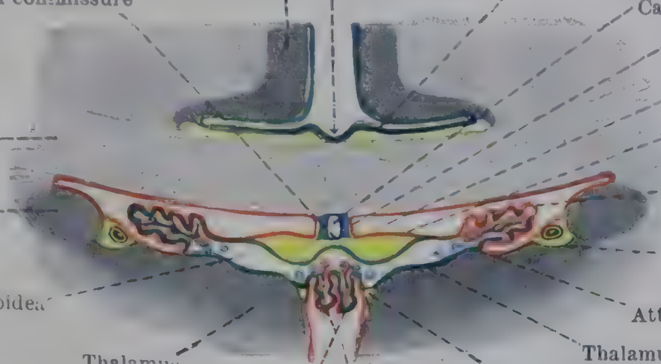

FIG. 850.—DIAGRAM OF CORONAL SECTION THROUGH CENTRAL PARTS OF LATERAL VENTRICLES.

tion of the choroid fissure, in which the choroid plexus is carried downwards and forwards.

On *the floor* of the inferior horn the following structures are seen: (1)

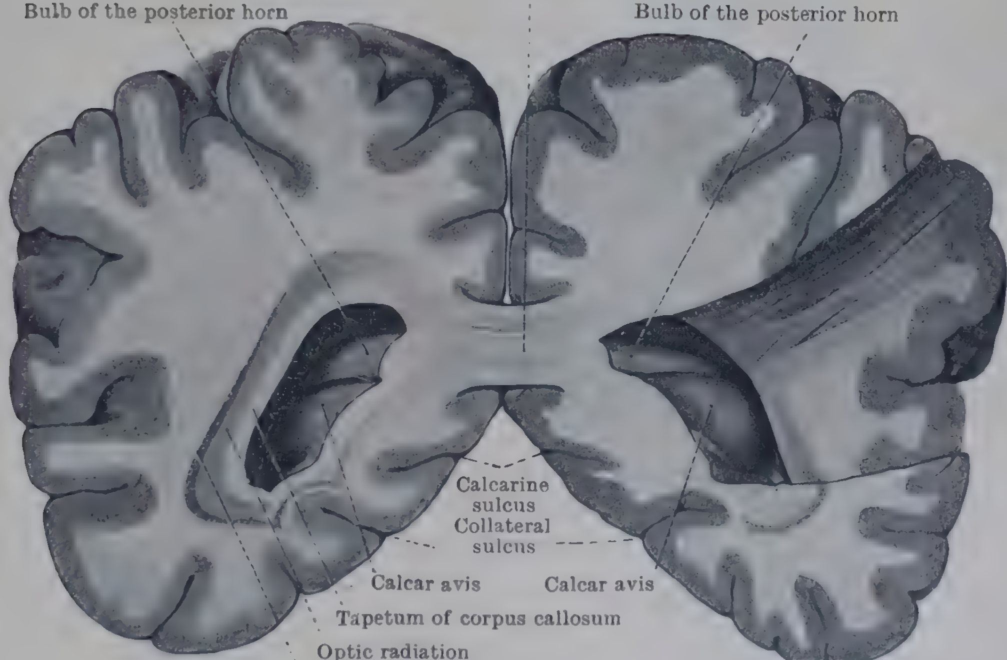

FIG. 851.—CORONAL SECTION THROUGH POSTERIOR HORNS OF LATERAL VENTRICLES, VIEWED FROM THE FRONT.

hippocampus; (2) the choroid plexus; (3) the fimbria; and (4) the collateral eminence.

The **hippocampus** forms an elongated swelling which extends to the tip of the inferior horn and is overlapped by the fimbria. At its anterior extremity it expands into a rounded and slightly lobulated eminence—the *pes hippocampi.* The hippocampus is for the most part covered by the choroid plexus. If this is detached the course of the choroid fissure is seen between the fimbria and the roof of the horn. This fissure appears at a very early date in the development of the cerebral hemisphere, and takes an arcuate course round the posterior end of

the thalamus (Fig. 837). In the region of the central part of the ventricle it extends as far forwards as the interventricular foramen and is formed by the involution of the ependymal part of the wall of the ventricle over the choroid plexus. In the region of the inferior horn, when the choroid plexus, with the involuted ependymal layer which covers it, is withdrawn, the choroid fissure is converted into an artificial gap which leads directly into the horn.

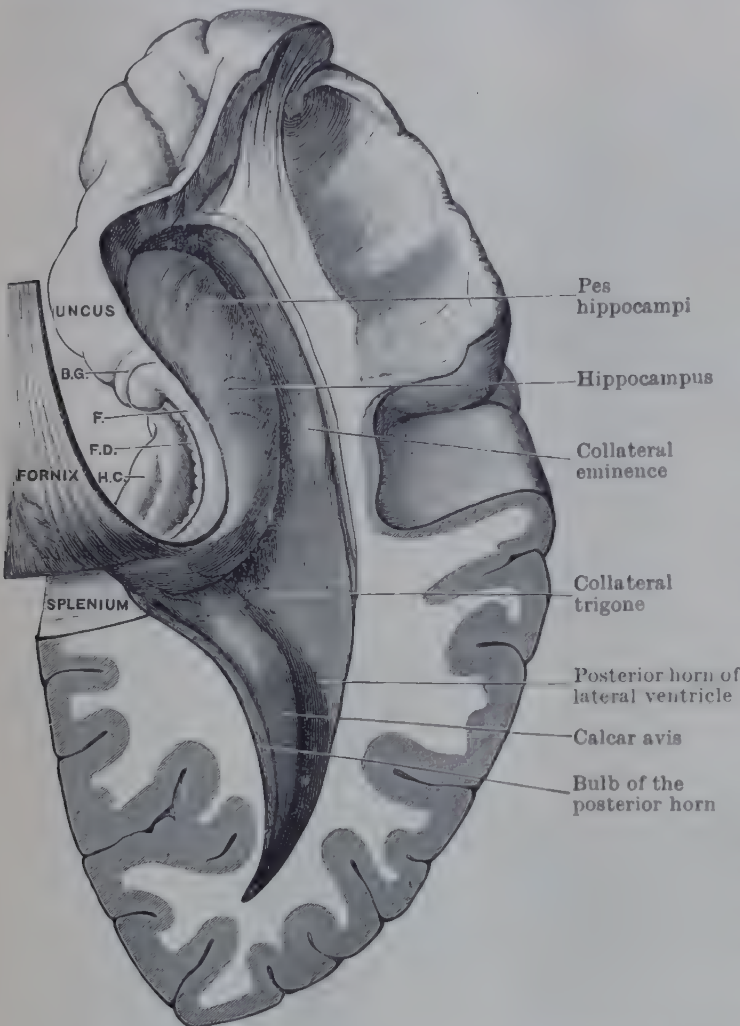

Fig. 852.—Dissection from above to show Posterior and Inferior Horns of Lateral Ventricle.

B.G. Tail of dentate gyrus. F.D. Dentate gyrus.
F. Fimbria hippocampi. H.C. Hippocampal gyrus.

The **choroid plexus** is a convoluted system of blood-vessels embedded in a fold of pia mater which is carried into the central part and the inferior horn of the ventricle. It lies on the surface of the hippocampus and is continuous, behind the posterior part of the thalamus, with the choroid plexus in the central part of the ventricle. But the choroid plexus does not lie free in the ventricular cavity. It is clothed in the most intimate manner by an ependymal layer which represents the medial wall of the inferior horn and central part of the ventricle involuted into the cavity over the plexus. The ventricle, therefore, opens on the surface through the choroid fissure only when that thin epithelial layer is torn away by the withdrawal of the choroid plexus. From the above, it will be understood that the choroid fissure, throughout its whole length (viz., from the interventricular foramen to the end of the inferior horn), is formed by the invagination of a portion of the wall of the hemisphere which remains ependymal. In the central part of the ventricle this layer is attached, on the one hand, to the margin of the fornix, and on the other to the upper surface of the thalamus; in the inferior horn it is attached to the edge of the fimbria, whilst, above, it joins the roof of the horn along the line of the stria semicircularis.

The **collateral eminence** (Fig. 852) varies greatly in its degree of development, which depends upon the depth of the corresponding part of the collateral sulcus in the tentorial surface of the temporal lobe.

Basal Nuclei

Under this heading are included certain masses of grey matter more or less completely embedded in the white substance of the hemisphere. They are the caudate and lentiform nuclei (which together form the corpus striatum) the amygdaloid nucleus, and the claustrum.

The **caudate nucleus** bulges into the lateral ventricle. It is a long curved mass of grey matter divisible into a head, a body and a tail. The head is the smooth bulging seen in the lateral wall of the anterior horn of the ventricle; and

its lower part is continuous with the anterior perforated substance. The body—much narrower—extends backwards in the floor of the central part of the ventricle where it is separated from the thalamus by the stria semicircularis. The tail curves downwards with a bold sweep and enters the inferior horn, in the roof of which it is prolonged forwards to join the amygdaloid nucleus. The caudate nucleus thus presents a free ventricular surface, covered with ependyma, and a deep surface applied to the medial side of the internal capsule and the base of the corona radiata; and, owing to its arched form, it is cut in two places in many of the sections of the hemispheres—both horizontal and coronal.

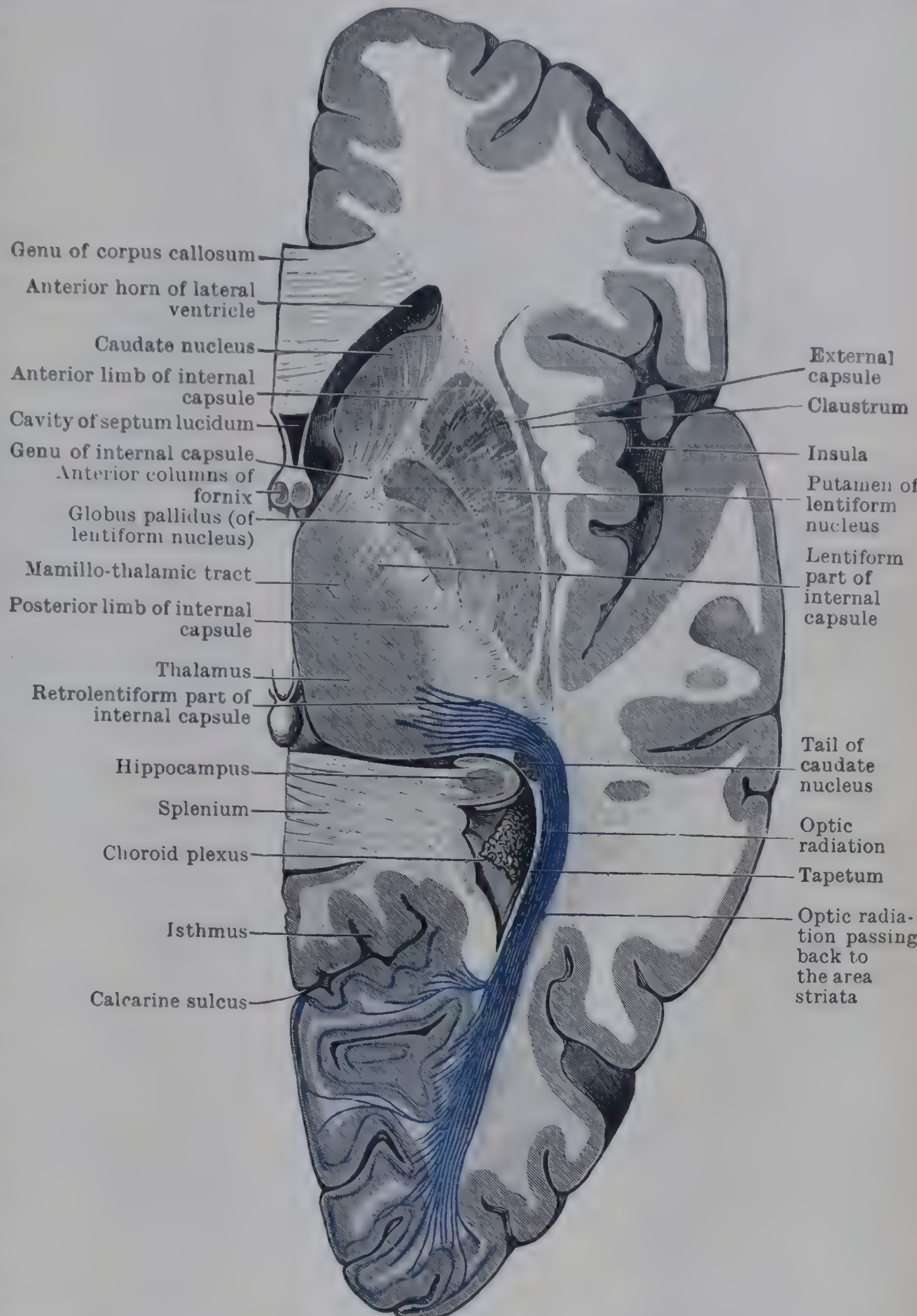

Fig. 853.—Horizontal Section of Right Cerebral Hemisphere at Level of Widest Part of Lentiform Nucleus.

The **lentiform nucleus** is for the most part embedded in the white substance of the cerebral hemisphere lateral to the thalamus and the head of the caudate nucleus. It does not extend either so far forwards or so far backwards as the caudate nucleus; indeed, in extent, it corresponds very closely with the insula. When seen in horizontal section, it presents a shape similar to that of a biconvex lens. Its medial surface bulges more than the lateral surface, and its point of highest convexity is placed opposite the stria semicircularis and the interval between the head of the caudate nucleus and the thalamus. In coronal section the appearance differs very much in different planes of section. Fig. 854 represents a section through its anterior portion. Here it is semilunar in outline; its lower part is directly continuous with the head of the caudate nucleus, and its upper part is intimately connected with the caudate nucleus by bands of grey matter which pass between the two nuclei, breaking up the anterior part of the internal capsule. It is due to the ribbed or barred appearance presented by such a section as this that the term **corpus striatum** is applied to the two nuclei. In the region of the anterior perforated substance both nuclei are fused together where they approach close to the basal surface of the brain.

When a section is made in a plane farther back (*e.g.*, immediately behind the

anterior commissure, as in Fig. 855) the lentiform nucleus has an altogether different shape, and is seen to be completely cut off from the body of the caudate nucleus by the base of the corona radiata (the knife having passed behind the uniting bars of grey matter). It is now wedge-shaped. Its *base* is turned towards the insula and is in direct relation to a thin lamina of white matter termed the external capsule. Its *medial surface* is oblique and is applied to the internal capsule, whilst its *inferior surface* is horizontal and is related to the amygdaloid nucleus and the white matter above the roof of the inferior horn of the ventricle. But, further, two white laminæ are now evident; they traverse its substance in a vertical direction and divide it into three masses; the lateral and larger mass is termed the **putamen**, and the medial two portions together constitute the **globus pallidus**.

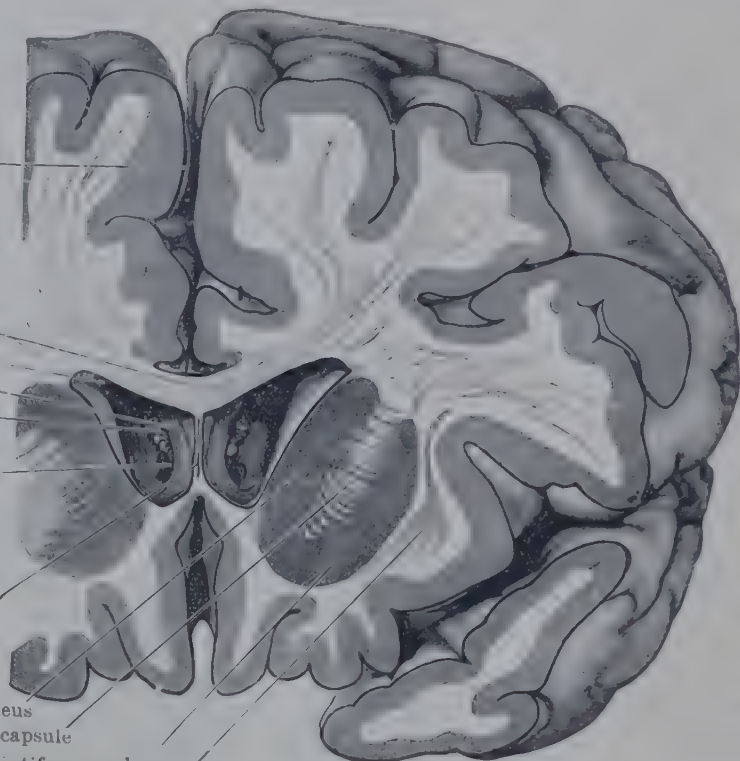

FIG. 854.—CORONAL SECTION THROUGH THE CEREBRAL HEMISPHERES. The section (viewed from the front) cuts the putamen of the lentiform nucleus in front of the globus pallidus.

The **putamen** is much the largest part of the lentiform nucleus. In colour it resembles the caudate nucleus, with which it is closely associated both in structure and in mode of development; and it is the only part of the lentiform nucleus which is connected by bands of grey matter with the caudate nucleus. In antero-posterior length as well as in vertical depth the putamen is larger than the globus pallidus; consequently, in both coronal and horizontal sections through the cerebrum it is encountered before the plane of the globus pallidus is reached.

The external capsule is loosely connected with the lateral surface of the putamen, and it can be readily stripped off. This accounts for the tendency, exhibited in hæmorrhages in this locality, for the effused blood to spread out in the interval between these structures.

The **globus pallidus** is composed of the two smaller and medial masses of the lentiform nucleus. They present a faint yellowish tint, and are paler and more abundantly traversed by medullated fibres than the putamen. The part next the putamen is much larger than the other and extends forwards to a point a little in front of the plane of the anterior commissure.

Structure and Connexions of Corpus Striatum.—It is remarkable, in spite of intensive investigations, that little is yet known of the details of the connexions and functions of this large mass of grey matter which lies embedded in each cerebral hemisphere. It may be said, however, that the corpus striatum represents the "head-nucleus" of a primitive efferent system of the brain—the so-called *extrapyramidal system*. This motor path precedes in evolutionary development the pyramidal tract system (whereby the lower motor levels of the brain-stem and spinal cord are brought under direct cortical control), and it is much more diffusely organized. Interposed in the course of the descending fibres which leave the corpus striatum and enter the brain-stem are a number of nuclear elements which have been described in previous sections, *e.g.*, the subthalamic nucleus, substantia

nigra, the red nucleus, and the olivary nucleus. All these are commonly included as component parts of the extrapyramidal system.

It has already been noted that the caudate nucleus and the putamen have the same macroscopic appearance in section, that they are incompletely separated from each other, and that their partial separation by the internal capsule and the base of the corona radiata is secondarily effected during embryonic development. In their histological structure the two elements are also identical, being composed of densely packed small cells with quite short axons, interspersed with which are scattered larger cells with longer axons. In contrast, the globus pallidus is composed of characteristic large multipolar cells, closely resembling in general appearance typical motor cells of the brain-stem and spinal cord. The structural distinction from the globus pallidus which the caudate nucleus and putamen show has led in recent years to a modification of the usual terminology applied to these elements, for many writers now use the term *striatum* for the caudate nucleus and putamen together, while the globus pallidus is referred to as the *pallidum*. These names have the considerable merit of brevity and convenience.

The afferent connexions of the **striatum** are very uncertain. It has been suggested

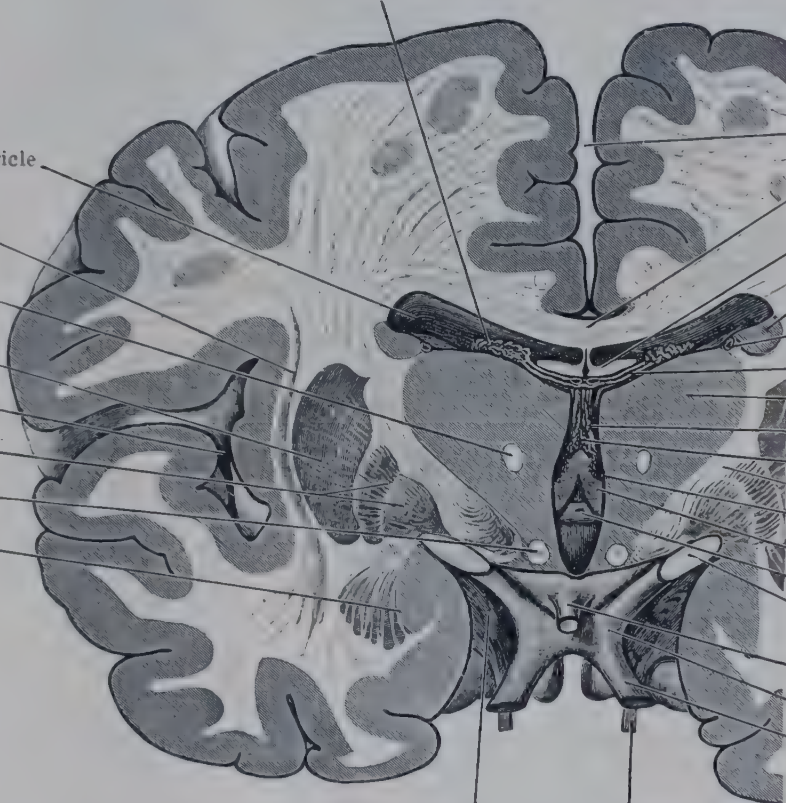

Fig. 855.—Coronal Section through the Cerebrum (viewed from behind) to show the Parts of the Lentiform Nucleus.

that ascending fibres from the subthalamus, conveying a variety of impulses, end in it, but a satisfactory demonstration of some of these presumed connexions has yet to be made. In recent years, however, it has been definitely established that the caudate nucleus receives ascending connexions from the substantia nigra. Descending connexions also exist between certain areas of the cerebral cortex and the caudate nucleus and putamen (see p. 972). Fibres which run in both directions between the striatum and thalamus have also been described, but while strio-thalamic connexions remain doubtful, thalamo-striate fibres almost certainly do not exist except in the case of the centre median nucleus (from which fibres probably pass to the globus pallidus). Numerous short connexions are known to interconnect different parts of the caudate nucleus and putamen with each other, and fibres also run from both these elements to the pallidum. Apart from the latter, no efferent fibres leave the striatum to reach other parts of the brain.

The afferent connexions of the **pallidum** are almost entirely derived from the other striatal elements. There is some evidence that ascending fibres from the hypothalamus and subthalamus reach it, and, in recent years, anatomical and electro-physiological studies have demonstrated that a few fibres of the medial lemniscus (which have their origin in the gracile and cuneate nuclei) terminate in the globus pallidus of the opposite side. Descending fibres from the premotor and general sensory areas of the cortex (and probably from certain other areas) also reach the globus pallidus.

The pallidum is essentially the *efferent* nucleus of the basal nuclei, and from its large motor cells numerous fine medullated fibres take their origin and stream in a downward and medial direction. They describe a characteristic loop over the fibres of the internal capsule where these emerge to form the basis pedunculi, and make their way into the subthalamus and the tegmentum of the mid-brain. This loop is called the **ansa lenticularis** (Fig. 856).

The fibres of the ansa lenticularis end in five main stations: (1) the hypothalamus, (2) the subthalamic nucleus, (3) the substantia nigra, (4) the red nucleus, and (5) the olivary nucleus. Some of these fibres may cross the median plane, but most end on the same side of the brain-stem.

It may be noted that the elucidation of the fibre-connexions of the basal nuclei is made exceptionally difficult by the fact that many fibres which penetrate them are fibres of passage only. For example, large numbers of afferent and efferent cortical fibres run through the caudate nucleus and the putamen on their way up to the cortex or down into the brain-stem.

Whatever the nature of the afferent impulses may be which reach the basal nuclei, it is clear that, by way of the efferent system which leaves the pallidum, they can influence the activities of the hypothalamus, and also those of the red nucleus, subthalamic nuclei and substantia nigra. The last three elements provide intermediate stations through which the basal nuclei are able to modify the activities of lower motor neurons in the brain-stem and spinal cord and thus play a part in the regulation of the tonus of the voluntary musculature of the body. Lastly, the pallido-olivary tract provides a pathway through which the basal nuclei are brought into functional relation with the cerebellar hemisphere of the opposite side.

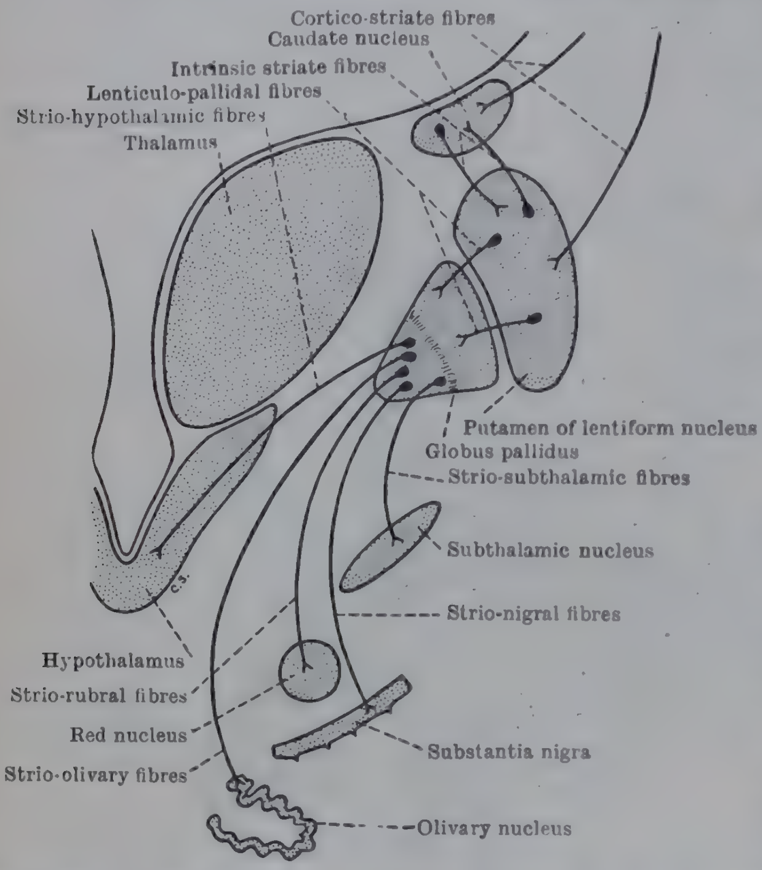

FIG. 856.—DIAGRAM ILLUSTRATING CONNEXIONS OF THE BASAL NUCLEI. The fibres that issue from the globus pallidus constitute the ansa lenticularis.

The relation of the basal nuclei to the control of muscle-tonus is emphasized by clinical observations. For example, lesions affecting the caudate nucleus and putamen are commonly associated with muscular rigidity and a characteristic tremor, while lesions of the globus pallidus are often associated with involuntary spasmodic movements (athetosis and chorea).

For further information on the connexions and functions of the corpus striatum, see *The Diseases of the Basal Ganglia*, edited by T. J. Putnam, 1942.

Claustrum.—This is a thin plate of grey substance embedded in the white matter between the lentiform nucleus and the cortex of the insula. Followed in an upward direction, it becomes gradually thinner and ultimately disappears.

As it is traced downwards, however, it thickens considerably, and at the base of the brain it fuses with the putamen of the lentiform nucleus where this comes to the surface at the anterior perforated substance. Its extent corresponds very closely with the area occupied by the insula, and its lateral surface shows ridges and depressions that correspond to the insular gyri and sulci.

In its histological structure, the claustrum shows resemblances to the underlying putamen, and also to the deeper layers of the superjacent cortex. Embryological evidence also indicates that it is of composite origin, derived from neuroblastic tissue which contributes to the development of the striatum and also from that which gives rise to adjacent parts of the cortex. The functional significance of the claustrum is quite unknown.

Amygdaloid Nucleus.—Near the anterior end of the temporal lobe, a fusiform mass of grey matter appears on the upper surface of the uncus (Fig. 842, p. 959), at the lateral border of the anterior perforated substance (Fig. 831, p. 950). It is part of a rounded mass, called the **amygdaloid nucleus**, which occupies a position in front of and to some extent above the anterior end of the inferior horn of the lateral ventricle. The amygdaloid nucleus is really a composite structure, composed of a number of subsidiary nuclear elements having diverse

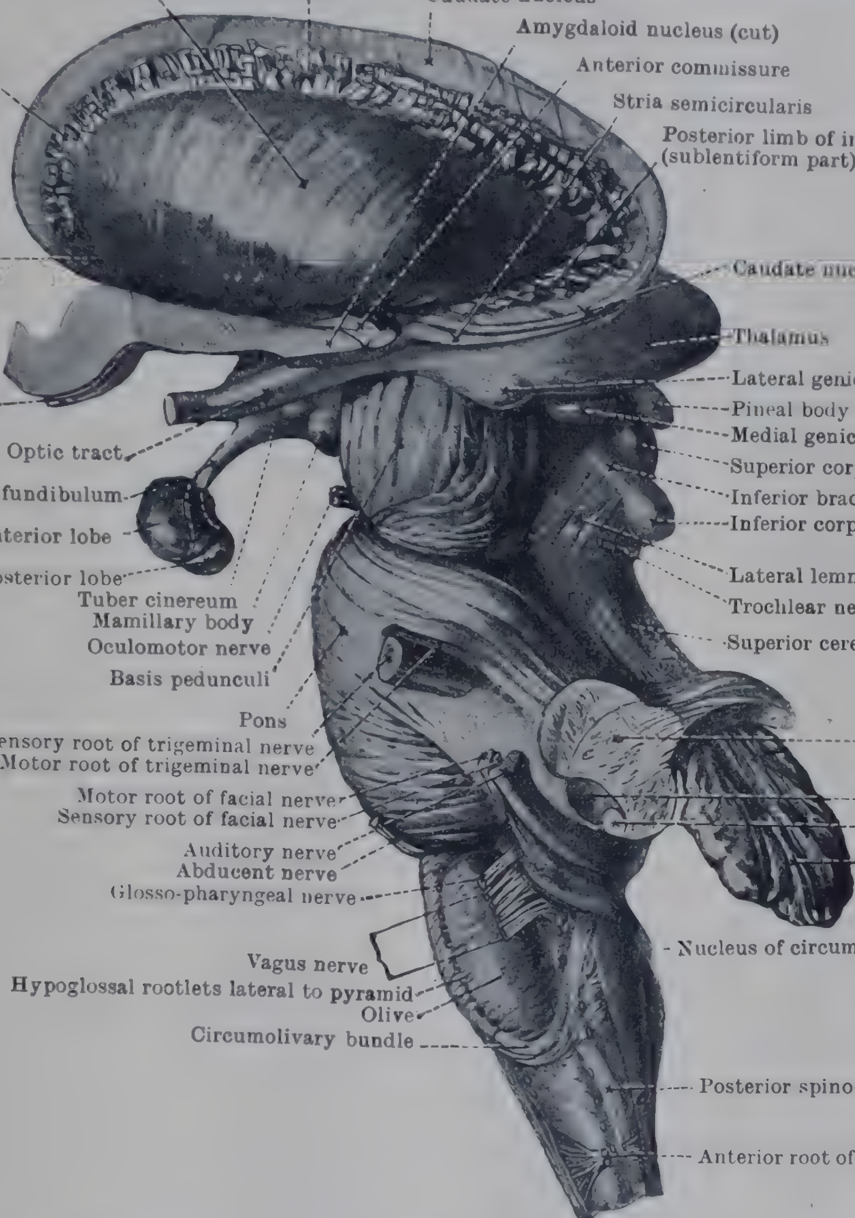

FIG. 857.—DISSECTION EXPOSING THE LENTIFORM NUCLEUS OF THE LEFT HEMISPHERE.

connexions. The tail of the caudate nucleus joins its lower part (Fig. 857), and its upper part is carried up into the putamen. Inferiorly it is continuous with the cortex of the piriform area, to which it is in part functionally related.

Stria Semicircularis.—This is a band of fibres which, for the most part, arises in certain nuclear elements of the amygdaloid nucleus. From this it runs backwards in the roof of the inferior horn of the lateral ventricle (Fig. 831, p. 950, and Fig. 857), and then arches upwards and forwards to gain the floor of the central part of the ventricle. In both situations it lies close to the medial side of the caudate nucleus: at the interventricular foramen it bends downwards towards the anterior commissure. Some of its fibres pass in front of the commissure and others behind it, and ultimately they end in the neighbourhood of the anterior perforated substance. The functional significance of this fibre-bundle is not certainly known, but it is probably related to olfaction.

Internal Capsule.—This term is applied to the broad band of white matter

which separates the lentiform nucleus from the thalamus and the head of the caudate nucleus. It presents different appearances according to the plane in which the brain is cut. A coronal section which passes through the cerebral peduncles shows that, in great part, the internal capsule is directly continuous with the basis pedunculi (Fig. 823, p. 938). Viewed from the lateral aspect after removal of all else of the cerebral hemisphere except the corpus striatum (Fig. 857), the cut ends of the fasciculi of the internal capsule form three-fourths of an ellipse, the other fourth of which is occupied by the bridge of union between the lentiform and caudate nuclei, the anterior perforated substance, the amygdaloid nucleus and the anterior commissure. It may be divided into an **anterior (lenticulo - caudate) part**, a **posterior (lenticulo - thalamic) part**, a **retrolentiform part** (not labelled in the figure), and a **postero-inferior (sublentiform) part**. The last three parts are usually grouped together as the posterior limb. In horizontal section the internal capsule is observed to be bent upon itself at the interval between the thalamus and the head of the caudate nucleus. This bend, which points medially, is called the **genu**. About one-third of the internal capsule lies in front of the genu, and is termed the anterior limb; the remaining two-thirds, which lie behind the genu, constitute the posterior limb (Fig. 853).

The **anterior limb of the internal capsule** intervenes between the lentiform nucleus and the head of the caudate nucleus. In its inferior and anterior part it is much broken up by the connecting bands of grey matter which pass between the anterior part of the putamen and the caudate nucleus.

The anterior limb of the internal capsule is composed largely of *corticipetal fibres* that arise in the anterior part of the ventral nucleus and in the medial nucleus of the thalamus, and go through the anterior limb to reach the cortex of the frontal lobe. It contains *corticifugal fibres* also. These are cortico-thalamic fibres (passing mainly to the medial nucleus of the thalamus), and the frontal components of the cortico-pontine fibres. The **fronto-pontine fibres** arise in the cortex of the frontal region, traverse the anterior limb of the internal capsule, form the medial fifth of the basis pedunculi, and finally end in the nuclei pontis.

The **posterior limb of the internal capsule** is placed between the thalamus and the lentiform nucleus, and it extends backwards for a short distance beyond the posterior end of the putamen on the lateral side of the posterior part of the thalamus. The posterior limb may therefore be described in three parts—lentiform, retrolentiform, and sublentiform.

The **lentiform** (or more properly, **lenticulo-thalamic**) **part** of the posterior limb is composed of both corticipetal and corticifugal fibres. The *corticipetal fibres* enter the internal capsule from the thalamus, where they arise from cells in the ventral and lateral nuclei and proceed upwards to the parietal lobe of the cerebral cortex.

The *corticifugal fibres* are the pyramidal fibres and the cortico-thalamic fibres. The great **motor** or **pyramidal tract** descends from the cerebral cortex through the corona radiata and enters the lentiform part of the internal capsule. The fibres that go to the nuclei of the oculomotor, trigeminal, and facial nerves lie close to the genu, and behind them there are the fibres which go to the hypoglossal nucleus; still farther back are the fibres that end around the motor cells of the anterior grey column of the spinal cord. The fibres of the pyramidal tract, therefore, occupy the genu and the anterior two-thirds of the posterior limb of the internal capsule. The fibres are segregated in the sense that the head-end of the body is represented most anteriorly and the tail-end most posteriorly. The pyramidal fibres have been observed occupying the middle part of the basis pedunculi, into which they pass directly from the internal capsule.

The **retrolentiform** and **sublentiform parts** of the posterior limb contain: (1) the fibres of the optic radiation as they pass from the lateral geniculate body to establish their connexions with the occipital cortex; (2) the fibres of the auditory radiation—*i.e.*, those which connect the medial geniculate body with the auditory cortical field in the temporal lobe (Figs. 825, 862, 864); (3) the *temporo-pontine tract* which is composed of fibres that take origin in the temporal gyri and pass through the sublentiform section of the internal capsule to reach the lateral part of the basis pedunculi. Through this they reach the nuclei pontis, where they end.

If the fibres of the internal capsule are traced upwards they are found to spread out widely from one another in a radiating or fan-shaped manner

to the various gyri of the cerebral hemisphere. This arrangement is termed the **corona radiata.** The fibres of the callosal system, as they proceed into the hemisphere, also radiate, and they intersect the fibres of the corona radiata (Fig. 864, p. 984).

External Capsule.—The thin lamina of white matter between the putamen and the claustrum is called the external capsule. This joins with the internal capsule in front of and behind the putamen, and in this manner the nucleus lentiformis is encapsuled by white matter.

INTRINSIC STRUCTURE OF CEREBRAL HEMISPHERE

The cerebral hemisphere is composed of an external coating of grey matter termed the **cortex**, spread over an internal mass of white matter. The cortex is of peculiar interest, seeing that there is good reason for believing that it is the seat of the higher functions of the brain, or those which may be classed under the general designation of the intellectual functions. It is the same layer of grey matter that provides the means for the conscious recognition of those external impressions which gain access to the cerebro-spinal axis through the sense-organs; and in it are placed also the centres which are concerned with the initiation and control of voluntary movements. The white centre is composed of nerve-fibres which constitute the paths along which nervous impulses are carried to and from the cortex, and from one part of the cortex to another.

CEREBRAL CORTEX

The cortex is spread over the entire surface of the cerebral hemisphere, but it does not form a layer of equal thickness. At the summit of a gyrus it is usually thicker than at the bottom of a furrow. The maximum thickness of cortex (about 4 mm.) is attained in the upper part of the motor area, whilst the minimum (about 1·25 mm.) occurs at the occipital pole. The amount of cortex and the complexity of its gyri differ considerably in different individuals.

In structure also marked differences may be noted in the cortex of different regions, and there is good reason for supposing that these structural peculiarities have a relation to the functional characteristics of particular areas and also play a part in determining the pattern of the furrows that divide the cerebral cortex into a series of ridges or gyri. This structural difference is quite apparent to the naked eye when sections are made through the cortex in a fresh brain, and in some cases sharp transitions in structure occur at the place where one area joins another. It is only to those general structural features which more or less characterize the entire cortical layer that we shall be able to refer.

When sections are made through the fresh brain, and the cut surface is closely inspected, it will usually be apparent that the cortex is distinctly stratified. On the outside there is a thin, whitish layer, and beneath this the grey matter presents two strata of very nearly equal thickness, viz., a middle, grey-coloured stratum and an inner, yellowish-red stratum. Between the two latter layers a narrow white band is visible in many places. This is termed the **outer band of Baillarger**. When the layers indicated above are present, four strata, superimposed one upon the other, are recognized; but in certain regions a second white streak traverses the deep or inner grey layer and divides it further. This is termed the **inner white band of Baillarger**, and, when it is present, the cortex becomes divided obscurely into six alternating white and grey layers.

The outer band of Baillarger is strongly marked in the region of the calcarine and post-calcarine sulci and gives a characteristic appearance to this portion of the cortex. In this locality it receives the name of the **visual stria** (Fig. 853, p. 969).

White Centre of the Cerebral Hemisphere.—The white matter of the hemisphere is composed of medullated nerve-fibres, arranged in a very intricate manner. But the arrangement of these fibres cannot be properly understood until the configuration of the surface of the hemisphere has been considered.

Histological Structure of Cerebral Cortex.—Sections of the cerebral cortex which have been stained with methylene blue show that its cell-content is very rich. Moreover, the cells are arranged in distinct layers, each layer being usually characterized by a predominance of cells of a certain type. The number of layers which can be defined anatomically, their relative thickness and the sharpness of their boundaries, and the types of cells of which they are composed, vary considerably from one part to another, and it is on the basis of these variations that the cortex has been mapped out into a mosaic of different areas, each of which is characterized by its particular histological structure (Figs. 866, 873).

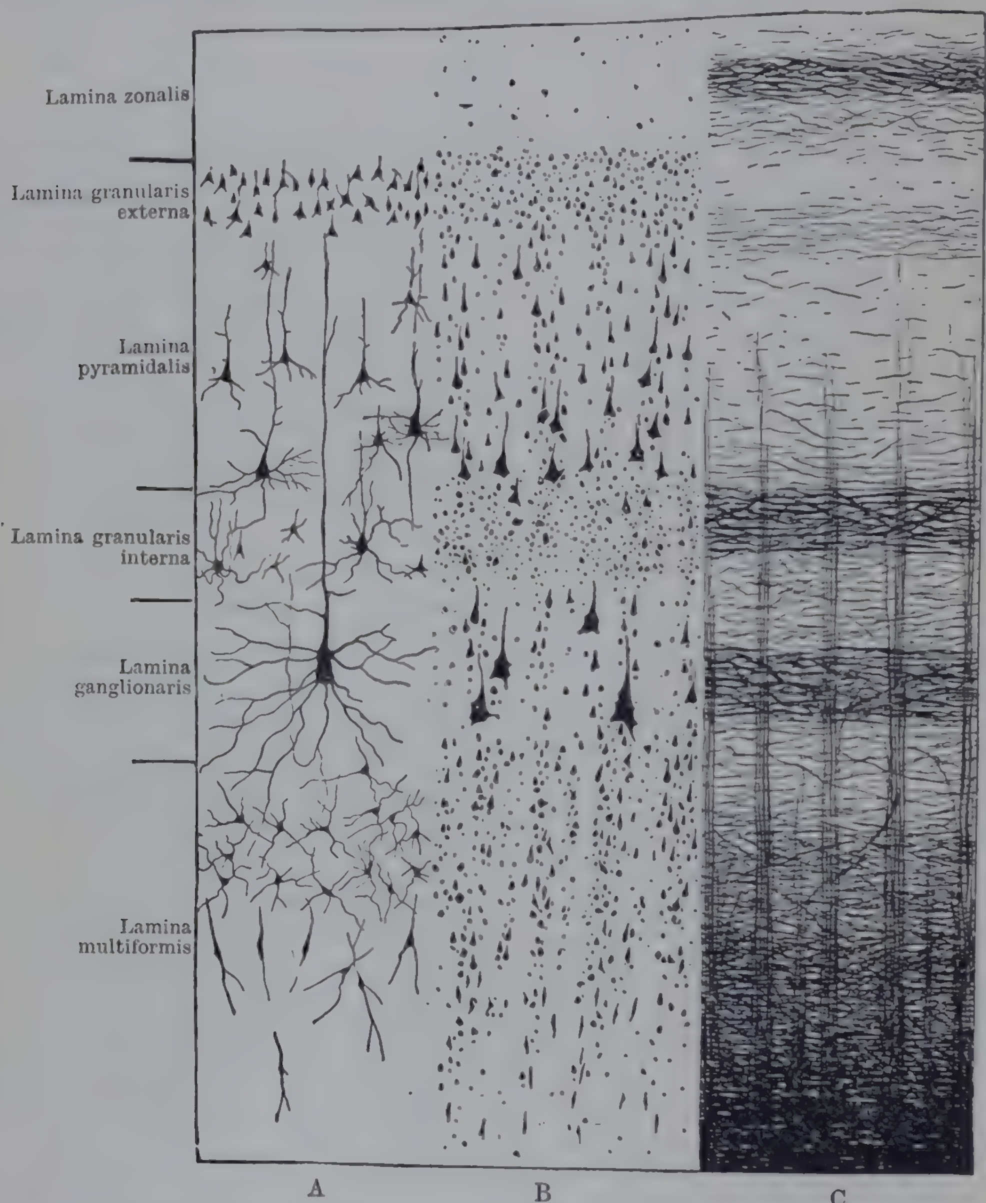

Fig. 858.—Diagram of Arrangement of Cells and of Medullated Nerve-Fibres in the Cerebral Cortex. (Herrick, 1938.)

A. Cells shown by Golgi method ; B. Cells shown by Nissl method ; C. Nerve-fibres shown by Weigert method.

Compare with photomicrograph of peristriate area in Fig. 859.

Some of these cortical areas can be sharply delimited on the surface of cerebral hemisphere, for at their margins the structure changes abruptly. Others pass by a gradual transition into neighbouring areas. Hence the total number of cortical areas which can be defined (and also their relative extent) is partly a question of personal discrimination. There is agreement, however, concerning the position and extent of the main structural areas, and many of these have been shown to correspond with specific functional areas.

In a typical part of the cortex the following laminæ can be defined (Figs. 858, 859) :

(1) **Lamina zonalis.**—This is a thin surface-layer composed of non-medullated and finely medullated fibres which form a closely meshed feltwork ; they are derived partly from ascending axons of subjacent cortical cells, and partly from the terminal branching of the apical dendrites of pyramidal cells. Among these fibres are occasional small spindle-shaped cells. Though relatively insignificant in appearance, the zonal lamina is

probably of considerable importance in the diffusion of nervous impulses in all directions over the surface of the cortex.

(2) **Lamina granularis externa.**—This is a thin and usually ill-defined layer of small cells. It really forms the superficial part of the next lamina, and is composed of the same morphological type of cell.

(3) **Lamina pyramidalis.**—As its name implies, the characteristic feature of this lamina is the pyramidal form of the cells which comprise it. They become progressively larger in the deeper levels of the lamina. From the apex of each pyramid a dendrite proceeds vertically towards the surface, usually reaching the lamina zonalis. Basal dendrites run more or less horizontally from the angles at the base of the cell. From the middle of the base the axon emerges, descends through the subjacent laminæ, and usually reaches the white matter.

(4) **Lamina granularis interna.**—This is composed of small granule-cells with numerous short dendritic processes that branch out in all directions, and many of them also have a very short axon which terminates in the immediate neighbourhood. There are small stellate pyramidal cells in this lamina, somewhat similar (except for their size) to the cells of the pyramidal lamina.

(5) **Lamina ganglionaris.**—The cells found in this lamina are of various types, but in certain areas of the cortex it contains relatively very large cells of the pyramidal type, with coarse dendrites that extend over a considerable area.

(6) **Lamina multiformis.**—This is the deepest of the cortical laminæ, and it is composed of rather closely packed cells of different types, many of them spindle-shaped or pyramidal. It contains also numerous cells with *ascending* axons, sometimes called the *cells of Martinotti*. This type of cell may be found also in the other laminæ, but in fewer numbers.

FIG. 859.—PHOTOMICROGRAPH OF SECTION OF PERISTRIATE AREA OF OCCIPITAL CORTEX SHOWING THE LAMINAR DIFFERENTIATION. The differentiation between the lamina ganglionaris and the lamina multiformis is much less distinct than it is in some other cortical areas. × 45.

Cortical Areas.—The classical works dealing with the histological differentiation of cortical areas are those of Brodmann (1909) and von Economo (1929). It is not appropriate here to consider in detail the range of variation in cortical structure over the cerebral hemisphere. By way of illustration, however, reference may be made to two exceptionally well-defined types of cortex—the motor cortex and the visual cortex.

The **motor cortex,** which is relatively thick, lies immediately in front of the sulcus centralis. It is characterized by the presence in the lamina ganglionaris of very large pyramidal cells—the *giant cells of Betz*—which may reach a size of 120 μ by 25 μ. The axons of these cells form a significant proportion of the fibres of the cortico-nuclear and cerebro-spinal tracts, through which voluntary movements are initiated. The Betz cells are similar to the large pyramidal cells of other regions of the cortex, differing only in the fact that they tend to reach a greater size in the motor cortex (Walshe, 1942). Pyramidal cells, almost as large, are found in a scattered form in the lamina ganglionaris

of the post-central cortex. It is of interest to note their occasional presence in the latter area, for this suggests that the postcentral cortex may also possess motor functions; indeed, there is experimental evidence to show that such functions are of some importance after destruction of the motor cortex proper. Another characteristic of the motor cortex is the absence of the lamina granularis interna, but this *agranular* type of cortex is found also in the premotor area, which lies immediately in front of the true motor cortex. Farther forwards in the frontal lobe, the cortex again shows a lamina granularis interna, forming what is sometimes called the frontal area of the brain.

The **visual cortex** (Fig. 860) is relatively thin, and it has already been noted that it can be distinguished macroscopically by the strong development of the outer band of Baillarger, known here as the *visual stria*. Microscopically it is also characterized by a duplication of the lamina granularis interna (the layer is split in two by the visual stria), and by the presence in the deepest layers of large pyramidal cells with very extensive, horizontally directed, basal dendrites. These cells are sometimes called the solitary cells of Meynert.

It has been suggested that a physiological significance can be attributed to the laminar

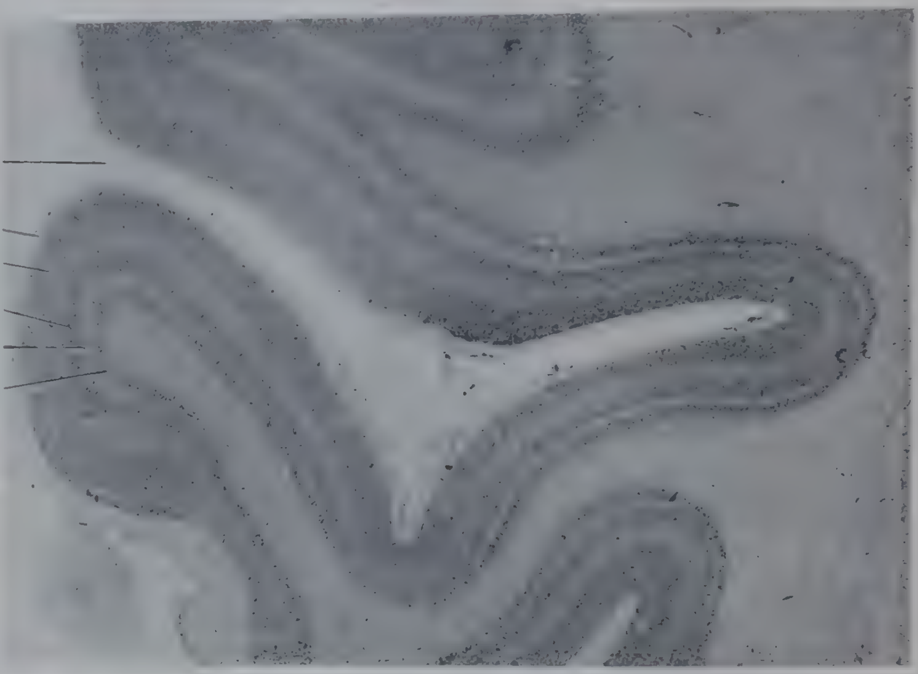

FIG. 860.—LOW-POWER PHOTOMICROGRAPH OF SECTION OF VISUAL (STRIATE) AREA OF OCCIPITAL CORTEX. × 6.

The visual stria is situated in the lamina granularis interna, *i.e.*, superficial to the deep stratum of that lamina indicated in the figure. The junction with the surrounding (peristriate) cortex is clearly seen opposite the X.

formation of the cortex, in the sense that each layer of cells has its specific functions. It is doubtful, however, whether such a conception can be carried very far, for it has been shown that the synaptic connexions between the various layers are of a very intimate nature, so that impulses arriving at one lamina can be immediately transmitted to other laminæ. Nevertheless, it is permissible to state that some of the laminæ have functional implications of a general kind. For example, there is evidence that the lamina granularis interna is predominantly the receptive layer of the cortex. Not only is it particularly well developed in sensory projection-areas and absent in the cortical areas which are mainly motor in function, but afferent fibres have been found by direct histological examination to terminate to a great extent among its cells. In the visual cortex the optic fibres can be seen running obliquely upwards, finally to break up almost entirely in the lamina granularis interna, though this does not preclude the possibility that a minority of the terminals may be related to the deeper levels of the pyramidal layer. The infragranular layers (lamina ganglionaris and lamina multiformis) appear to be concerned partly with the efferent functions of the area concerned. Commissural fibres probably have their origin from the cells of these layers; in the motor cortex they contain the Betz cells; and there is evidence that the large solitary cells of Meynert in the visual cortex give rise to descending fibres that pass down to the mid-brain. Lastly, the lamina pyramidalis seems to be largely concerned with the association functions of the cortex. Running vertically upwards into the cortex are numerous fine fibres (radial fibres) which in some areas are arranged in discrete

fasciculi. Experimental evidence indicates that the radial fibres are partly derived from adjacent areas of the cortex, and they can be seen to terminate mainly in the lamina pyramidalis. It should be emphasized again that these differences in the connexions of the different cortical laminæ are by no means clear-cut.

NEOPALLIUM

The whole of the grey cortex which forms the surface layer of the cerebral hemispheres is sometimes called the *pallium* or mantle. In lower vertebrates the pallium is apparently entirely concerned with olfactory functions, receiving olfactory impulses directly by fibre tracts which relay them from the secondary olfactory centres. In mammals, sensory impressions other than those of smell come to acquire a representation in the pallium, and are relayed to the latter by way of the thalamus. This more recently developed part of the cortex is termed the *neopallium*, and its increasing extent and complexity are the most conspicuous features in the evolution of the brain in the higher mammals.

Fibre-tracts proceed into different districts of the neopallium from the various nuclei of the thalamus to serve as the channels through which tactile, visual, auditory, and other kinds of sensory impulse are poured into it. These districts may be regarded as the **receptive sensory areas** (tactile, visual, auditory, etc.). Another circumscribed area of the cortex, the **motor area**, is characterized by its contribution to the fibres of the pyramidal tract through which voluntary movements are initiated and controlled. Besides the motor area and the various receptive areas, there are large tracts of cortex which cannot be regarded as the territory of any one sense, but as the anatomical substratum of those mental processes which are based on the functional correlation of a variety of sensory impulses. These are the so-called **association areas.** In the human brain the neopallium becomes mapped out into a large series of areas which differ one from the other in structure and in their connexions, and presumably therefore in their functions; and many of these areas may be further subdivided into a series of less obtrusively differentiated territories (Figs. 866 and 873).

As the cortex increases in volume during its development, its depth is increased to a limited extent only. On the other hand, it undergoes a very considerable expansion of its surface area. Thus, it happens that in all larger mammalian brains, as the cerebral hemisphere expands and there is an increasing disproportion between the bulk of the hemisphere and the area of its surface, the cortex must become folded to accommodate itself to the limited area of surface upon which it has to be packed. The situations of the furrows or **sulci** which make their appearance are in part determined by the arrangement and the relative rates of expansion of the various areas into which the neopallium becomes differentiated.

Many furrows belong to a group which we may call (1) **limiting sulci**, *i.e.*, they make their appearance along the boundary lines between areas of different structure; the rhinal and central sulci are examples of this group. Another group, which may be called (2) **axial sulci**, develop by the folding of areas of uniform structure, *i.e.*, along the axis of certain territories; the post-calcarine sulcus and the lateral occipital sulcus belong to this group. There is a third group of (3) **operculated sulci**, where the edge of one area becomes pushed over an adjoining territory, so that a trough is formed (Fig. 861 C), which is neither a limiting nor an axial sulcus; the sulcus lunatus is an example. And finally (4) there is a group in which some more definitely mechanical factor has a predominating influence in the determination of the development of a furrow; the parieto-occipital sulcus and the lateral sulcus are examples of the fourth group.

Longitudinal Fissure.—The longitudinal fissure is not a sulcus of the cortex but is the great cleft between the two cerebral hemispheres. In front and behind it separates the cerebral hemispheres completely. In its middle part, however, the fissure is interrupted and floored by the corpus callosum—a white commissural band which passes between the hemispheres and connects them together. The longitudinal fissure is occupied by a median fold of dura mater, termed the falx

cerebri, which partially divides the part of the cranial cavity allotted to the cerebrum into a right and left chamber.

External Configuration of Cerebral Hemispheres.—Each cerebral hemisphere has three surfaces—supero-lateral, medial, and inferior. The *supero-lateral surface* is convex and is adapted accurately to the internal surface of the cranial vault. The *medial surface* is flat and vertical and bounds the longitudinal fissure; in great part it is separated from the corresponding surface of the opposite hemisphere by the falx cerebri. The *inferior surface* is irregular and is adapted to the floors of the anterior and middle cranial fossæ and, behind them, to the upper surface of the tentorium cerebelli. Traversing this surface in a transverse direction, nearer the anterior end of the hemisphere than the posterior end, is the stem of the lateral sulcus. This deep cleft divides the inferior surface into an anterior or *orbital area*, which rests on the orbital part of the frontal bone and is concave from side to side, and a more extensive posterior or *tentorial area*, which lies on the floor of the lateral part of the middle cranial fossa and on the tentorium cerebelli. This surface is arched from before backwards, and looks medially as well as downwards. In its posterior two-thirds it is separated from the cerebellum by the tentorium cerebelli.

The borders between the surfaces are the supero-medial, the superciliary, the

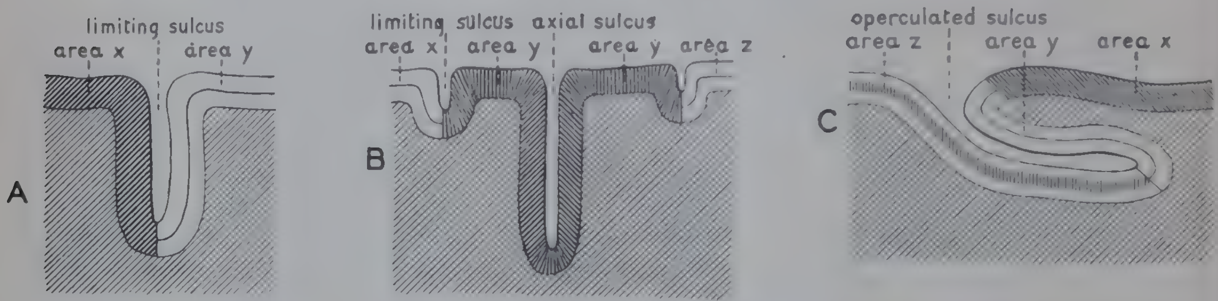

Fig. 861.—Diagrams to explain Three Types of Cerebral Furrows.

infero-lateral, the medial occipital, and medial orbital. The *supero-medial border*, convex from before backwards, intervenes between the supero-lateral surface and the medial surface of the hemisphere. The *superciliary border* is highly arched and separates the orbital surface from the supero-lateral surface. The *infero-lateral border* marks off the tentorial surface from the supero-lateral surface. The *medial occipital border* can be seen only when the brain has been hardened *in situ*. It extends from the occipital pole towards the splenium of the corpus callosum and intervenes between the medial and tentorial surfaces. It lies along the straight blood-sinus and occupies the angle between the falx cerebri and the tentorium cerebelli. The *medial orbital border* separates the orbital surface from the medial surface.

The anterior end of the cerebral hemisphere is called the **frontal pole**, and the posterior end is termed the **occipital pole**. On the inferior surface of the hemisphere the prominent point of cerebral substance which extends forwards below the lateral sulcus receives the name of the **temporal pole**. In a well-hardened brain a broad groove is usually present on the medial and inferior aspect of the occipital pole of the right hemisphere; it corresponds to the commencement of the right transverse venous sinus; the left transverse sinus may make a less distinct groove on the occipital pole of the left hemisphere. On the tentorial surface, a short distance behind the temporal pole, a well-marked depression, called the **petrous impression,** is always visible; it corresponds to the elevation on the anterior surface of the petrous portion of the temporal bone over the superior semicircular canal.

White Matter of Cerebral Hemispheres

According to the connexions which they establish, the nerve-fibres in the white matter of the hemispheres may be classified into three groups, viz., (1) commissural fibres; (2) association fibres; and (3) itinerant (projection) fibres.

Commissural Fibres.—These are fibres which link together corresponding

parts of the cortex of opposite cerebral hemispheres. They are arranged in three groups forming three definite structures, viz., the corpus callosum, the anterior commissure, and the hippocampal commissure.

The **corpus callosum** has in a great measure been already described (p. 963). As it enters each hemisphere, its fibres spread out in an extensive radiation. It thus comes about that most parts of the cerebral cortex, with the exception of the olfactory bulb, the olfactory parts of the hemisphere, and the inferior and anterior part of the temporal lobe, are reached by the callosal fibres. But it should be noted that all the regions of the cortex do not receive an equal proportion of fibres.

The **anterior commissure** is small, and quite subsidiary to the corpus callosum, although originally it was the principal cerebral commissure long before the corpus callosum was evolved. It connects together the two olfactory bulbs, and also portions of the opposite temporal lobes. It has a cord-like appearance and in median section appears as a small oval bundle in the lamina terminalis (Fig. 842, p. 959). The median free portion is placed immediately in front of the anterior columns of the fornix as they curve downwards, and also in intimate relation to the anterior end of the third ventricle. Posteriorly the small portion of the anterior commissure which appears in the ventricle between the two columns of the fornix is clothed with ependyma.

The lateral part of the anterior commissure penetrates the cerebral hemisphere, and, gaining the inferior part of the anterior end of the internal capsule, divides into two portions, viz., a small olfactory part and a much larger temporal part.

The **olfactory portion** of the anterior commissure is an exceedingly small fasciculus. It passes downwards and forwards, and it finally enters the olfactory tract. It is composed of decussating fibres of the olfactory tract and of commissural fibres which bind one olfactory bulb to the other.

The **temporal portion** is formed of almost the whole of the fibres of the commissure. It is carried laterally under the lentiform nucleus, until it gains the interval between the globus pallidus and the putamen. At this point it changes its direction and sweeps backwards. In coronal sections through the brain, behind this bend, the temporal portion of the anterior commissure appears as an oval bundle of fibres cut transversely and placed in close contact with the inferior surface of the lentiform nucleus. Finally it turns sharply downwards on the lateral aspect of the amygdaloid nucleus, and its fibres are lost in the white centre of the temporal lobe. When the lateral part of the anterior commissure is displayed by dissection, it is seen to be twisted like a rope.

The **hippocampal commissure** is composed of fibres that connect the two hippocampi. It is described on p. 960.

Association Fibres.—The association fibres bind together different portions of the cortex of the same hemisphere. They are grouped into long and short association bundles (Fig. 862).

The greater number of the **short association fibres** pass between adjacent gyri. They curve round the bottoms of the sulci in U-shaped loops (Fig. 862). Some of them occupy the deepest part of the cortex itself, and are termed *intracortical association fibres*; others lie immediately subjacent to the grey matter and receive the name of *subcortical fibres.* Many groups of short association fibres, instead of linking together contiguous gyri, pass between gyri more or less remote. It is only after birth that these association fibres assume their sheaths of myelin and acquire their full functions.

The **long association bundles** lie more deeply and can be traced by dissection for considerable distances in the white matter. They contain fibres that unite districts of the cortex far removed from each other, but experiments on lower mammals, as well as ordinary dissection, suggest that they include also groups of fibres that run in them for relatively short distances. The best defined of these long fasciculi are the following: (1) the uncinate; (2) the cingulum; (3) the superior longitudinal; and (4) the inferior longitudinal.

The **fasciculus uncinatus** is composed of fibres which arch over the stem of the lateral sulcus and connect the frontal pole and the orbital gyri with the anterior

portion of the temporal lobe; its middle and most definite part is easily found if the grey matter of the limen insulæ is scraped away.

The **cingulum** is a very well-marked and distinct band which is closely associated with the medial edge of the neopallium. Beginning in front, in the region of the anterior perforated substance, it arches round the genu of the corpus callosum and is carried backwards on its upper surface under cover of the gyrus cinguli, and it stands in intimate relation to the white centre of this gyrus (Fig. 846, p. 962). At the posterior end of the corpus callosum the cingulum turns round the splenium and is carried forwards, in relation to the hippocampal gyrus, to the uncus and the temporal pole.

The **superior longitudinal bundle** is an arcuate bundle placed on the lateral side of the base of the corona radiata; it connects the frontal, occipital, and temporal regions of the hemisphere. It lies in the root of the fronto-parietal operculum

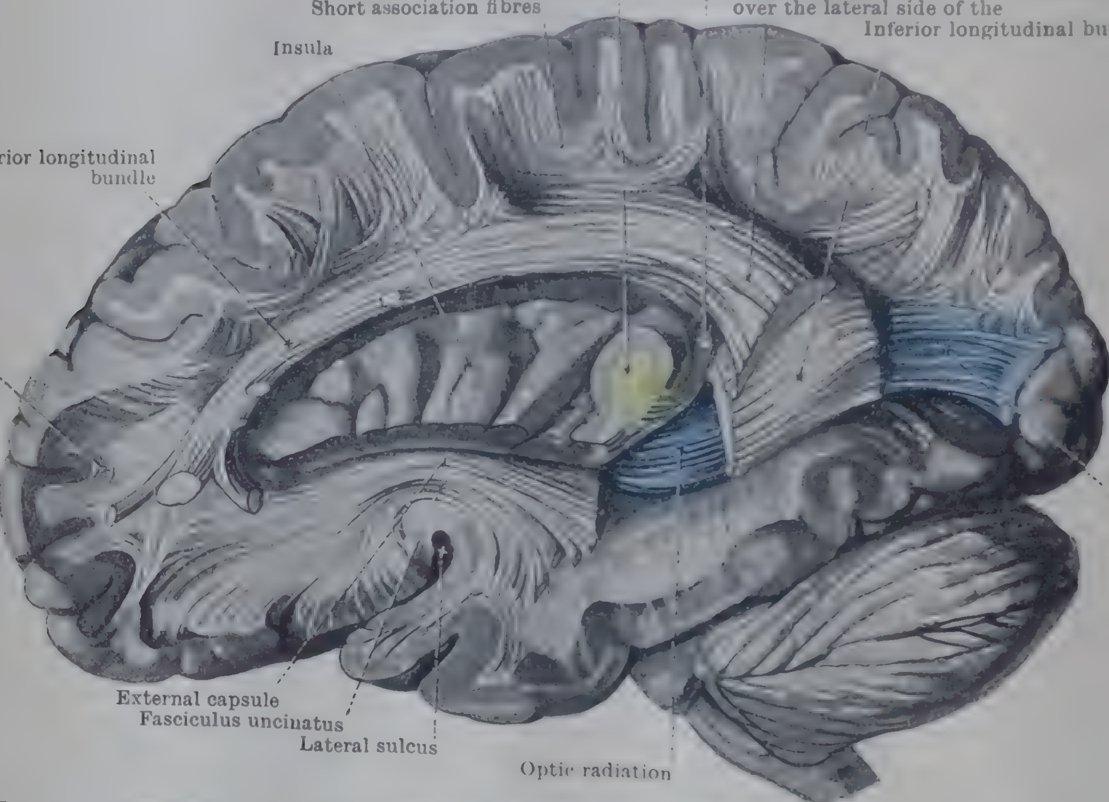

FIG. 862.—DISSECTION OF LEFT CEREBRAL HEMISPHERE TO DISPLAY THE OPTIC AND AUDITORY RADIATIONS AND THE GENERAL DIRECTION OF THE PRINCIPAL ASSOCIATION BUNDLES.

and sweeps backwards over the insular region to the posterior end of the lateral sulcus. There it bends downwards round the posterior end of the putamen and proceeds forwards in the temporal lobe to reach its anterior extremity. As it turns downwards to reach the temporal lobe numerous fibres radiate from it into the occipital lobe.

The **inferior longitudinal bundle** is a very conspicuous one which extends along the whole length of the occipital and temporal regions. In the occipital lobe the inferior longitudinal bundle is immediately lateral to the optic radiation, which takes a similar direction and from which it is distinguished by the greater coarseness of its fibres (Figs. 851, p. 967; 862).

Other long association bundles have been described (*e.g.*, the fronto-occipital); but they are small, and it is difficult to define them by dissection.

Projection Fibres.—We have already seen that many parts of the cerebral cortex are linked to other cortical areas, not only in their own neighbourhood (short association fibres) (Fig. 862), but also in some cases in more distant parts of the hemisphere (long association fibres), as well as to the cortex of the other hemisphere (commissural fibres). In addition there are two large series of fibres: (i) an ascending group which conveys to the cerebral cortex impulses coming from the thalamus and, through it, from the various other sensory nuclei scattered throughout the

brain-stem and spinal cord; and (ii) a descending group connecting the cerebral hemisphere with various parts of the diencephalon, mesencephalon and hind-brain as well as with all the motor nuclei scattered throughout the central nervous system. These two groups of tracts, respectively passing to and from the cerebral cortex, are known collectively as its **projection** or **itinerant fibres**.

While the general arrangement of the projection fibres of the cerebral hemisphere is being examined, it is convenient to refer incidentally to certain other fibre-tracts which do not fall strictly within this group.

Sensory Tracts.—A certain proportion of the fibres that enter the spinal cord by its posterior root, mediating proprioceptive impulses from muscles, tendons, and joints, pass upwards without interruption in the posterior white columns throughout the whole length of the spinal cord until they reach the medulla oblongata, where they end in the nucleus gracilis and nucleus cuneatus. From those nuclei, arcuate fibres arise, and, after crossing the median plane, proceed upwards in the **medial lemniscus** of the other side to end in the ventral nucleus of the thalamus. There a third group of fibres arises and proceeds upwards through the internal capsule to the cerebral cortex, where the impulses conveyed by it excite a consciousness of position and movement. But the sensory fibres that transmit impulses subserving touch, pain and temperature end in the spinal cord near their place of entry into it, and from the cells related to the endings of those fibres new tracts (**spino-thalamic**) arise, cross the median plane to reach the anterior and lateral white columns of the opposite side. They then proceed upwards throughout the whole length of the spinal cord and brain-stem to the thalamus, where they end in relationship with cells of the ventral nucleus. The fibres that arise from this nucleus proceed to the postcentral gyrus and convey impulses to it which may excite a consciousness of touch, pressure, pain, heat, or cold. Some of these spino-thalamic fibres join the medial lemniscus in the medulla oblongata, but others remain separate from it until they reach the level of the pons, where they become added to its lateral margin (Fig. 863).

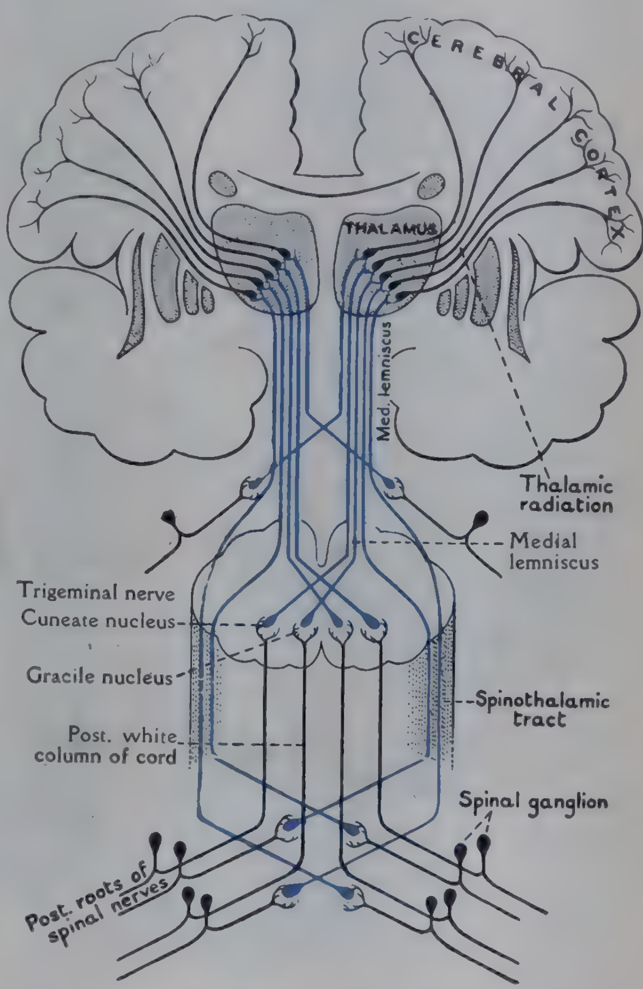

FIG. 863.—DIAGRAM OF THE SENSORY TRACTS TO THALAMUS AND CEREBRAL CORTEX.

Other groups of fibres, serially homologous with both medial lemniscus and the spino-thalamic tracts, come from the nuclei of the trigeminal nerve and become added to the great strands that are proceeding upwards towards the thalamus (Fig. 863).

Of the other great ascending tracts in the spinal cord, such as the two pairs of spino-cerebellar tracts, nothing further need be said; nor is it necessary to do more than remind the reader that from the dentate nucleus of the cerebellum a great tract (superior cerebellar peduncle) ascends to the opposite red nucleus and thalamus, and through the thalamus establishes an indirect connexion with the cerebral cortex in the precentral region.

The other sensory pathways to the cerebrum auditory, vestibular, visual, gustatory, and olfactory—are described elsewhere.

Corticifugal Strands.—The **pyramidal tract**—the great motor tract—is composed of fibres many of which arise from the giant pyramidal cells of Betz in the district immediately in front of the central sulcus (p. 994). The fibres descend through the corona radiata into the genu and posterior limb of the internal capsule. From this point the further course of the pyramidal fibres has been traced, viz., through the basis pedunculi and pons, and the pyramid of the medulla oblongata. At the level of the foramen magnum the pyramid partially decussates in the manner already described; and it enters the spinal cord as the lateral cerebro-spinal and

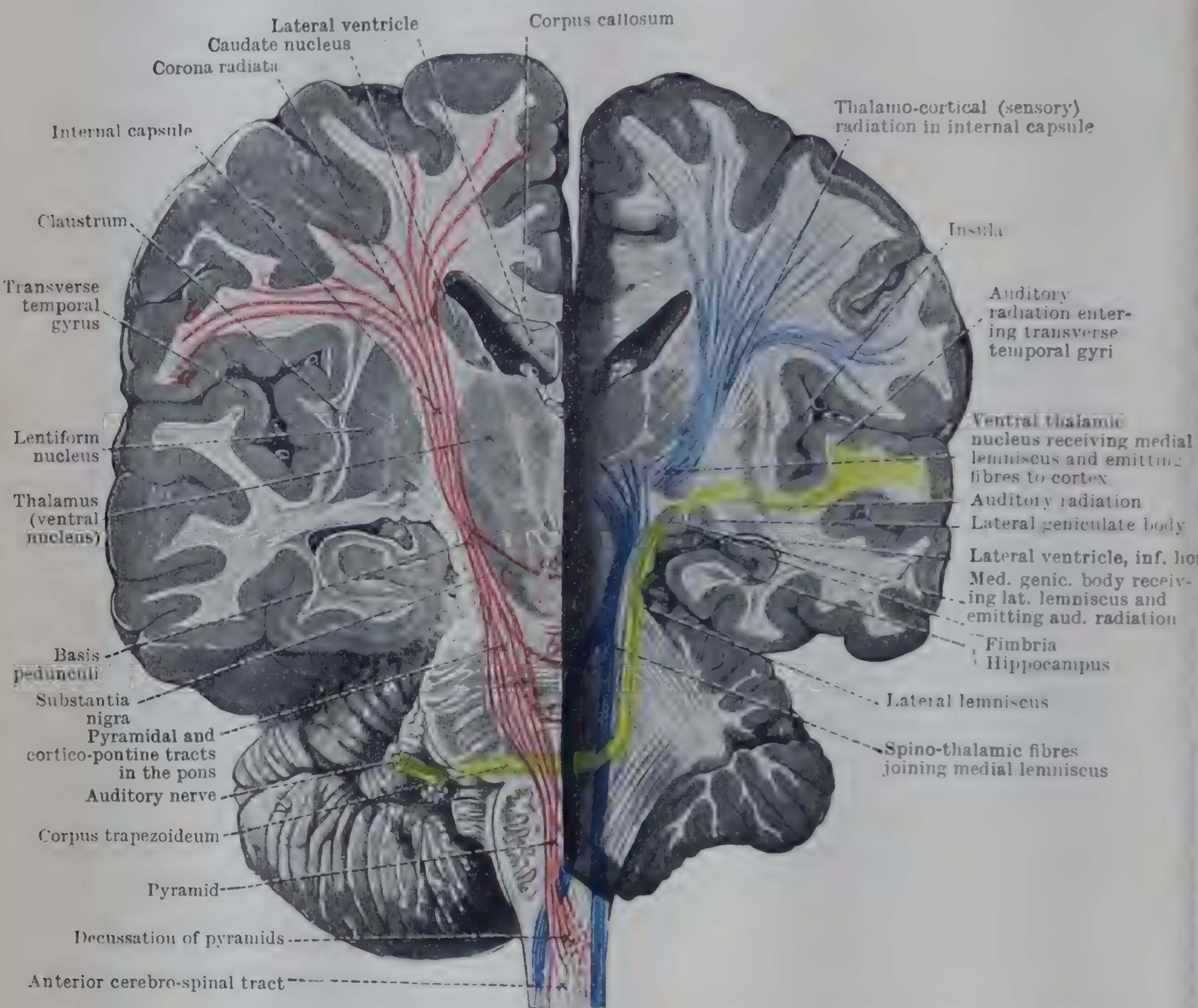

FIG. 864.—CORONAL SECTIONS OF BRAIN, PASSING IN THE RIGHT HALF (left side of Fig.) IN THE LINE OF THE PYRAMIDAL TRACT (*marked in red*). Sensory fibres (*blue*) and auditory fibres (*yellow*) have been represented in the left half, which is cut on a more posterior plane.
a, *b*, *c*, Cortico-nuclear fibres.

anterior cerebro-spinal tracts. The fibres that compose these tracts end in connexion with the motor column of cells from which the fibres of the anterior roots of the spinal nerves arise.

Similar fibres arise from the lower part of the precentral area and proceed through the internal capsule and cerebral peduncle to all the somatic motor nuclei of the opposite half of the brain-stem. Hence the cerebral cortex of one hemisphere can control all the voluntary muscles of the opposite half of the body.

It is of some practical importance to recognize that the large Betz cells which give rise to fibres of the pyramidal tract are not confined to the precentral gyrus (though they are characteristic of this region). Scattered Betz cells are also to be found in the cortex of the postcentral gyrus (see p. 977).

The **fronto-parieto-pontine tract** is composed of fibres which arise as the axons of the cells in the frontal and parietal cortex. It descends in the internal capsule and enters the medial part of the basis pedunculi, through which it gains the basilar

part of the pons. In the pons its fibres end amongst the cells of the nuclei pontis, from which axons arise and establish relations with the cortex of the opposite cerebellar hemisphere.

The **temporo-occipito-pontine tract** consists of fibres which spring from the cells of the temporal and occipital cortex. It passes medially under the lentiform nucleus, enters the sublentiform part of the posterior limb of the internal capsule, and thus gains the lateral part of the basis pedunculi. From there it descends into the basilar part of the pons, in which it ends in the nuclei pontis.

Other Descending Fibres from Cerebral Cortex.—The cortex is connected also with the elements of the basal nuclei, particularly the caudate nucleus and the putamen, and with the thalamus.

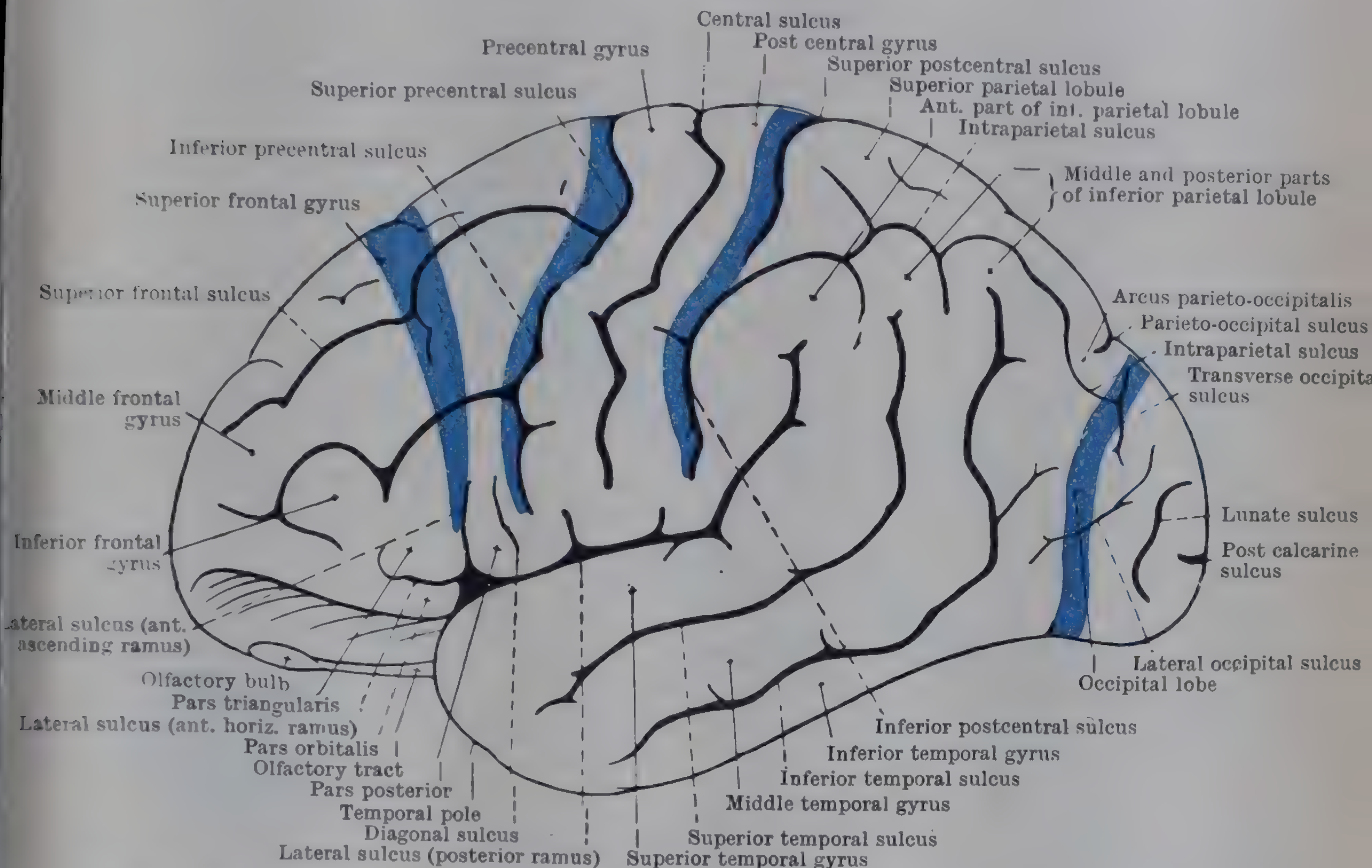

FIG. 865.—DIAGRAM OF SULCI AND GYRI ON SUPERO-LATERAL SURFACE OF HEMISPHERE WITH THE "SUPPRESSOR AREAS" COLOURED.

The middle frontal sulcus, sometimes found between the superior and inferior frontal sulci, is not shown.

Cortico-Striate Fibres.—In recent years, the existence of important descending connexions between certain areas of the cortex and the basal nuclei have been demonstrated by anatomical and electro-physiological studies. In the first place, certain narrow bands of cerebral cortex were shown on stimulation to have an inhibitory effect on cortical functions as a whole, manifested in the suppression of the normal electrical activity of the cortex and of the motor responses which normally follow stimulation of the motor cortex. These bands of cortex have been called "**suppressor areas**". The approximate extent and position of suppressor areas in the human brain (as inferred indirectly from experimental observations on the brain of the chimpanzee) are shown in Fig. 865. As will be seen by comparing this diagram with Fig. 866, the areas are represented by strips of cortex which lie *approximately* (1) along the posterior margin of the main frontal area, (2) along the boundary between the motor and premotor areas, (3) along the posterior boundary of the general sensory area, and (4) along the margin of the visuo-sensory area. On the medial surface of the brain another suppressor area is accommodated in the gyrus cinguli.

From all these suppressor areas, cortico-striate fibres descend to the caudate nucleus where they terminate. These connexions have been shown experimentally to mediate impulses which ultimately lead to the inhibitory effects noted above.

Other cortico-striate connexions have been shown to descend from the premotor and general sensory areas to the globus pallidus, and from the motor area to the putamen. (Dusser de Barenne *et al.*, 1941; 1942.)

Cortico-Thalamic Fibres.—These fibres descend from all those areas of the cortex which receive ascending fibres from the thalamus, and they terminate in the corresponding thalamic nuclei. They have already been mentioned in the account of the connexions of the thalamus. It has also been noted that *cortico-tectal fibres* descend from the occipital cortex to end in the superior corpus quadrigeminum.

SULCI AND GYRI OF CEREBRAL HEMISPHERES

Lateral Sulcus of Cerebrum.—This is the most conspicuous furrow on the surface of the cerebral hemisphere. In reality it is formed not as a furrow on the surface of the hemisphere but as a great fossa, the margins of which develop

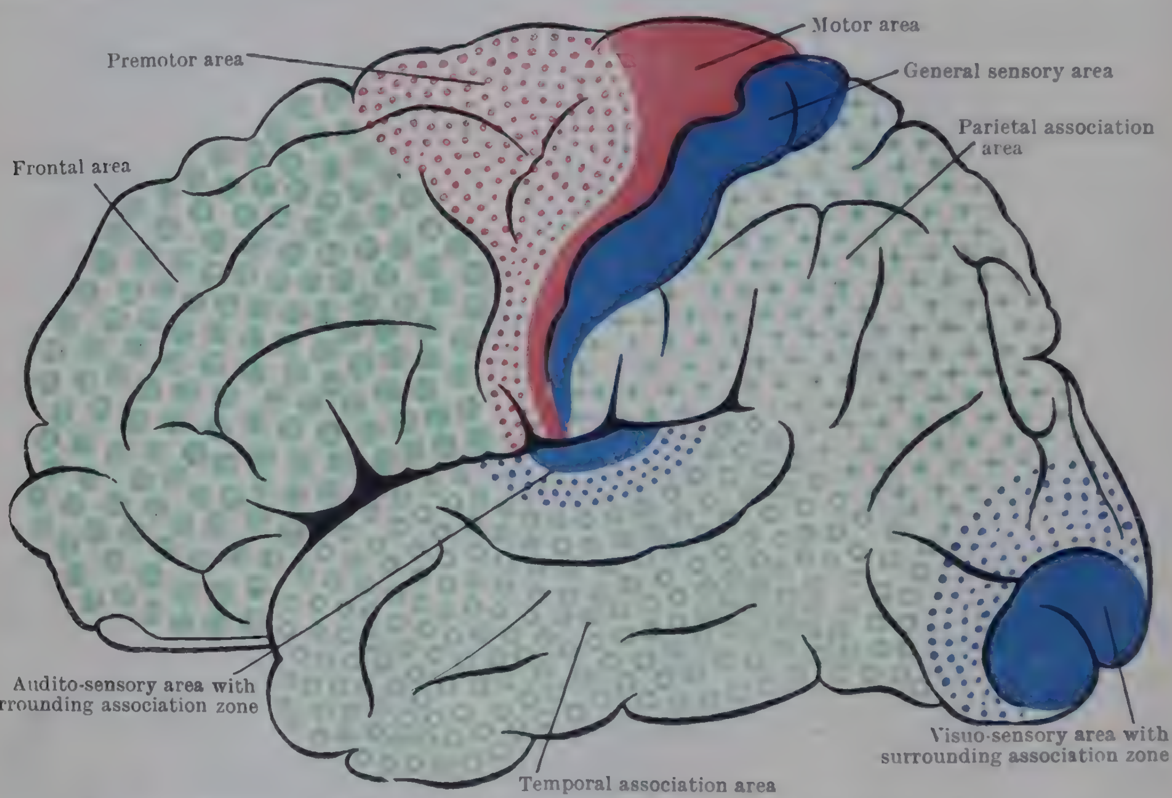

Fig. 866.—Principal Cortical Areas on Lateral Surface of Cerebral Hemisphere. Motor areas, *red*; sensory areas, *blue*; general association areas, *green*.

into large lip-like folds that bulge over the fossa and meet to form the superficial pattern of the lateral sulcus. It has a main stem and three rami. The **stem** is on the inferior surface of the hemisphere. It begins at the vallecula cerebri and passes laterally, forming a deep cleft between the temporal pole and the orbital surface of the frontal region. Appearing on the lateral surface of the hemisphere, the sulcus divides into three radiating rami. These are: (1) the posterior ramus, (2) the anterior horizontal ramus, (3) the anterior ascending ramus—the last of which is inconstant.

The **posterior ramus** is the longest and most constant of the three branches. It extends backwards, with a slight inclination upwards, on the lateral surface of the hemisphere for a distance of about 3 inches. It separates the frontal and parietal regions, which lie above it, from the temporal region, which lies below it; and it finally ends by turning upwards into the part of the parietal region that is subjacent to the parietal eminence of the cranium.

The **anterior horizontal ramus** extends forwards in the frontal region for a distance of about ¾ of an inch immediately above and parallel to the posterior part of the superciliary margin of the hemisphere.

The **anterior ascending ramus** proceeds upwards and slightly forwards, into the lower part of the lateral surface of the frontal region for a variable distance

(1 inch or less). In many cases the two anterior limbs spring from a short common stem, and not infrequently there is only a single anterior limb.

Circular Sulcus.—If the lips of the posterior ramus are pulled widely apart, the **insula** will be seen at the bottom. When the lateral sulcus is closed, the insula is completely hidden from view by overlapping portions of the cerebral hemisphere, and, when brought into view in the manner indicated, it is observed to present a triangular outline and to be surrounded by a limiting groove named **the circular sulcus**.

The insula consists of three areas of different structure. At the antero-inferior corner (where the circular sulcus is deficient) the knee-like bend of the area piriformis (see Figs. 867 and 868) appears at the **limen insulæ**. The rest is divided by an oblique furrow into a posterior part divided into two *long gyri* and an anterior part divided into several *short gyri*.

Opercula Insulæ.—The overlapping portions of the cerebral substance which cover over the insula are termed the insular opercula, and they form, by the apposition of their margins, the boundaries of the three rami of the lateral sulcus.

The **temporal operculum** extends upwards over the insula from the temporal region, and its upper margin forms the lower lip of the posterior ramus.

The **fronto-parietal operculum** is carried downwards from the frontal and parietal regions over the insula, and its lower margin, meeting the temporal operculum, forms the upper lip of the posterior ramus.

The small triangular piece between the ascending and horizontal anterior rami is called the **frontal operculum.** It covers over a small part of the anterior portion of the insula, and is sometimes termed the **pars triangularis**.

The **orbital operculum** is, for the most part, on the inferior surface of the hemisphere. It lies below and to the medial side of the horizontal anterior ramus of the lateral sulcus, and proceeds backwards from the orbital surface of the frontal lobe over the anterior part of the insula.

Development of Lateral Sulcus and of Insular District of Cerebral Hemisphere.—It is only during the latter half of intra-uterine life that the opercula take shape and grow over the insula to shut it out from the surface. In its early condition the insula presents the form of a depressed area on the side of the cerebral hemisphere, surrounded by a distinct boundary wall (Fig. 867 A). After a time the depressed area assumes a triangular outline, and then the bounding wall is observed to be composed of three distinct parts, viz., a superior or fronto-parietal, an inferior or temporal, and an anterior or orbital part (Fig. 867 B). The angle formed by the meeting of the superior and anterior portions of the boundary may become flattened, and a short oblique part of the limiting wall develop into a small triangular frontal operculum (Fig. 867 F.). Each of these portions of the bounding wall of the depression becomes a line of growth from which an operculum takes origin, and by the approximation of these opercula the insula becomes closed in and the rami of the lateral sulcus are formed (Fig. 867 C).

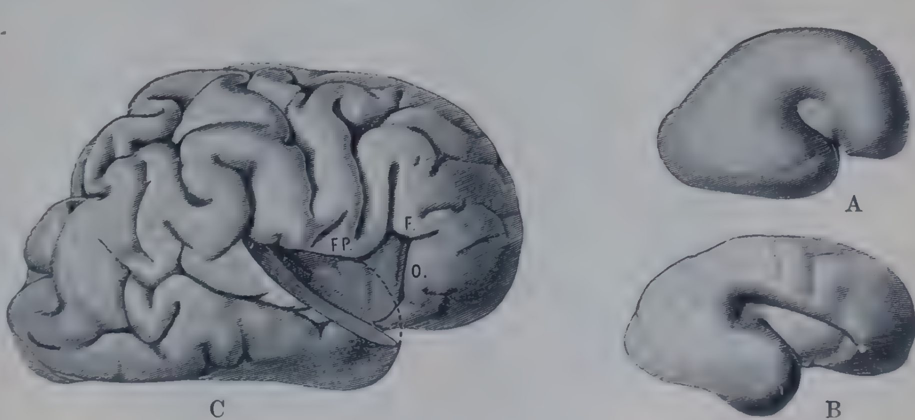

FIG. 867.—RIGHT HEMISPHERES OF HUMAN FŒTUSES SHOWING THREE STAGES IN DEVELOPMENT OF INSULA AND INSULAR OPERCULA.

A, Right cerebral hemisphere from a fœtus in latter part of fourth month; B, Right hemisphere in fifth month; C, Right hemisphere in latter part of eighth month.

In C the temporal operculum has been removed, and a large part of the insula is thus exposed. The outline of the temporal operculum is indicated by a dotted line.

F.P., Fronto-parietal operculum. F., Frontal operculum. O., Orbital operculum.

The lateral sulcus is an example of the fourth category of furrows enumerated on p. 979. It is largely the result of the operation of the mechanical factors incidental to the bending downwards of the pallium in front of and behind the place where

the wall of the hemisphere is supported and held in position by the corpus striatum. The cortical area roughly corresponding to the surface of the corpus striatum is the insula; the temporal region extends downwards behind it, and the frontal region to a less extent in front of it (Fig. 867 A). Then, towards the end of the fifth month of intra-uterine life the exuberant growth of the free fronto-parietal pallium above the insula (Fig. 867 B) and the temporal pallium below and behind it leads to the development of lip-like folds of neopallium—the opercula—which gradually approach one another (Fig. 867 C) and eventually cover up the insula. Other factors come into play in determining the form and topographical relations of the lateral sulcus. For example, the posterior part of the sulcus is the morphological boundary between the auditory and tactile territories of the neopallium.

TEMPORAL LOBE

The part of the cerebral hemisphere which lies below the level of the lateral sulcus is the **temporal lobe**. Anteriorly it ends in a free, rounded extremity—the temporal pole—which, in the skull, fits into the middle cranial fossa beneath the edge of the lesser wing of the sphenoid. Posteriorly its boundary with the occipital lobe is usually taken to be a notch on the lower border of the hemisphere (*preoccipital notch*), about an inch and a half in front of the occipital pole.

Viewed from the surface it is possible to distinguish two main temporal sulci which are more or less horizontally disposed. The *superior temporal sulcus* runs nearly parallel to the lateral sulcus. Anteriorly it turns downwards on the surface of the temporal pole, while posteriorly it inclines upwards and ends in the inferior

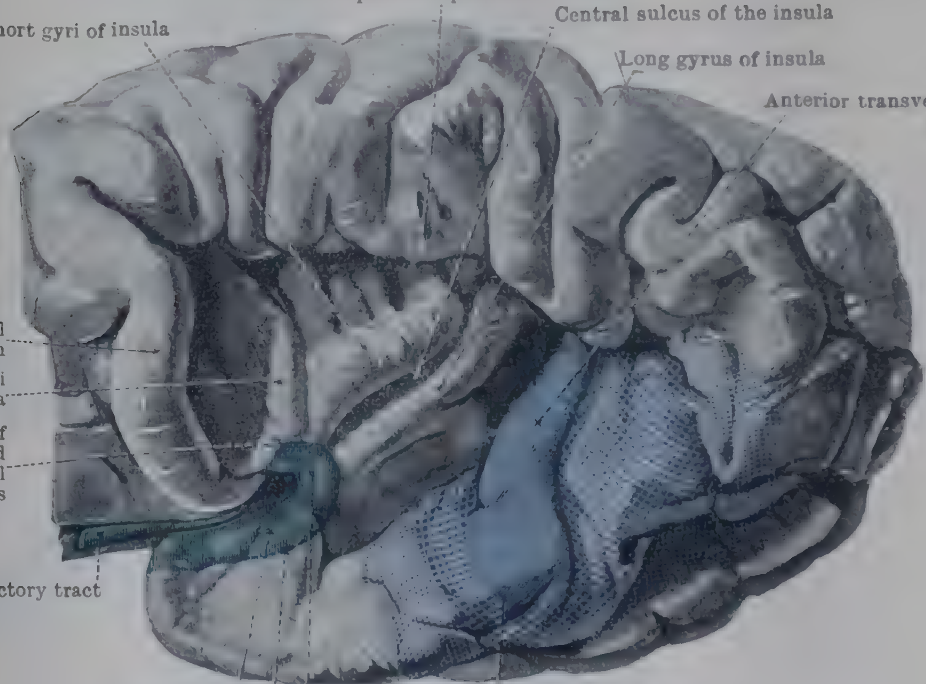

FIG. 868.—PART OF LEFT CEREBRAL HEMISPHERE WITH OPERCULA WIDELY SEPARATED TO EXPOSE INSULA AND SUPERIOR SURFACE OF TEMPORAL OPERCULUM.

Auditory area, *uniform blue*; surrounding association areas, *blue spots*; olfactory parts, *green*.

parietal lobule. Between the lateral sulcus and the superior temporal sulcus is the **superior temporal gyrus**.

The *inferior temporal sulcus* is usually difficult to define, for it is commonly composed of a series of separate sulci which may show an irregular arrangement. Its posterior extremity may be seen to turn up into the inferior parietal lobule. Between the superior and inferior temporal sulci is the **middle temporal gyrus**, while below the inferior temporal sulcus is the **inferior temporal gyrus**.

On the infero-medial aspect of the temporal lobe two other longitudinal sulci

are to be distinguished. One of these is the *occipito-temporal sulcus*, which extends back into the occipital lobe and forms the medial boundary of the **lateral occipito-temporal gyrus**. The other is the *collateral sulcus*. This marks the lateral boundary of the **hippocampal gyrus**, a strip of cortex which lies between it and the *hippocampal sulcus*, and is not to be confused with the hippocampus, which, as already noted, is invaginated into the floor of the descending horn of the lateral

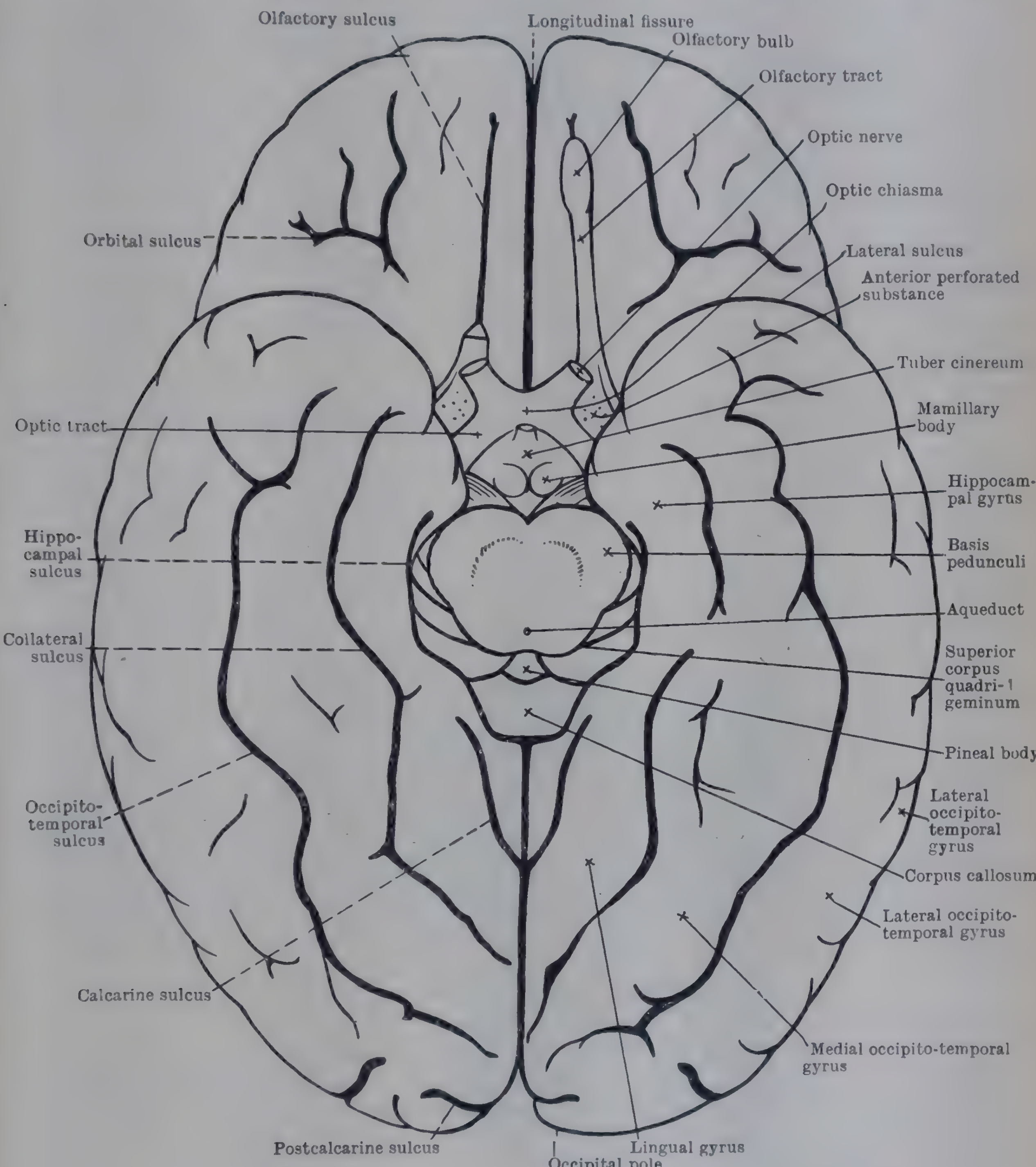

FIG. 869.—DIAGRAM OF SULCI AND GYRI ON INFERIOR SURFACE OF THE HEMISPHERES.

ventricle. Between the occipito-temporal and collateral sulci is the **medial occipito-temporal gyrus.**

On the medial aspect of the temporal pole is the hook-shaped piece of cortex called the **uncus**. It has been mentioned that the uncus is partly formed of olfactory cortex in which the lateral root of the olfactory tract terminates.

From the practical point of view, one of the most important elements of the temporal lobe is the auditory cortex, in which terminate the fibres of the auditory radiation conveying impulses from the cochlea by way of the medial geniculate body. At the fifth month of intra-uterine life (Fig. 867, B), as well as in every later stage up to the adult condition, an area on the upper surface of the temporal operculum

can be seen to slope medially towards the circular sulcus behind the insula. This area is the receiving centre for auditory impressions, and its extent is approximately marked on the surface by transverse elevations—the **transverse temporal gyri**. The auditory area is thus almost entirely buried within the lips of the lateral sulcus, but a small portion of its lateral margin may extend on to the exposed upper border of the middle third of the superior temporal gyrus.

In studying the brain-stem we have seen that a tract of fibres originating in the cochlear nuclei (in the medulla) crosses the median plane (corpus trapezoideum) and turns upwards in the lateral lemniscus of the other side (Fig. 821) to end in the medial geniculate body. From the medial geniculate body a new tract arises composed of tertiary auditory neurons, and passes laterally (Figs. 821 and 823) to end in the transverse temporal gyri. This tract is called the **auditory radiation.** It should be noted that the auditory reception area is of very limited extent, so that it is possible for a very small pathological lesion to affect the whole of it at once.

Apart from the auditory area, and a narrow strip of cortex along the lower border of the posterior ramus of the lateral sulcus behind it, which receives fibres from the pulvinar, no part of the cortex of the temporal lobe receives any ascending fibres from the thalamus. Herein the temporal lobe contrasts strongly with the other lobes of the cerebral hemisphere.

Nervous Mechanism of Hearing.—As with some other sensory mechanisms of the nervous system, the anatomy of auditory centres and paths is more precisely known in the higher than in the lower functional levels of this system. Thus, the position and extent of the auditory cortex have been determined with considerable accuracy in the human brain from clinico-pathological studies, and in the brains of lower mammals from cytological, experimental, anatomical, and oscillographic studies. It is known, also, that the auditory cortex receives its afferent connexions entirely from the medial geniculate body and that this projection involves some degree of spatial localization. The course and terminations of the auditory path (lateral lemniscus) in the mid-brain have been followed by the Marchi method, and it is now realized that previous studies of this tract have not always taken into account the fact that it is intermingled with other fibre-paths which have no apparent relation to hearing. The most uncertain part of the central nervous mechanism of hearing concerns the immediate termination of cochlear fibres in the brain-stem, and the question whether fibres of saccular origin end in the main cochlear nuclei. There is undoubtedly an intermingling of vestibular and cochlear fibres in the auditory nerve and the problem is to disentangle these in order to determine their end-stations. There is some inferential anatomical evidence that at least a part of the macula sacculi is concerned with hearing, but no final proof of this has yet been obtained. The problem is complicated anatomically by the presence of aberrant bundles of fibres which arise from the spiral ganglion of the cochlea, run a circuitous course with the vestibular part of the eighth nerve and subsequently rejoin the cochlear part. Conversely, some fibres (forming the ramus cochleo-saccularis) have their sensory endings in the saccule while their ganglion-cells lie in close relation to the spiral ganglion and seem to form a part of it (Fig. 1027, p. 1201). The destination of the proximal processes of these ganglion-cells is clearly of the greatest importance in connection with the functional significance of the macula sacculi.

OCCIPITAL REGION

We have already seen (Fig. 831) that each optic tract ends in the lateral geniculate body and sends a few fibres to the mid-brain. From the lateral geniculate body a tract arises which conveys visual impulses to the occipital lobe. This **optic radiation** is seen from various points of view in several of the accompanying figures, but it is possible (see Fig. 853) to expose it in a section which will display it in its relationship to the rest of the visual path (Fig. 870).

From this it will be seen that the fibres of the optic radiation, after emerging from the lateral geniculate body, bend backwards in the lateral wall of the posterior horn of the lateral ventricle and proceed to an extensive district of thin cortex on the medial surface and the pole of the occipital area. A section of the cortex in this area is distinguished by the presence of a very distinct white line, called the *visual stria* (Fig. 870), which was first noticed by Gennari (1782) in the year 1776.

If the visual receptive **striate area** (Figs. 866, 873) of the occipital cortex is excised and spread out in one plane it will be found to present an elongated ovoid form and a superficial extent of about 3000 sq. mm. (varying in different brains from about 2700 to 4000). The narrow end of the oval is a short distance behind and below the splenium of the corpus callosum; and from that point

the area extends horizontally backwards to the occipital pole, and beyond it to a slight extent on to the lateral aspect of the hemisphere. In the course of development the area striata becomes folded during the sixth month, and the furrow thus formed becomes the **calcarine** and **postcalcarine sulci**. The name "calcarine" was applied to the furrow by Huxley because its deep, anterior part indents the whole thickness of the medial wall of the hemisphere, and the swelling so produced in the posterior horn of the lateral ventricle resembles a cock's spur and was hence called the **calcar avis** (see Fig. 852, p. 968).

The calcarine sulcus is much deeper, more constant in form and position, and more precocious in development than the post-calcarine. The part of the area striata which is prolonged on to the lateral surface may also become folded in the line of its axis, and so give rise to a **sulcus calcarinus lateralis**.

There is a fundamental distinction between the calcarine and the post-calcarine sulci in their relations to the area striata. For the visual stria is found only in the inferior wall of the calcarine sulcus, which is therefore a sulcus limitans; whereas the stria extends throughout both walls of the postcalcarine sulcus, and in most cases beyond its lips on to the surface of the **cuneus** and the **lingual gyrus** (Figs. 871 and 873), *i.e.*, the exposed cortical areas above and below the postcalcarine sulcus.

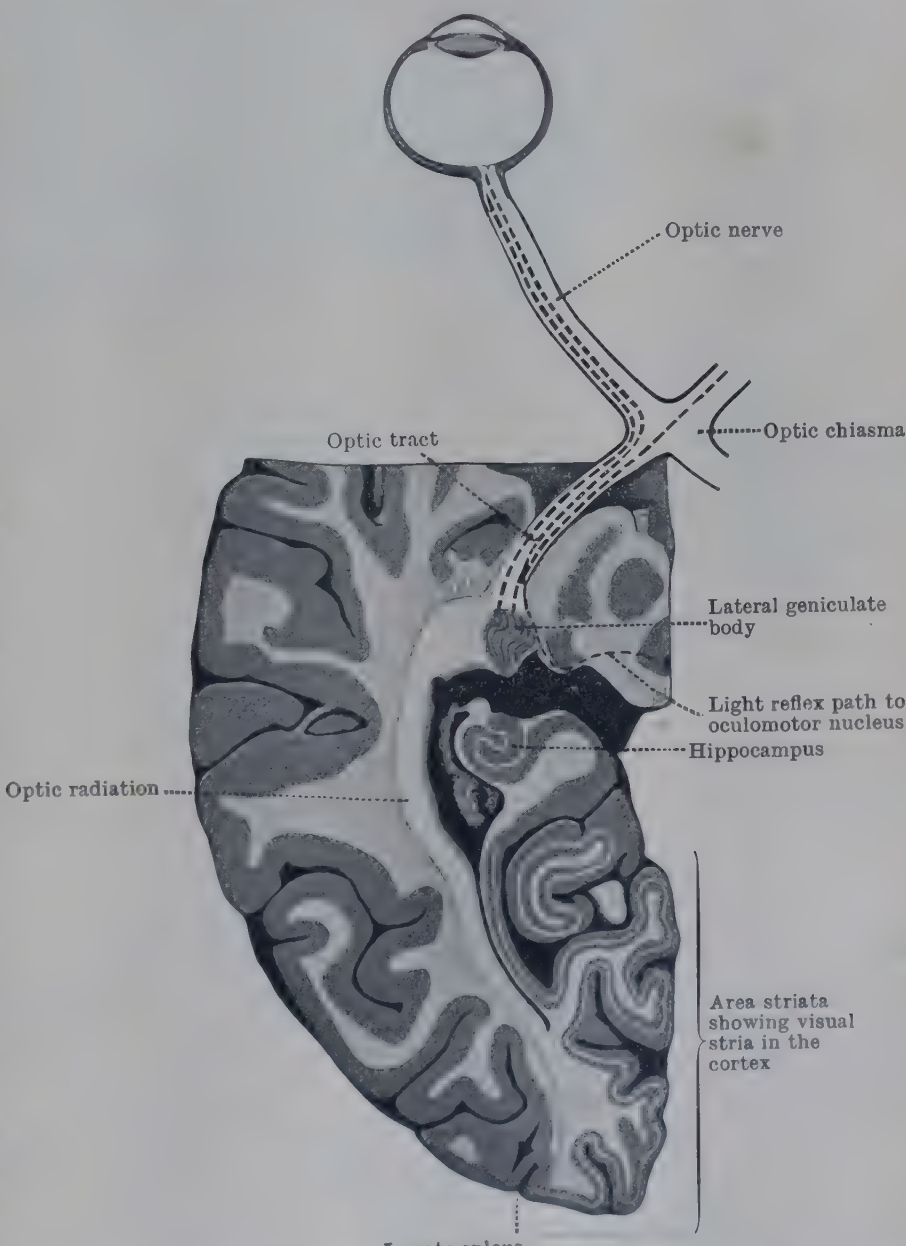

FIG. 870.—HORIZONTAL SECTION TO DISPLAY COURSE OF OPTIC TRACT AND OPTIC RADIATION IN LEFT HALF OF BRAIN.

On the lateral surface of the hemisphere a small semilunar furrow may develop a short distance in front of the anterior edge of the striate area. This is the **sulcus lunatus**. The larger the lateral extension of the striate area, the longer and deeper is the sulcus lunatus. In some cases it may be so conspicuous as to reproduce in the human brain the type of sulcus lunatus characteristic of the ape's brain.

The area striata is surrounded by a peripheral concentric band of cortex — the **area peristriata**. This area receives ascending fibres from the pulvinar. The lateral surface of the occipital lobe in front of the lunate sulcus is marked by a variable furrow called the **lateral occipital sulcus**.

The **parieto-occipital sulcus** (Fig. 872) is a deep furrow on the medial surface of the hemisphere which passes downwards and forwards from the supero-medial

border and appears to join the calcarine sulcus near its union with the post-calcarine, forming on the surface a >-shaped pattern, the stem of which is calcarine,

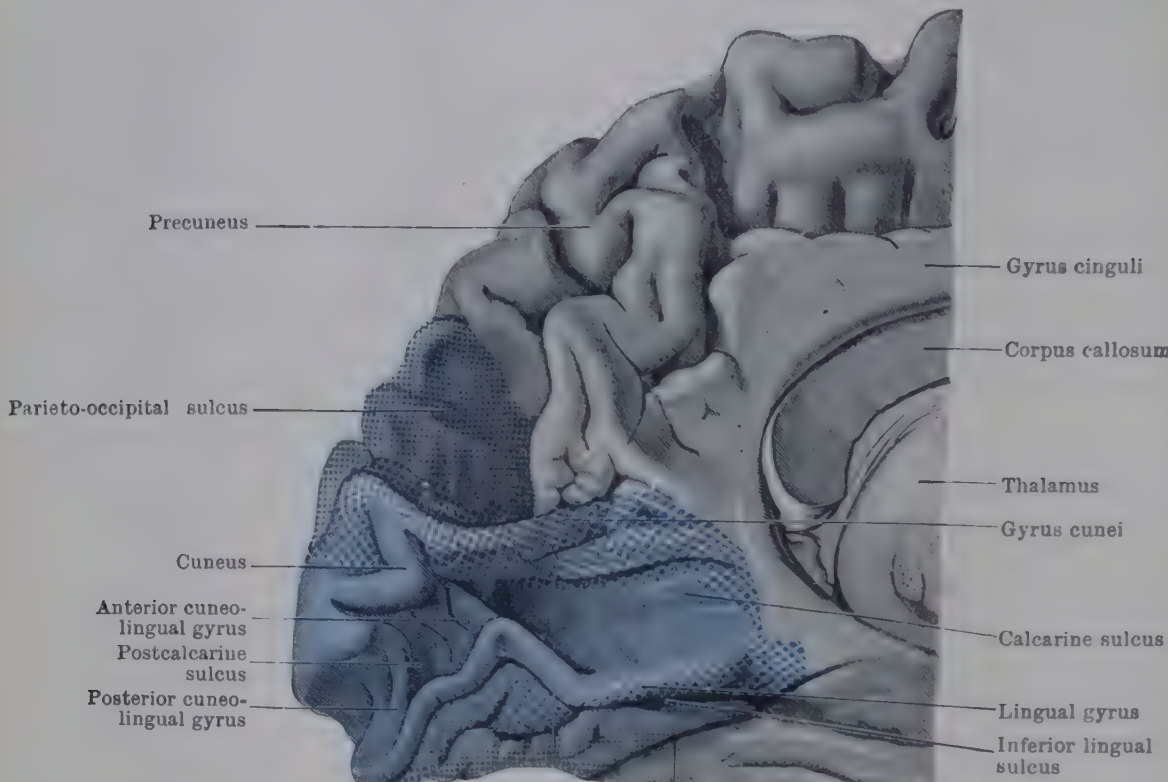

FIG. 871.—PARIETO-OCCIPITAL AND CALCARINE SULCI FULLY OPENED UP, TO SHOW THE DEEP TRANSITIONAL GYRI SEPARATING THE ELEMENTS OF THE >-SHAPED SYSTEM. Area striata, *uniform blue*; surrounding association areas, *blue spots.*

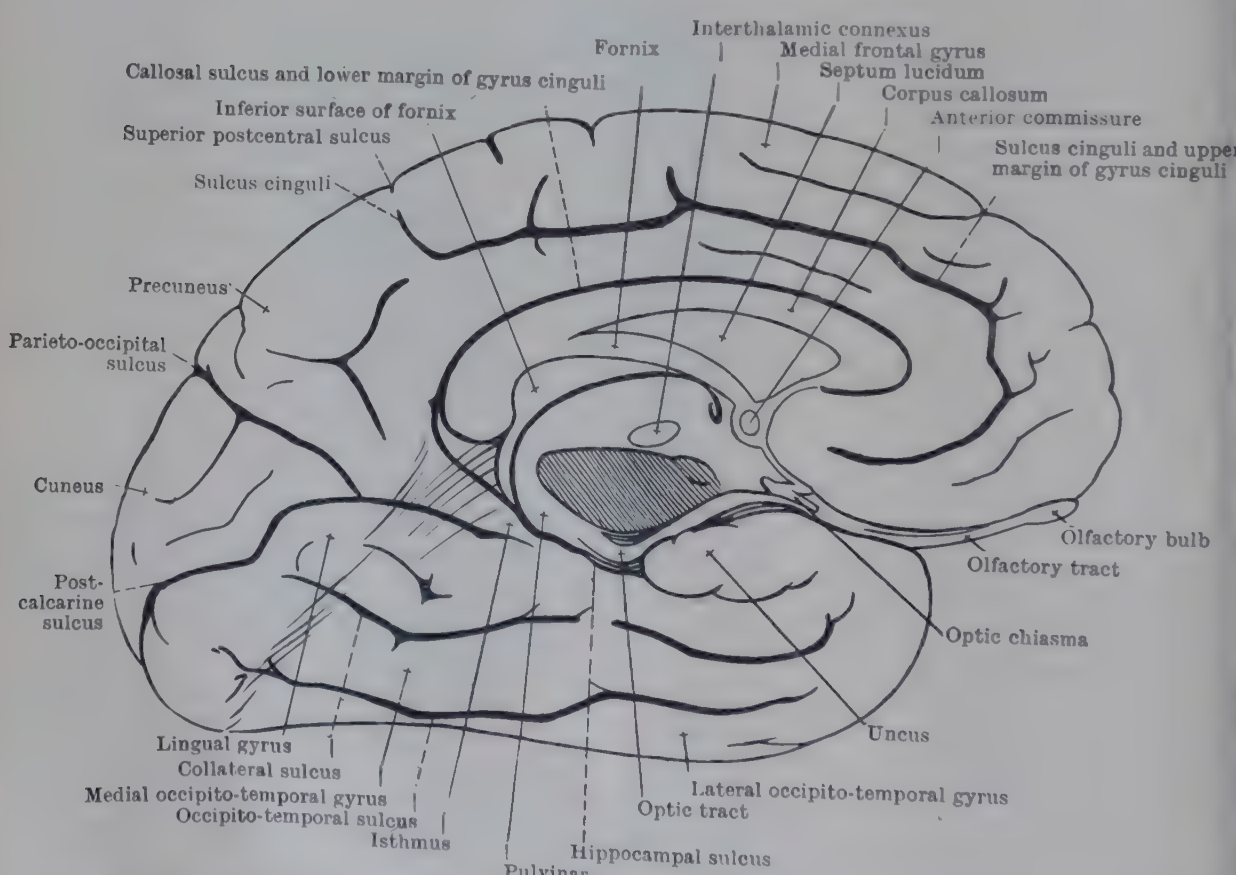

FIG. 872.—DIAGRAM OF SULCI AND GYRI ON MEDIAL AND TENTORIAL SURFACES OF HEMISPHERE.

the limbs postcalcarine and parieto-occipital, and the wedge-shaped area of cortex between the limbs the **cuneus** (Fig. 872).

If, however, the lips of the three furrows are separated (Fig. 871), the parieto-occipital depression will be found to be separated from the calcarine by a prominent submerged cortical ridge (gyrus cunei), and the parieto-occipital will be found to be something more than a mere sulcus. It is, in fact, a great fossa in which are submerged the anterior part of the peristriate area, and the posterior part of the parietal area known as the **precuneus**, as well as the sulci which separate those territories one from the other. It is a great trough formed by the splenium of the corpus callosum as in the course of its development it thrusts itself backwards and crumples up the cortex. When the corpus callosum fails to develop, no parieto-occipital sulcus makes its appearance.

Collateral Sulcus.—This is a strongly marked furrow on the tentorial surface of the brain. It begins near the occipital pole and extends forwards towards the rhinal sulcus, with which it sometimes becomes confluent. In its posterior part it is parallel to the calcarine and postcalcarine sulci, from which it is separated by the **lingual gyrus**.

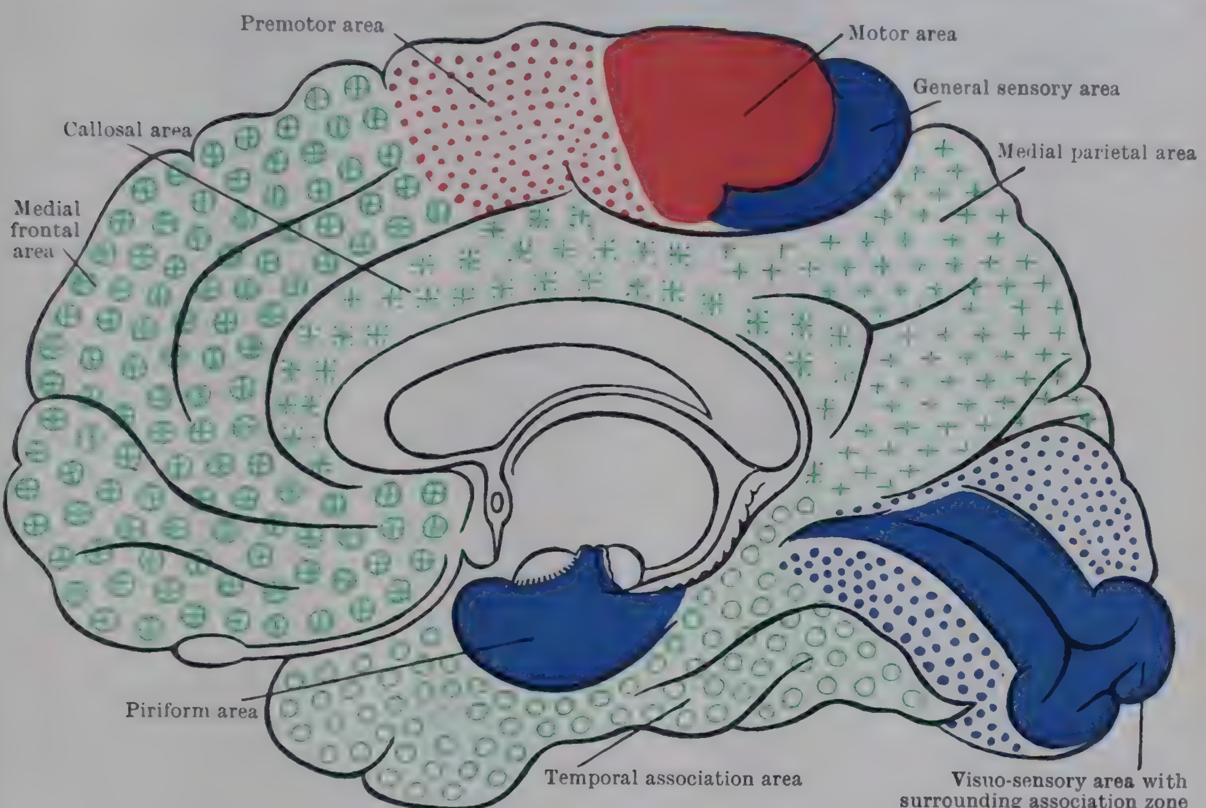

FIG. 873.—PRINCIPAL CORTICAL AREAS ON MEDIAL SURFACE OF CEREBRAL HEMISPHERE. Motor areas, *red* ; sensory areas, *blue* ; general association areas, *green*.

PARIETAL REGION

We have seen that the auditory pathway leads into the temporal region and the visual pathway into the occipital region. The facts of clinical medicine show that large areas in these two regions beyond the limits of the cortex in which the auditory and optic radiations end are in some way concerned with the functions of hearing and vision. The lower part of the parietal cortex is interposed between the temporal and occipital territories, and its integrity and normal functioning are necessary conditions for the proper performance of many acts, such as reading written or printed documents, in the appreciation of which both hearing and vision play some part. But the parietal region also includes the cortical area in which a part, at least, of the chief thalamo-cortical tract ends—the bundle of fibres that represents the third stage of the great sensory pathway, the first stage of which is formed by the spinal and cerebral sensory nerves and their central prolongations, and the second stage by the spino-thalamic tracts and the fibres which pass upwards in the medial lemniscus and end in the ventral nucleus of the thalamus. The sensory area in question forms part of the **postcentral gyrus**, which intervenes

between two oblique furrows—the **central** and **postcentral sulci**—which extend across the whole breadth of the hemisphere above the lateral sulcus (Fig. 866).

Central Sulcus.—During the sixth and seventh months of intra-uterine life the expanding postcentral area becomes raised up into a prominent ridge, and a similar ridge is formed immediately in front of it (Fig. 874) from the area which emits the great motor pyramidal tract. As these ridges become raised up a depression is left between them: this is the *central sulcus.* At first it is in two parts (an upper and a lower, Fig. 874, r^2 and r^1); but as a rule they become confluent later.

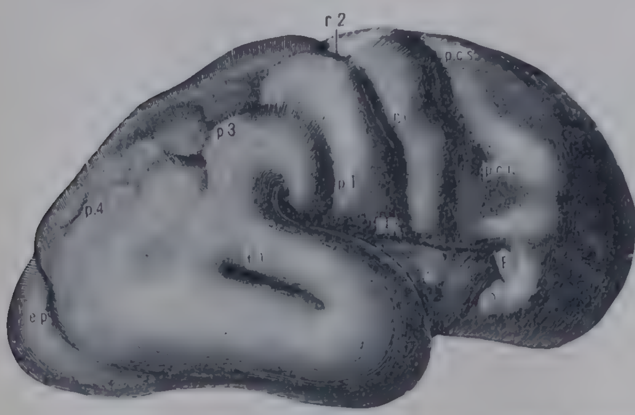

Fig. 874.—Right Cerebral Hemisphere, from Early Seventh-Month Fœtus.

p.c.s.	Superior precentral sulcus.
p.c.i.	Inferior precentral sulcus.
r^1.	Inferior part of central sulcus.
r^2.	Superior part of central sulcus.
p^1.	Inferior postcentral sulcus.
p^3.	Intraparietal sulcus proper.
p^4.	Paroccipital sulcus.
t^1.	Superior temporal sulcus.
S.	Lateral fossa.
F.P.	Fronto-parietal wall.
F.	Frontal wall.
O.	Orbital wall.

The central sulcus in the adult takes an oblique course across the supero-lateral surface of the hemisphere, and, intervening between the frontal and parietal regions, it forms the immediate posterior boundary of the motor area of the cortex. Its upper end cuts the supero-medial border of the hemisphere a short distance behind the mid-point between the frontal and occipital poles, and is then continued downwards and backwards for a short distance on the medial surface, whilst its lower end terminates above the middle of the posterior ramus of the lateral sulcus. In its general direction the sulcus is oblique, and it takes a sinuous course across the hemisphere. This is largely due to the varying breadth of the motor areas representing the lower limb, trunk, upper limb, and head, which are placed immediately in front of it.

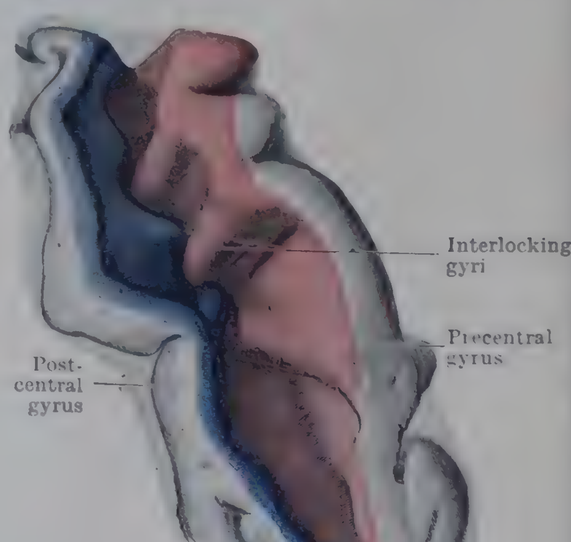

Fig. 875.—Right Central Sulcus fully opened up, to exhibit Interlocking and Deep Transitional Gyri.

Motor cortex coloured *red*, sensory cortex *blue*.

When the central sulcus is widely opened up, so that its bottom and its opposed sides may be fully inspected, it will be seen that the two bounding gyri are dovetailed into each other by a number of interlocking gyri which do not appear on the surface (Fig. 875). Further, two of these, placed on opposite sides of the sulcus, are frequently joined across the bottom of the sulcus in the form of a sunken bridge termed a *deep transitional gyrus.* The continuity of the sulcus is thus, to some extent, interrupted. This condition is related to the development of the sulcus. The deep interlocking gyri indicate a great exuberance of cortical growth in this situation in the early stages of the development of the sulcus; and the presence of the deep transitional gyrus is explained by the fact that the sulcus generally develops in two pieces which run into each other to form the continuous sulcus of the adult, viz., a part corresponding to the lower two-thirds, and a part which represents the upper third and appears at a slightly later date. In very rare cases the two parts of the sulcus fail to unite, and the deep transitional gyrus remains on the surface.

If a section is made at right angles to the central sulcus in a fresh brain (Fig. 876), it will be seen that its anterior and posterior walls present a marked contrast, and that the transition from the one type of cortex to the other takes

place at or near the bottom of the sulcus. The cortex of the anterior wall is thick (3·5 to 4 mm.) and is pervaded by white matter arranged in the form of three or four pale bands with blurred edges and multitudes of fine pencils of fibres passing to and fro between it and the white centre of the hemisphere. The cortex of the posterior wall is thin (1·5 mm.), and contains two narrow and sharply defined white lines.

The sensory area forms little more than the posterior wall of the central sulcus, and barely emerges on the surface to form the posterior lip of the sulcus (Fig. 875). Here, it becomes continuous with a slightly thicker cortex with doubled lines which are less dense than those of the sensory cortex ; this area forms the crest of the postcentral gyrus, and then gives place to another slightly modified type of cortex which forms the anterior wall of the postcentral sulcus.

The motor and sensory areas cross on to the medial surface of the hemisphere into a region known as the **paracentral lobule.**

Behind and parallel to the central sulcus is the **postcentral sulcus**, and between the two is the **postcentral gyrus.** The postcentral sulcus is often divided into upper and lower portions—the *superior* and *inferior postcentral sulci.*

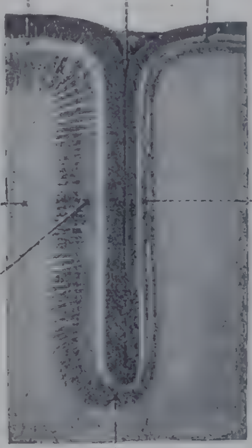

FIG. 876.—SECTION ACROSS SUPERIOR PART OF CENTRAL SULCUS IN FRESH BRAIN.

That portion of the parietal region which intervenes between the postcentral gyrus and the occipital region is usually subdivided into two distinct parts—the **superior and inferior parietal lobules**—by a horizontal furrow, called the **intraparietal sulcus.** This sulcus, which is variable in its form and disposition, commonly joins the inferior postcentral sulcus anteriorly, at least superficially. Posteriorly it extends into the occipital lobe, and here terminates in a short transverse fissure—the *transverse occipital sulcus.* The intraparietal sulcus serves to divide the parietal lobe into the superior and inferior parietal lobules.

The **superior parietal lobule** is composed of moderately thick cortex (2·5 to 3 mm.) placed between the intraparietal sulcus and the superior border of the hemisphere, where it becomes continuous with the precuneus on the medial surface. Each of these parts is subdivided by a transverse sulcus, the superior lobule by the **sulcus parietalis superior** (Fig. 865) and the precuneus by the **sulcus præcunei** (Fig. 872).

The latter sulcus usually joins a small inverted U-shaped furrow **(suprasplenial sulcus)** which encloses a cortical territory of distinctive structure—the **area parasplenialis** (**præcunei**).

The **inferior parietal lobule** is a region of great functional significance, and it is divided into three parts in relation to the upturned ends of three sulci that cut into it. The *anterior part* forms a convolution (supramarginal gyrus) surrounding the upturned extremity of the lateral sulcus. The *middle part* (angular gyrus) surrounds the extremity of the superior temporal sulcus ; and the *posterior part* is an area of cortex called the *post-parietal gyrus* related to the posterior extremity of the inferior temporal sulcus (Fig. 865).

The topographical boundary between the parietal and occipital lobes is commonly taken to be the parieto-occipital sulcus. This sulcus cuts the upper margin of the hemisphere and extends laterally for about half an inch.

FRONTAL REGION

The frontal region is the biggest of the main cortical areas—the so-called "lobes". On the supero-lateral surface it is bounded behind by the central sulcus and below, in part, by the lateral sulcus. It has a supero-lateral surface, a medial surface, and an inferior or orbital surface. The *supero-lateral surface* is broken up by a large number of variable furrows.

The **precentral sulcus** is approximately parallel with the central sulcus, and is usually divided into upper and lower parts.

The **precentral gyrus** is the long gyrus between the central and precentral sulci. Inferiorly it is continuous with the post-central gyrus below the lower end of the central sulcus.

The **superior frontal sulcus** extends forwards in a more or less horizontal direction from the upper part of the precentral sulcus and maps off the **superior frontal gyrus** between itself and the supero-medial border of the hemisphere.

The **inferior frontal sulcus** begins at or near the lower part of the precentral sulcus; it proceeds forwards towards the superciliary margin of the hemisphere and ends a short distance from that in a terminal bifurcation (Fig. 865). The **middle frontal gyrus** is the name given to the broad convolution which lies between the superior and inferior frontal sulci. The **inferior frontal gyrus** is the region in front of the lower part of the precentral sulcus and below the inferior frontal sulcus. Crossing its posterior extremity obliquely is the **diagonal sulcus.**

On the *medial surface* of the frontal region there are two gyri separated by the **sulcus cinguli** (Fig. 872). The larger, peripheral area is named the **medial frontal gyrus**, and the smaller inner part encircling the corpus callosum is the **gyrus cinguli.** The posterior part of the sulcus cinguli is generally distinct from the anterior part and, turning upwards towards the supero-medial border of the hemisphere, it circumscribes a broad area—the **paracentral lobule**—which is continuous with the precentral and postcentral gyri of the supero-lateral surface. It is important to note that the paracentral lobule accommodates the upper part of the motor area of the cortex, which is particularly concerned with the movements of the lower limb of the opposite side.

On the *orbital surface of the frontal region* there are two sulci, viz., the olfactory and the orbital. The **olfactory sulcus** is a straight furrow which runs parallel to the medial orbital border of the hemisphere. It is occupied by the olfactory tract and bulb, and it cuts off a narrow strip alongside the medial border named the **gyrus rectus**. The **orbital sulcus** is a composite furrow which assumes many different forms. It is essentially a U-shaped furrow, the convexity of which is directed forwards (Fig. 869), and one or two variable branches passing forwards from it.

The conventional manner of subdividing the cortex in front of the central sulcus into gyri, which has just been sketched, is apt to convey a misleading idea of the distribution of the anatomical areas of differentiated cortex.

The precentral gyrus together with the major portion of the paracentral lobule and the posterior part of the superior, middle and inferior frontal gyri form a natural subdivision of the cortex which is concerned with voluntary movement. It is composed of a series of areas of different structure. The posterior of these areas, often called the *motor cortex proper* (giant pyramidal area), is coloured solid red in Figs. 866, 873. It contains the giant pyramids of Betz, the axons of which (pyramidal fibres) have been followed to the motor nuclei of the fifth, seventh, tenth (nucleus ambiguus), eleventh (nucleus ambiguus), and twelfth cranial nerves, and to the cells of the anterior grey column of the spinal cord.

The area immediately in front of the motor cortex proper is called by many writers the premotor cortex. All the areas in the wide region defined above have been found to be electrically excitable, and so also have certain cortical areas behind the central sulcus. But the thresholds for the various areas differ and so does the nature of the muscular response obtained. In front of the premotor area is the frontal area of the cerebral cortex, which can be subdivided into a number of subsidiary areas on the basis of differences in histological structure. The frontal area as a whole is distinguished from the motor and premotor cortex by the presence in it of a distinct lamina granularis interna. It receives ascending fibres from the medial nucleus of the thalamus.

It has already been mentioned (p. 943) that the medial thalamic nucleus receives fibres from the hypothalamus; these ascend alongside the wall of the third ventricle and form a part of what is termed the "periventricular system of fibres". It seems clear, therefore, that the frontal area of the cortex is essentially a receptive area on which are projected impulses representing the resultants of hypothalamic activity. This fact is of importance for the consideration of the functions of the frontal area, particularly in relation to the operation of "*frontal leucotomy*" which is now frequently performed in an attempt to mitigate the emotional disturbances associated with certain types of mental disorder. The frontal area of the cerebral cortex is also intimately connected with the hypothalamus by efferent systems of fibres

which descend to terminate in the hypothalamus directly (including the paraventricular and supra-optic nuclei and the mamillary body), or indirectly by way of the medial nucleus of the thalamus (Le Gros Clark, 1948).

For a discussion of the general question of functional localization in the frontal lobes, see Fulton (1949).

MENINGES OF BRAIN AND SPINAL CORD

The brain and spinal cord are enclosed in three membranes or meninges named, from without inwards, dura mater, arachnoid mater, and pia mater. Between the dura and the arachnoid mater is the subdural space—a potential space only, for these two membranes are normally in direct apposition; the much more roomy interval between the arachnoid and pia mater is called the subarachnoid space; and the interval that separates the spinal dura mater from the walls of the vertebral canal is called the extradural space.

Dura Mater

The dura mater is a dense and strong fibrous membrane divisible into two parts—the spinal dura mater and the dura mater of the brain—which are continuous with each other at the foramen magnum.

Dura Mater of Brain.—This part of the dura mater is adherent to the inner

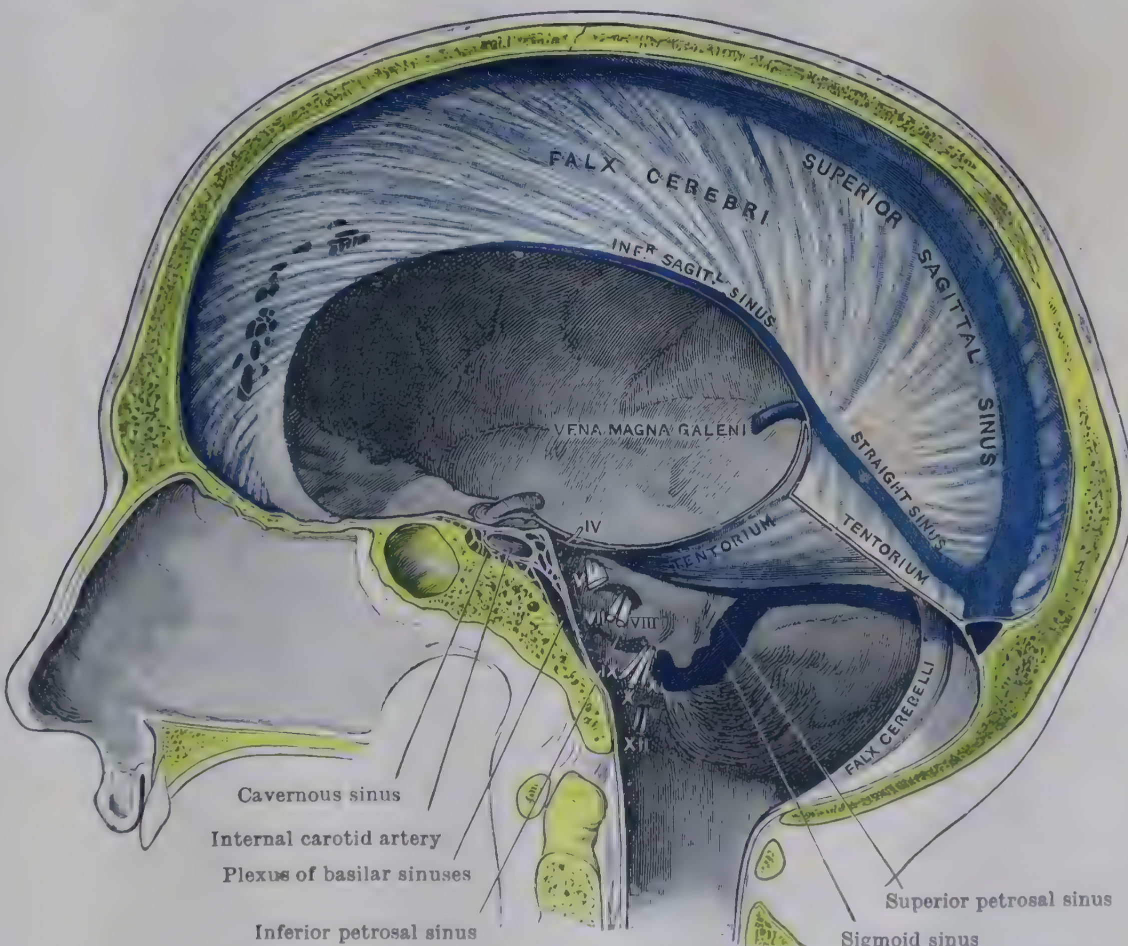

Fig. 877.—Sagittal Section of Skull, a little to Left of Median Plane, to show arrangement of Dura Mater.

Cranial nerves are indicated by numerals. Vena magna Galeni = Great cerebral vein.

surface of the cranial wall, and performs a double office. It serves as a periosteum for the intracranial aspect of the bones which it lines, and it constitutes an envelope for the brain. Its inner surface is smooth and glistening, and is covered with a layer of mesothelial cells. The outer surface, when separated from the cranial wall, is rough, owing to numerous fine fibrous processes and blood-vessels which pass between it and the bones. Its degree of adhesion to the cranial wall differs considerably in different regions. To the vault of the cranium,

except along the lines of the sutures, the connexion is by no means strong. So long as the sutures are open the dura mater is connected with the periosteum on the exterior of the skull by the sutural ligaments. Around the foramen magnum, and on the floor of the cranial cavity, the dura mater is very firmly adherent to the bone. This is more particularly marked in the case of the projecting parts of the cranial floor, as, for example, the petrous portions of the temporal bones, the clinoid processes, and so on. The firm adhesion in these regions is still further strengthened because the nerves, as they leave the cranium through the various foramina, are followed by sheaths of the fibrous dura mater. Outside the cranium the prolongations of the membrane blend with the fibrous sheaths of the nerves, and also become connected with the periosteum on the exterior of the skull. In the child, during the growth of the cranial bones, and also in old age, the dura mater is more adherent to the cranial wall than during the intervening portion of life.

The dura mater of the brain has two layers intimately connected with each other, but yet capable of being demonstrated in most regions; and along certain lines they separate to enclose channels lined with endothelium. These channels are the **venous blood-sinuses**, and they receive the blood from veins which come from various parts of the brain. They are described in the section dealing with the Vascular System.

Strong fibrous septa are given off along certain lines from the deep surface of the dura mater. They project into the cranial cavity, and divide it partially into compartments which all freely communicate with one another, and each of which contains a definite division of the brain. These septa are: (1) the falx cerebri; (2) the tentorium cerebelli; (3) the falx cerebelli; and (4) the diaphragma sellæ.

The **falx cerebri** is a sickle-shaped partition which descends in the great longitudinal fissure between the two hemispheres of the cerebrum. Its anterior end is narrow, and is attached to the crista galli of the ethmoid; it increases in its vertical measurement as it is traced backwards; its upper border is highly convex and is attached to the cranial vault along the median line from the crista galli to the internal occipital protuberance; the anterior and longer part of its lower border is concave and free, and comes into close relation with the splenium of the corpus callosum at its posterior end; the posterior part of this border is united to the tentorium cerebelli. The anterior part of the falx is often cribriform, and may form an open lacework. Along its borders it splits to enclose blood-sinuses—the superior sagittal sinus in the upper border, the inferior sagittal in the free part of the lower border, and the straight sinus along the attachment to the tentorium.

The **tentorium cerebelli** is a large crescentic partition which forms a membranous tent-like roof for the posterior cranial fossa, and thus intervenes between the posterior portions of the cerebral hemispheres and the cerebellum. It is accurately applied to the upper surface of the cerebellum. Thus, its highest point is in front and in the median plane, and thence it slopes downwards towards its attached border. It is kept at a considerable degree of tension, and this depends on the integrity of the falx cerebri which is attached to its upper surface in the median plane.

The *posterior border* of the tentorium is convex, and is attached to the horizontal ridge which marks the inner surface of the occipital bone. Beyond the occipital bone, on each side, it is fixed to the postero-inferior angle of the parietal bone, and then forwards and medially along the upper border of the petrous portion of the temporal bone. From the internal occipital protuberance to the postero-inferior angle of the parietal bone the border encloses the *transverse sinus*, whilst along the upper border of the petrous bone it encloses the *superior petrosal sinus*. The *anterior border* of the tentorium is sharp, free, and concave, and forms with the dorsum sellæ an oval opening shaped posteriorly like a pointed arch. The opening is called the **tentorial notch**, and within it lies the mid-brain. Beyond the apex of the petrous part of the temporal bone the two margins of the tentorium cross each other; the free margin is continued forwards to be attached to the anterior clinoid process, whilst the attached border proceeds medially to be fixed to the posterior clinoid process.

The **falx cerebelli** is a small, sickle-shaped ridge of dura mater which projects forwards from the internal occipital crest, and occupies the posterior notch of the cerebellum.

The **diaphragma sellæ** is a small area of dura mater which forms a roof for the hypophysial fossa. A small opening is left in its centre for the transmission of the infundibulum.

Innervation of Dura Mater in Skull.—Apart from sympathetic fibres which accompany the meningeal vessels, the dura mater of the brain is supplied by extremely fine branches from the trigeminal and vagus nerves. The distribution of these sensory nerves is of some importance in relation to headache. From the ophthalmic division of the trigeminal nerve recurrent branches (*nervi tentorii*) arise in the wall of the cavernous sinus. These run back into the tentorium cerebelli and here spread out in a fan-like arrangement, supplying also the posterior third of the falx cerebri and the dura on the outer surface of the posterior parieto-occipital region of the cerebral hemisphere (Fig. 878). The dura mater of the middle fossa of the skull is supplied mainly from branches of the second and third divisions of the trigeminal nerve. Of these, one twig, the *nervus spinosus*, frequently leaves the main trunk of the mandibular nerve outside the skull and enters through the foramen spinosum. A branch which may arise from the maxillary nerve inside the skull (*nervus meningeus medius*) accompanies the anterior branch of the middle meningeal artery. In the anterior fossa, fine branches of the anterior and posterior ethmoidal nerves supply the dura mater in the neighbourhood of the cribriform plate,

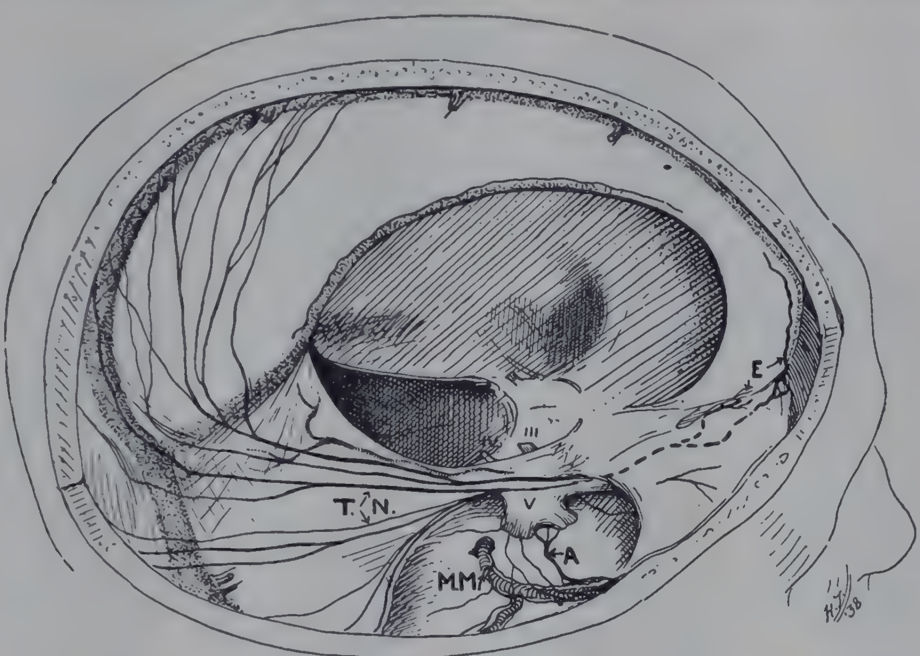

FIG. 878.—DISTRIBUTION OF SENSORY NERVES TO DURA MATER OF ANTERIOR AND MIDDLE CRANIAL FOSSÆ, FALX CEREBRI, AND TENTORIUM CEREBELLI. (Penfield & McNaughton, 1940.)

M.M. Middle meningeal artery.
A. Nervus meningeus medius.
T.N. Tentorial nerves.
E. Branches of ant. and post. ethmoidal nerves to falx and sup. sagittal sinus.

and also the anterior extremity of the falx cerebri and superior longitudinal sinus. Lastly, the dura mater of the posterior fossa is innervated by recurrent branches of the vagus nerve, one of which usually passes up through the jugular foramen. It has been stated that the accessory and hypoglossal nerves also contribute to the supply of the dura mater at the base of the skull, but this is not certainly established.

Spinal Dura Mater.—In the vertebral canal the dura mater forms a tube which encloses the spinal cord, and extends from the foramen magnum above to the level of the second piece of the sacrum below. It is very loosely related to the spinal cord and the cauda equina; in other words, it is very capacious in comparison with the volume of its contents. Moreover, its calibre is not uniform. In the cervical and lumbar regions it is considerably wider than in the thoracic region, whilst in the sacral canal it rapidly contracts and finally ends blindly. At the upper end of the vertebral canal the spinal dura mater is firmly fixed to the second and third cervical vertebræ, and around the margin of the foramen magnum. In the sacral canal the filum terminale, which pierces it and drags off a sheath from it, extends downwards to blend with the periosteum on the back of the coccyx; the inferior end of the tube is thus securely anchored and held in its place.

Within the cranial cavity the dura mater is closely adherent to the bones, and forms for them an internal periosteum. As it is followed into the vertebral canal its two constituent layers separate. The inner layer is carried downwards as the long

cylindrical tube which encloses the spinal cord. The outer layer, which is much thinner, becomes continuous round the margin of the foramen magnum with the periosteum on the exterior of the cranium. The spinal dura mater, therefore, corresponds to the inner layer of the cranial dura mater, and to it alone. It is separated from the walls of the vertebral canal by an interval—the **extra-dural space**—which is occupied by soft fatty tissue and a plexus of thin-walled veins. In connexion with the spinal dura mater there are no blood-sinuses such as are present in the cranial cavity, but it should be noted that the veins in the extra-dural space, placed as they are between the periosteum of the vertebral canal and the tube of dura mater, occupy the same morphological plane as the cranial blood-sinuses. Another feature which serves to contrast the spinal dura mater with the

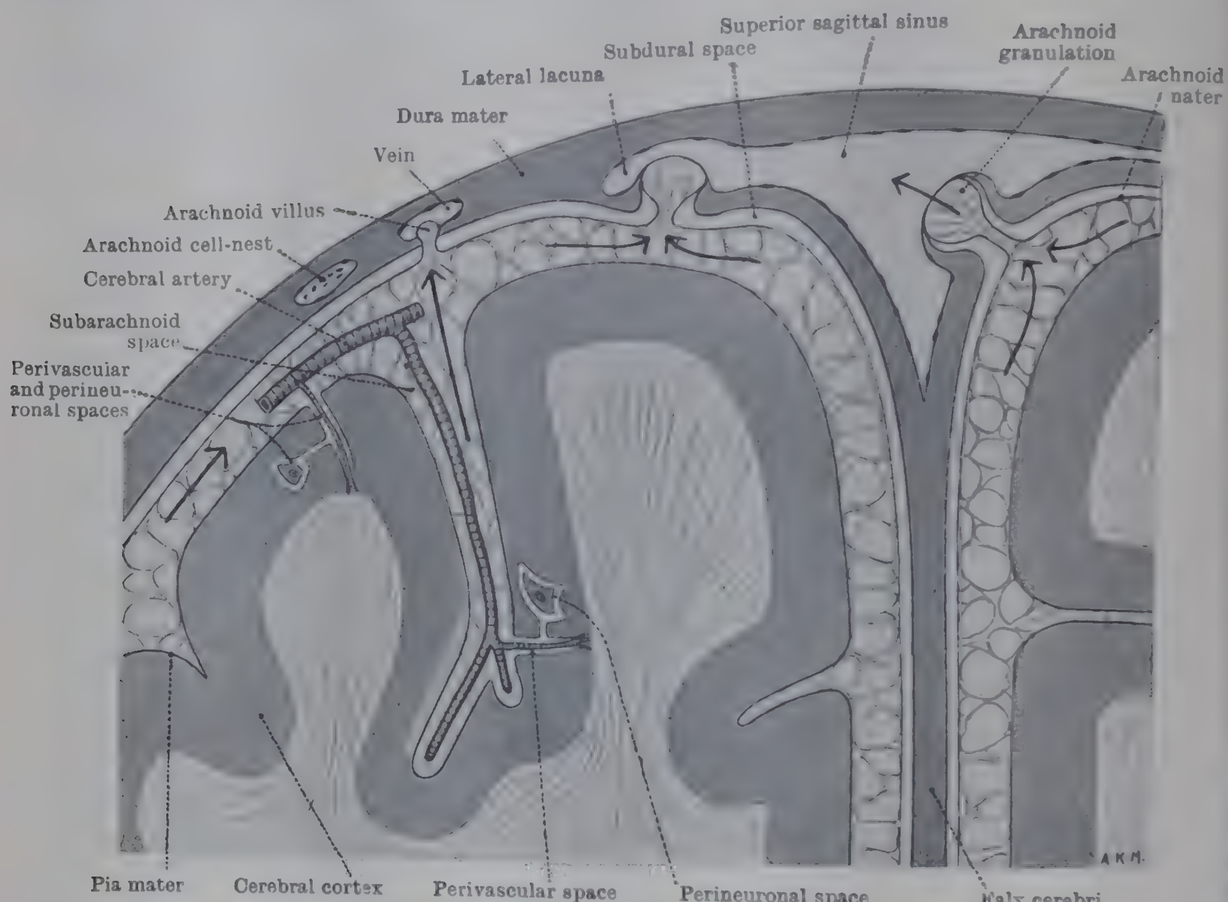

FIG. 879.—DIAGRAM TO SHOW RELATION OF MENINGES TO BRAIN AND OF SUBARACHNOID SPACE TO ARTERIES, NEURONAL ELEMENTS, AND VENOUS CHANNELS OF DURA MATER.

cranial dura mater is that it gives off no partitions or septa from its deep surface.

The spinal dura mater does not lie quite free within the vertebral canal. Its attachments, however, are of such a character that they in no way interfere with the free movement of the vertebral column. On each side the spinal nerve-roots, as they pierce the dura mater, carry with them into the intervertebral foramina tubular sheaths of the membrane, whilst in front loose fibrous prolongations—more numerous above and below than in the thoracic region—connect the tube of dura mater to the posterior longitudinal ligament of the vertebral column. No connexion of any kind exists between the dura mater and the posterior wall of the vertebral canal.

When the interior of the tube of spinal dura mater is inspected, the series of apertures of exit for the roots of the spinal nerves is seen. They are ranged in pairs opposite each intervertebral foramen.

Viewed from the inside of the tube of dura mater, each of the two roots of a spinal nerve is seen to carry with it a special and distinct sheath. When examined on the outside, however, the appearance is such that one might be led to conclude that both roots are enveloped in one sheath of dura mater. That is due to the fact that the two sheaths are firmly held together by areolar tissue. The two tubular sheaths remain distinct as far as the spinal ganglion and then blend with each other.

Subdural Space.—The dura mater and the arachnoid mater are closely applied to each other, and the capillary interval between them is termed the **subdural space.** It contains a film of fluid—just sufficient to moisten the opposed surfaces of the two membranes.

The subdural space in no way communicates with the subarachnoid space. It is carried outwards for a very short distance on the various cranial and spinal nerves; and, in the case of the optic nerve, the sheath of dura mater is carried along its whole length, and with it the subdural space is prolonged to the back of the eyeball.

Arachnoid Mater

The **arachnoid mater** is a very thin membrane, remarkable for its delicacy and transparency, which envelops both the brain and the spinal cord between the dura mater and the pia mater. The **arachnoid mater of the brain** is carried into the longitudinal fissure by the falx cerebri and into the stem of the lateral sulcus by the lesser wing of the sphenoid; but otherwise it does not dip into the sulci. In that respect it differs from the pia mater. It bridges over the inequalities on the surface of the brain. Consequently, on the basal aspect it is spread out in the form of a very distinct sheet over the medulla oblongata, the pons, and the hollow above the pons, and in certain of these regions it is separated from the brain-surface by relatively wide intervals.

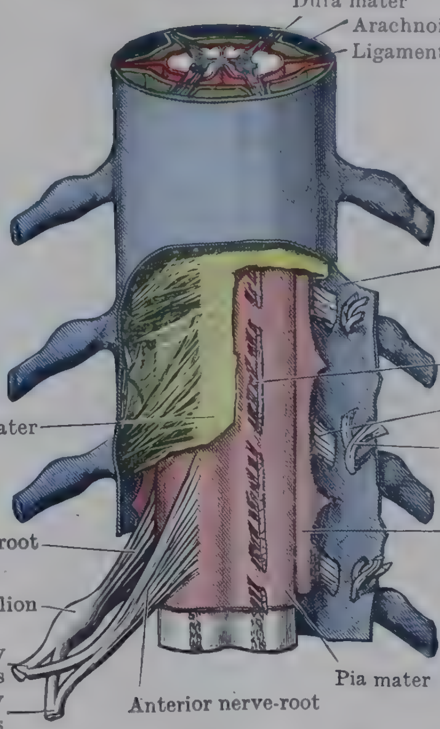

Fig. 880.—Membranes of Spinal Cord, and mode of Origin of Spinal Nerves.

The **spinal arachnoid mater**, which is directly continuous with that of the brain, forms a loose, wide investment for the spinal cord. The spinal arachnoid sac is most capacious towards its lower part, where it envelops the lower end of the spinal cord and the cauda equina.

As the cranial and spinal nerves pass outwards they receive an investment from the arachnoid which runs for a short distance upon them.

Subarachnoid Space.—The interval between the arachnoid and the surface of the brain or spinal cord receives the name of the **subarachnoid space.** It contains the cerebro-spinal fluid, and communicates freely, through apertures in the roof of the fourth ventricle, with the cavities in the interior of the brain.

Within the cranium the subarachnoid space is broken up by a meshwork of fine filaments and trabeculæ. On the surface of the brain, this meshwork is condensed to form what appears, on ordinary dissection, to be a fairly definite layer of tissue. This is the *pia mater*. It should be noted, however, that there is no clear distinction between the arachnoid tissue and the pial tissue. Where the arachnoid mater passes over the summit of a gyrus, and is consequently closely applied to the subjacent brain, the meshwork is so dense and the trabeculæ so short that it is hardly possible to discriminate between the two membranes. In the intervals between gyri, however, there are distinct angular spaces where the sub-arachnoid trabecular tissue can be studied to great advantage. These intervals on the surface of the cerebrum constitute numerous communicating channels which serve for the free passage of the cerebro-spinal fluid from one part of the surface of the brain to

another. The larger branches of the arteries and veins of the brain traverse the subarachnoid space; their walls are directly connected with the subarachnoid trabeculæ, and are bathed by cerebro-spinal fluid (Fig. 879).

In certain situations within the cranium the arachnoid is separated from the pia mater by intervals of considerable width and extent. These expanded portions of the subarachnoid space are termed **subarachnoid cisterns**. In them the subarachnoid tissue is much reduced. There is no longer a close meshwork; the trabeculæ take the form of long filamentous intersecting threads which traverse the spaces. All the subarachnoid cisterns communicate in the freest manner with one another and also with the narrow channels on the surface of the cerebrum.

Certain of these cisterns require special mention. The largest and most conspicuous is the **cerebello-medullary cistern**. It is formed by the arachnoid membrane bridging over the wide interval between the posterior part of the cerebellum and the medulla oblongata. It is continuous through the foramen magnum with the posterior part of the subarachnoid space of the spinal cord.

The **pontine cistern** is the continuation upwards on the floor of the cranium of the anterior part of the subarachnoid space of the spinal cord. In the region of the medulla oblongata it is continuous behind with the cerebello-medullary

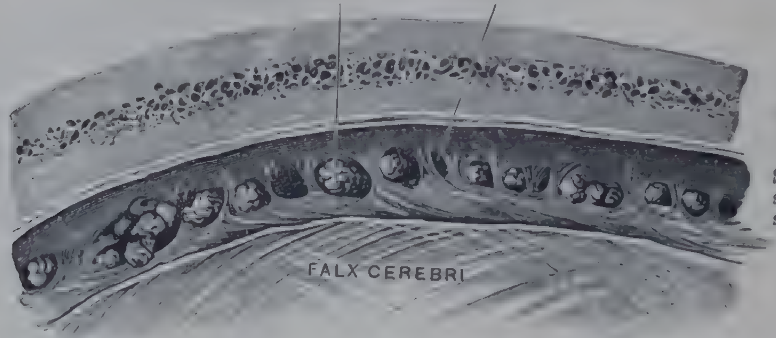

FIG. 881.—MEDIAN SECTION THROUGH CRANIAL VAULT IN FRONTAL REGION, *ENLARGED.*
Displays a portion of the superior sagittal sinus and the arachnoid granulations protruding into it.

cistern; therefore this subdivision of the brain, like the spinal cord, is surrounded by a wide subarachnoid space.

Above the pons the arachnoid mater bridges across between the temporal lobes, and covers in the deep hollow in this region of the brain. This space is called the **interpeduncular cistern,** and within it are placed the large arteries which take part in the formation of the circulus arteriosus. Leading out from the interpeduncular cistern there are certain wide subarachnoid channels. A pair of these are the **cisterns of the lateral sulci.** Each accommodates the middle cerebral artery. Anteriorly the interpeduncular cistern passes into a space in front of the optic chiasma, and from there it is continued into the longitudinal fissure above the corpus callosum. In this subarachnoid passage the anterior cerebral arteries are lodged.

The spinal part of the subarachnoid space is a very wide interval partially subdivided into compartments by three incomplete septa. One of these is a median partition which connects the pia mater covering the back of the spinal cord with the arachnoid. In the upper part of the cervical region this partition is imperfect, and is represented merely by some strands passing between the two membranes; in the lower part of the cervical region and in the thoracic region it becomes more complete. The other two septa are formed by the **ligamenta denticulata** which spread laterally one from each side of the spinal cord. They will be described with the pia mater.

Arachnoid Villi and Granulations.—When the surface of the dura mater is inspected after the removal of the calvaria, a number of small fleshy-looking excrescences, white or pink in colour, are seen ranged in clusters on each side of the superior sagittal sinus, and when the sinus is opened they are observed protruding into its interior. They are the arachnoid granulations, and they are found also, in smaller numbers and distinctly smaller size, in connexion with other blood-sinuses, such as the transverse sinus, the straight sinus, and the cavernous sinus.

At first sight they appear to belong to the dura mater, but in reality each granulation is a little bulbous protrusion of the arachnoid mater. It is attached to the arachnoid by a narrow pedicle, and into its interior there is prolonged through the pedicle a continuation of the subarachnoid space filled with cerebro-spinal fluid. The distal end of the protrusion passes between the interstices of the dura mater into contact with the endothelial lining of the sinus, with which the extremity of the diverticulum becomes fused. In this situation the subdural space is obliterated and the single membrane resulting from the fusion alone separates the blood from the cerebro-spinal fluid.

On each side of the superior sagittal sinus there are a number of irregular spaces in the dura mater which communicate with the sinus either by small apertures or narrow channels. These spaces are called the **lacunæ laterales**, and it is into these cavities that most of the arachnoid granulations insinuate themselves, a few only being invaginated directly into the sinus. The granulations enlarge with age, and the cranial wall overlying them becomes absorbed so that small pits are hollowed out on its internal surface for their reception, though of course the granulations do not come directly into contact with the bone but are separated from it by the periosteal layer of the dura, the lumen of the lacuna or sinus, and, except where the arachnoid is fused with endothelium, by the dura of the sinus floor and the subdural space.

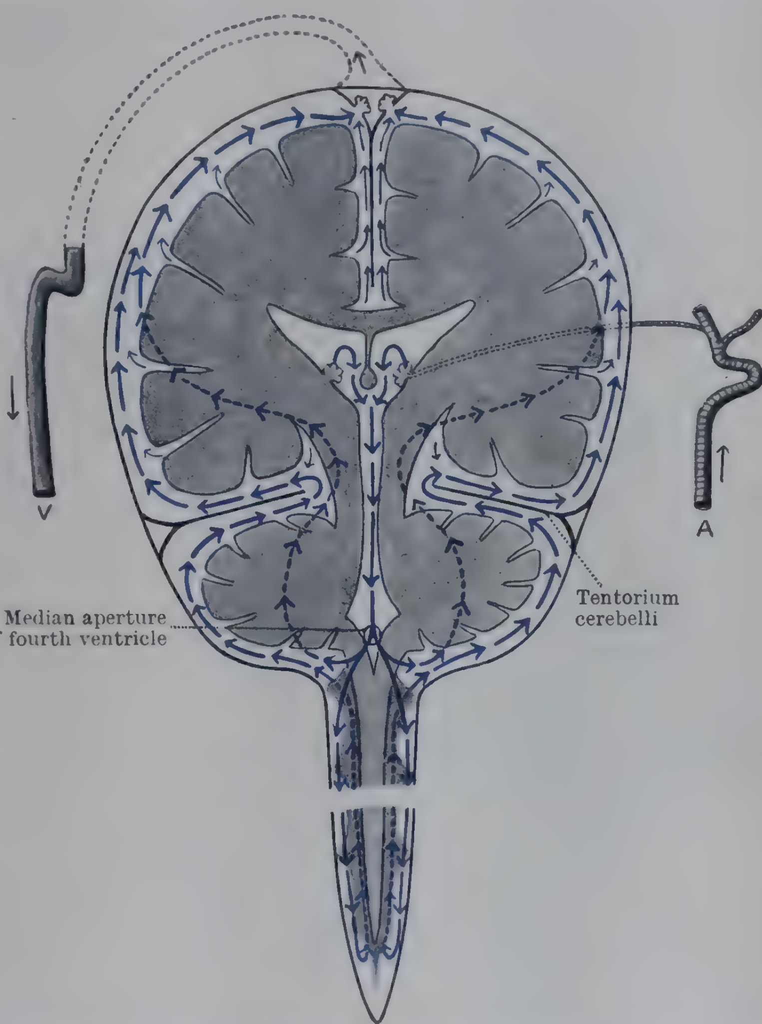

Fig. 882.—Diagram to show the Main Points relating to the Production, Course, and Absorption of the Cerebro-Spinal Fluid. (After Dott, 1928.)

Besides these macroscopic protrusions of the arachnoid mater there are innumerable microscopic processes of this membrane, called **arachnoid villi**, which have the same relation to the venous sinuses. It should be recognized, however, that there is no distinction at all between arachnoid granulations and arachnoid villi, except that of size. These arachnoid villi and arachnoid granulations form the most important pathway for the return of the cerebro-spinal fluid to the venous blood. This takes place by filtration through the membrane formed by the fusion of the arachnoid mater with the vascular endothelium. In infants very few arachnoid granulations are to be seen macroscopically, but as age advances some of the villi, especially those in relation to the posterior part of the superior sagittal sinus, become enlarged to form arachnoid granulations.

Production and Circulation of the Cerebro-Spinal Fluid

The main bulk of the cerebro-spinal fluid is formed within the lateral ventricles of the brain through the agency of the choroid plexuses. It is a clear, colourless fluid of low specific gravity and alkaline reaction which in health is almost free of

protein and cells (2 or 3 lymphocytes per c. mm.) but contains the same crystalloids as the blood. From the lateral ventricles this fluid passes by way of the interventricular foramina into the third ventricle. Here more fluid is added from the choroid plexus of the roof. Then the fluid passes through the aqueduct into the fourth ventricle, where further additions are made from the choroid plexuses in its roof. From the fourth ventricle the fluid escapes by the median and lateral apertures into the subarachnoid space, and is received into the adjacent cisterns which lie below the tentorium. Some of the fluid passes downwards into the spinal subarachnoid space, but the major part rises through the tentorial notch and finds its way slowly over the surface of the hemispheres to be absorbed mainly through the arachnoid villi and granulations into the venous system. Some cerebro-spinal fluid is carried away by the perineural lymphatics. The subarachnoid space is carried outwards for a short distance on the nerves in their arachnoid sheaths, and it is in the region where the arachnoid sheath comes to an end that the cerebro-spinal fluid gains access to the perineural lymphatic channels of the peripheral nerves. This connexion is more free in the olfactory, the optic, and the auditory nerves than in other nerves.

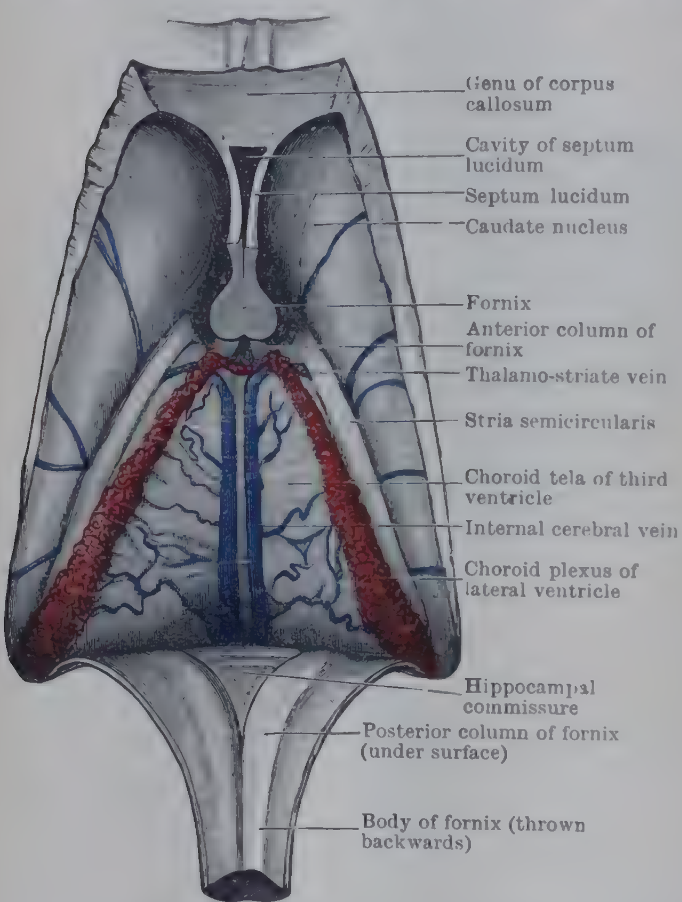

Fig. 883.—Dissection to show Tela Chorioidea of Third Ventricle and the Parts near it.

Each blood-vessel as it enters or leaves the brain-substance is surrounded by a tubular prolongation of the subarachnoid space by means of which cerebro-spinal fluid can follow all the vascular ramifications. The finest perivascular channels communicate ultimately with the perineuronal spaces and so lead the fluid into contact with the neurons themselves (Fig. 879). The normal flow of the cerebro-spinal fluid in these perivascular channels is from within outwards into the main subarachnoid space so that certain products of metabolism may be eliminated by these currents. It is into these channels also, in certain pathological conditions, that the brain capillaries discharge great numbers of leucocytes (in some diseases polymorphs, in others lymphocytes) which are passed out to the main subarachnoid space, thus altering the cellular content of the cerebro-spinal fluid.

For a general account of the relation of the cerebro-spinal fluid to the ventricular system and the meninges, see Weed, 1938.

Pia Mater

The pia mater is the name given to the condensation of subarachnoid tissue which immediately invests the brain and spinal cord, and it forms a delicate and very vascular membrane. The nerves that leave both the brain and spinal cord receive closely applied sheaths from the pia mater, which blend with the fibrous tissue sheaths of the nerves.

Pia Mater of the Brain.—The pia mater which covers the brain is finer and more delicate than that which clothes the spinal cord. It follows closely all the inequalities on the surface of the brain, and in the case of the cerebral hemisphere it dips into each sulcus in the form of a fold which lines it completely.

On the cerebellum the relation is not so intimate; it is only into the larger fissures that it penetrates in the form of definite folds.

The blood-vessels on the surface of the brain lie in the subarachnoid space, and the finer twigs ramify in the pia mater before they proceed into the substance of the brain. As they enter, they carry with them sheaths derived from the pia mater. When a portion of the membrane is raised from the surface of the brain, numerous fine processes are withdrawn from the cerebral surface. They are the blood-vessels with their sheaths, and they give the deep surface of the pia mater a rough and flocculent appearance.

Where the pia mater covers the lower part of the roof of the fourth ventricle it receives the name of the **tela chorioidea of the fourth ventricle**, and it is in connexion with this portion of the pia mater that the choroid plexuses of that cavity are developed. The **tela chorioidea of the third ventricle** is a fold of pia mater which has the appearance of having been invaginated into the brain, so that it comes to lie over the third ventricle and to project, in the shape of choroid plexuses, into the lateral ventricles. The invaginated fold requires special notice.

Tela Chorioidea of Third Ventricle.—This is a double layer of pia mater which intervenes between the body of the fornix, which lies above it, and the ependymal

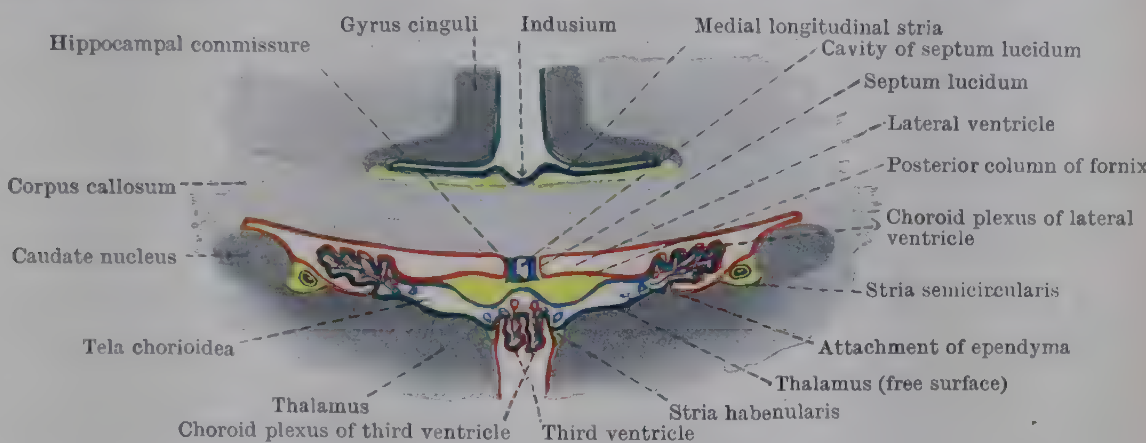

FIG. 884.—DIAGRAM OF CORONAL SECTION THROUGH TELA CHORIOIDEA OF THIRD VENTRICLE.

roof of the third ventricle and the two thalami, which lie below it. Between its two layers there are blood-vessels and some subarachnoid tissue. In shape it is triangular, and the narrow, anterior end or apex lies between the interventricular foramina. The base lies under the splenium of the corpus callosum, and here the two layers of the tela separate and become continuous with the pia mater on the surface of the brain by passing out through a cleft called the **transverse fissure.**

Along each margin the tela chorioidea of the third ventricle is bordered by the choroid plexus of the central part of the lateral ventricle, which projects into the ventricular cavity from under cover of the margin of the fornix. It should be borne in mind that the ependymal lining of the ventricle gives a complete covering to the choroid plexus. Posteriorly the choroid plexus is continuous with the similar structure in the inferior horn of the ventricle, whilst in front it narrows greatly, and becomes continuous across the median plane with the corresponding plexus of the opposite side, behind the ependymal layer which lines the interventricular foramen. From the median junction a pair of much smaller choroid plexuses run backwards on the under surface of the tela chorioidea, and bulge downwards into the third ventricle. They are the choroid plexuses of the third ventricle (Fig. 884).

The most conspicuous blood-vessels in the tela chorioidea are a pair of internal cerebral veins which run backwards, one on each side of the median plane (Fig. 883). In front, each is formed at the apex of the fold by the union of the thalamo-striate vein and a large vein that issues from the choroid plexus; behind, they unite to form the **great cerebral vein**, and this pours its blood into the anterior end of the **straight sinus** (Fig. 877, p. 997).

The continuous cleft through which the choroid plexuses are introduced into the lateral ventricle is called the choroid fissure, and is described on pp. 941, 955, 968.

Spinal Pia Mater.—The pia mater of the spinal cord is thicker and denser than that of the brain. This is largely due to the addition of an outer layer in which the fibres run chiefly in the longitudinal direction. The pia mater is very firmly adherent to the surface of the spinal cord, and in front it sends a fold into the anterior median fissure. The posterior median septum is firmly attached to its deep surface. In front of the anterior median fissure the pia mater is thickened in the form of a longitudinal glistening band, termed the **linea splendens**, which runs along the whole length of the cord and blends with the filum terminale below. The blood-vessels of the spinal cord lie in the deeper layer of the pia mater.

The **ligamentum denticulatum** is a strong fibrous band which stretches out like a wing from the pia mater on each side of the spinal cord and connects the pia mater with the dura mater. The pial or medial attachment of the ligament extends in a continuous line along the surface of the spinal cord between the anterior and posterior nerve-roots, from the level of the foramen magnum to the level of the first lumbar vertebra. Its lateral margin is serrated or denticulated, and for the most part free. From twenty to twenty-two denticulations may be recognized. They occur in the intervals between the spinal nerves, and, pushing the arachnoid before them, they are attached by their pointed ends to the inner surface of the dura mater, and by means of them the spinal cord is suspended in the middle of the dural tube (Fig. 880).

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PERIPHERAL NERVOUS SYSTEM

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The Peripheral Nervous System, as distinct from the Central Nervous System comprising the brain and spinal cord, is broadly divisible into three series of fibres. (I) The **cranial nerves**, which are attached to the brain and pass through openings in the base of the skull to be distributed for the most part to the head region. (II) The **spinal nerves**, which are attached to the spinal cord, pass through the intervertebral foramina, and innervate the trunk and limbs, that is, the somatic area of the body. These two sets of fibres are sometimes grouped together as the cerebro-spinal system of nerves. (III) The **autonomic nervous system**, which is subdivided into (*a*) the sympathetic system and (*b*) the parasympathetic system. Each of these parts has a wide distribution and is composed of ganglia and nerve-fibres which in many localities form complicated plexuses. The sympathetic system is connected with spinal nerves in the thoracic and upper lumbar regions, whilst the parasympathetic system is associated with certain cranial and sacral spinal nerves. No one of the three groups can be considered wholly apart from the others, since, although presenting certain differences in structure, arrangement, and distribution, they are not independent or separate systems, and all are connected to the central nervous system. The subdivision is, however, the most convenient one for descriptive purposes (Hovelacque, 1927).

CRANIAL NERVES

The cranial nerves are twelve pairs of symmetrically arranged nerves which are attached to the brain, leave the skull through foramina at its base, and are in the main distributed to the various structures of the head and neck. The site where the nerve-fibres composing it (rootlets) enter or leave the brain surface is usually termed the **superficial origin** of the nerve, and the more deeply placed group of cells from which the fibres arise or around which they terminate is called the **nucleus of origin** or **of reception** respectively, and forms the **deep origin** of the nerve. It is also customary to trace the course of a nerve from its superficial origin to the periphery irrespective of the actual direction of the impulses carried by it. In this Section the cranial nerves are described from their superficial origins onwards; their deep origins and connexions are dealt with in the account of the Brain (pp. 924-939), and certain general points are also touched upon in the paragraphs introductory to the Nervous System (p. 835).

Classification of Cranial Nerves.—The nomenclature of the cranial nerves reflects the confusion that is associated with the history of their study. In the spinal cord a simple arrangement of dorsal (afferent) and ventral (efferent) nerve-roots is found. Comparable types of fibres comprise the cranial nerves, but there is little of the simplicity of arrangement that characterizes the spinal nerves. Although it may be presumed that some of the cranial nerves (*e.g.*, the hypoglossal) are originally based on some such simple plan, the complications imposed on the head-end of the organism in development have led to a suppression of some elements and fusion of others, with the resulting formation of a series of nerves of very mixed types. It is doubtful if other cranial nerves are even phylogenetically based on such a simple plan. The terminology employed to describe the various cranial nerves has varied from time to time, and even to-day the accepted nomenclature is not beyond reproach. Although no regrouping of the cranial nerves is here suggested, some brief reference to their classification will help to clarify certain points about some of them (see following Table).

COMPONENT AND FUNCTIONAL ANALYSIS OF CRANIAL NERVES

No.	Name	Components	Distribution	Functions
I.	**Olfactory**	Afferent	Olfactory mucous membrane.	Smell.
II.	**Optic**	Afferent	Retina.	i. Sight (*via* lat. genic. body to visuo-sensory cortex). ii. Light reflex (*via* pretectal nucleus).
III.	**Oculomotor**	Efferent : *i. Somatic*	Sup., med., and inf. recti, and inf. oblique muscles of eyeball; levator palp. sup. muscle.	Associated in conjunctive and disjunctive movements of eyes.
		ii. Parasympathetic	Ciliary ganglion; ciliary and sphincter pupillæ muscles of eyeball.	Pupillary constriction and accommodation.
		Afferent	The above muscles.	Proprioceptive (? *via* mesencephalic nucleus of V).
IV.	**Trochlear**	Efferent	Sup. oblique muscle of eyeball.	Associated in movements of eyes.
		Afferent	The above muscle.	Proprioceptive (? *via* mesencephalic nuc. V).
V.	**Trigeminal**	Efferent	Muscles of mastication.	Mandibular movements.
			Digastric (ant. belly) and mylo-hyoid muscles.	Mastication and deglution.
			Tensor palati.	Associated in movements of soft palate and pharyngo-tympanic tube.
			Tensor tympani.	Modifies movements of tympanic membrane and ossicles.
		Afferent	Skin of face and anterior scalp. Mucous membrane of mouth including gums and tongue (ant. $\frac{2}{3}$); teeth. Mucous membrane of nasal cavities and paranasal sinuses. Meninges.	General sensibility.
			Muscles of mastication and expression, and of tongue.	Proprioceptive (*via* mesencephalic nucleus).
VI.	**Abducent**	Efferent	Lateral rectus muscle of eyeball.	Lateral movement of eye, especially in conjugate deviation.
		Afferent	The above muscle.	Proprioceptive (? *via* mesencephalic nucleus of V.).
VII.	**Facial**	Efferent : *i. Branchial*	Muscles of face and scalp.	Facial expression.
			Digastric (post. belly) and stylo-hyoid muscles.	Elevation of hyoid bone.
		ii. Parasympathetic	Spheno-palatine ganglion; glands of nasal cavities, of hard and soft palates, and lacrimal gland. Submandibular and sublingual ganglia; submandibular and sublingual glands and glands of tongue (ant. $\frac{2}{3}$).	Secreto-motor and vaso-dilator.
		Afferent	Mucous membrane of tongue (ant. $\frac{2}{3}$) (excluding vallate papillæ).	Taste.
VIII.	**Auditory**	Afferent	From duct of cochlea.	Hearing.
			From maculæ of utricle and saccule. From ampullæ of semicircular canals.	Equilibration (statokinetic receptors).

COMPONENT AND FUNCTIONAL ANALYSIS OF CRANIAL NERVES—*continued*

No.	Name	Components	Distribution	Functions
IX.	**Glosso-pharyngeal**	Efferent:		
		i. Branchial	Stylo-pharyngeus muscle. Middle constrictor.	Pharyngeal and laryngeal movements.
		ii. Parasympathetic	Otic ganglion; parotid gland.	Secreto-motor and vaso-dilator.
		Afferent	Mucous membrane of pharynx and tongue (post. ⅓) including tonsillar region.	General sensibility.
			Mucous membrane of tongue (post. ⅓) (including vallate papillæ).	Taste.
			Mucous membrane of tympanic cavity and antrum.	General sensibility.
			Carotid body and carotid sinus.	Vaso-sensory (chemo-receptors and pressure receptors).
X.	**Vagus (and Cranial Root of Accessory)**	Efferent:		
		i. Branchial	Levator palati muscle.	Associated in movements of soft palate and pharyngo-tympanic tube.
			Pharyngeal muscles.	Deglutition and other pharyngeal movements.
			Laryngeal muscles.	Control of laryngeal apertures in respiration and phonation.
		ii. Parasympathetic	Plain muscle of œsophagus, stomach, intestine, and gall-bladder.	Movements of these viscera.
			Pancreas and gastric glands.	Secreto-motor.
			Heart (nodal tissue and cardiac muscle).	Cardiac depressor.
			Lungs (plain muscle of bronchi and bronchioles).	Broncho-constriction.
		Afferent	Mucous membrane of larynx and respiratory passages.	General and visceral sensibility.
			Region of epiglottis.	Taste.
			Part of auricle and ext. auditory meatus.	Cutaneous sensibility.
			Lungs.	Respiratory reflexes.
			Glomus aorticum and wall of aorta.	Vaso-sensory.
			Wall of alimentary canal.	? Visceral sensibility.
XI.	**Accessory (Spinal Root)**	Efferent	Trapezius and sterno-mastoid muscles.	Movements of head and shoulder. Fixation of scapula.
XII.	**Hypoglossal**	Efferent	Muscles of tongue.	Movements of tongue.

Two of the nerves, the olfactory and optic, are not nerves in the usually accepted sense but rather tracts of fibres belonging to the central nervous system, as will be pointed out in greater detail under the appropriate headings. The third, fourth, and sixth nerves, all associated with the extra-ocular muscles, are predominantly motor nerves; but the third contains important parasympathetic preganglionic fibres, and all three of them have a small admixture of sensory fibres—without, however, possessing any ganglia or separate sensory roots (Tozer & Sherrington, 1910). The fifth, seventh, and eighth nerves are all complex, and there are good reasons for considering each of these as comprising two (or more) separate nerves. The fifth has a large sensory component with very extensive distribution in the face and head and a smaller motor component (*nervus masticatorius*) of localized distribution which accompanies its mandibular division. Both, however, possess the same superficial origin from the brain-stem. The seventh or facial nerve possesses two portions, one the facial proper, a motor nerve to muscles of expression in the main, and the other a smaller mixed nerve, the "sensory" root of the seventh, which from the viewpoint of distribution and function has little in common with the facial proper; it is in part composed of afferent fibres subserving taste, and, in large measure, of preganglionic fibres of the parasympathetic system for certain glands of the head (secreto-motor). The eighth nerve is readily separable into two entirely different functional elements—the cochlear and vestibular nerves—which are both sensory, and in development are closely associated. The

ninth and tenth are both mixed nerves, the latter in particular containing a large proportion of parasympathetic fibres. The eleventh nerve comprises two quite different parts, the cranial portion, which is closely associated functionally with the vagus, and the spinal portion, of quite distinct and separate distribution. The twelfth or hypoglossal nerve represents the compounding of the motor supply to several occipital myotomes which form the basis of the tongue-musculature. This nerve has lost completely, or almost so, the elements which would correspond with the dorsal root of a spinal nerve. Reference may here be made to the first cervical nerve (*suboccipital nerve*) which emerges between the skull and the atlas. It is in series with the twelfth and, like it, is in the process of losing its sensory components, so that a dorsal root ganglion is commonly absent in the adult. It was originally classed as a cranial nerve by Willis (1664), and its inclusion amongst the cervical spinal nerves accounts for the presence of eight cervical nerves, the first lying above the first vertebra and the second emerging below it.

OLFACTORY NERVE

The pathway taken by olfactory impulses from the nasal mucosa to the brain may be considered in various parts: (1) a series of fine **nerves** which run to (2) the

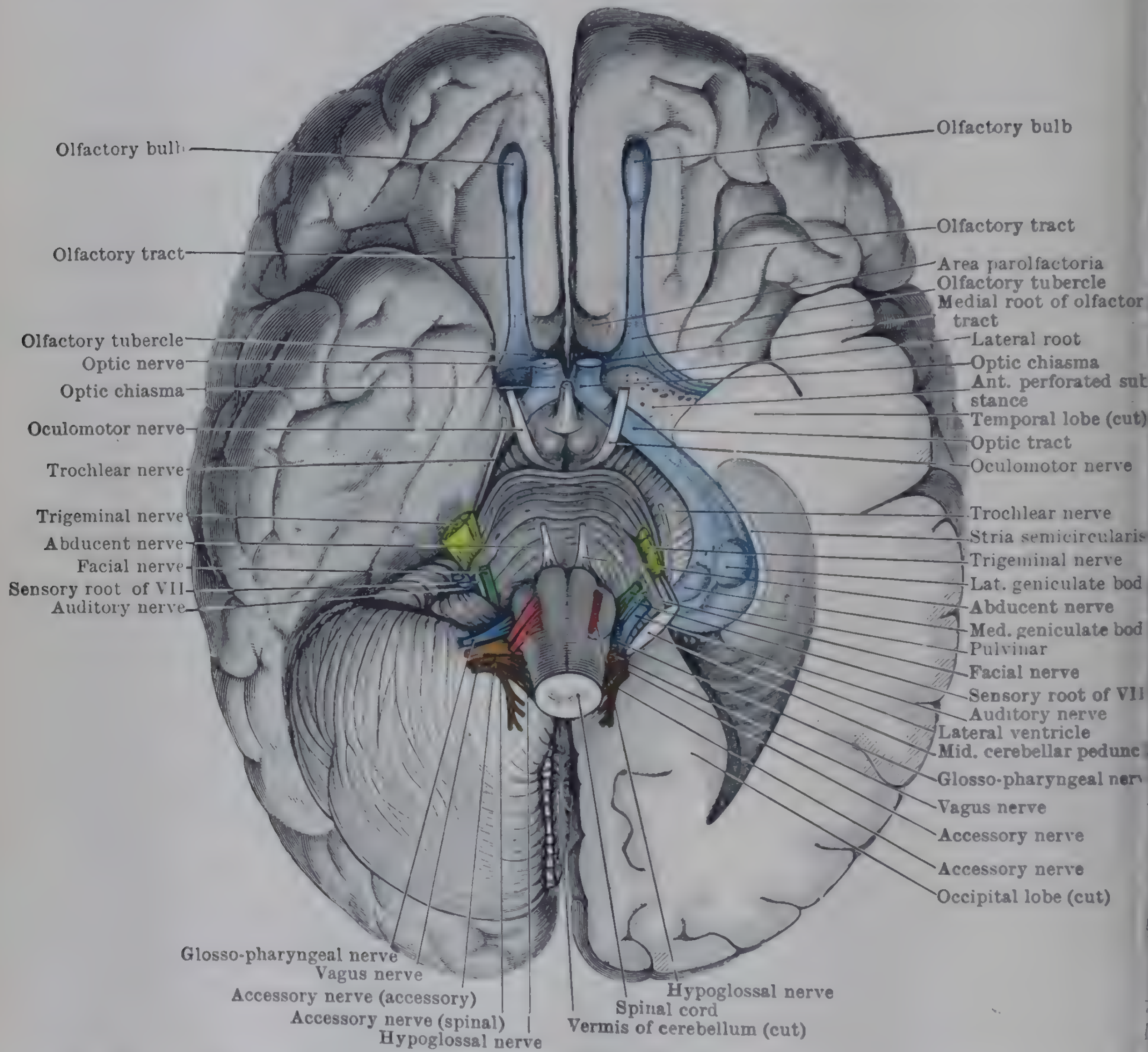

FIG. 885.—INFERIOR SURFACE OF BRAIN TO SHOW SUPERFICIAL ATTACHMENTS OF CRANIAL NERVES.
The lower portion of the left temporal and occipital lobes, and the left half of the cerebellum have been removed.

olfactory bulb; the bulb is connected by (3) the **olfactory tract** with the brain; to which it is attached by (4) two **roots** (Fig. 885).

The anatomy of the olfactory bulb, the olfactory tract and its roots is described on pp. 957 to 960; and the histology of the cells on p. 957.

The **olfactory nerve** consists of about twenty separate filaments which arise in the olfactory areas of the nasal mucosa and proceed to the olfactory bulb in the

anterior cranial fossa, passing in their course through the cribriform plate of the ethmoid bone. The fibres comprising these filaments are the central processes of bipolar nerve-cells which lie in the olfactory mucosa. They are exceedingly fine and are non-medullated. The filaments proceed by the shortest route to the holes in the cribriform plate and then direct to the olfactory bulb, on the surface of which they form an intricate plexus before terminating in the glomeruli of the bulb. In the region of the cribriform plate meningeal extensions are continued for a short way along the bundles of nerve fibres.

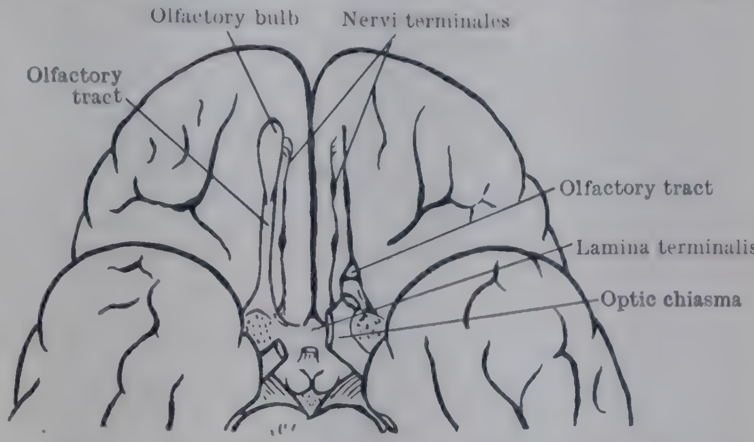

Fig. 886.—Diagram of part of Lower Surface of Adult Human Brain to show position of Nervi Terminales and their Relations to Olfactory Tracts and Gyri Recti. (After Brookover, 1914.)

The olfactory bulb and part of the tract have been removed on the left side, and the right optic nerve and the greater part of the optic chiasma have been cut away to expose the lamina terminalis.

The cell-bodies and the peripheral processes of the olfactory cells lie in the epithelium which covers the upper third of the nasal septum and nearly the whole of the superior concha (Figs. 893, 894). The cell-body is small with a rounded nucleus embedded in a scanty cytoplasm. The short peripheral process, or olfactory rod, is somewhat thicker than the central process and terminates at the surface in a small cup-shaped swelling; fine olfactory hairs project from the margin of the terminal swelling. (Le Gros Clark & Warwick, 1946)

Two other pairs of nerves have been found related to the olfactory system in lower vertebrates and in mammals with a well-developed sense of smell. Both are closely related to the olfactory nerve itself throughout its course. They are (1) the *vomero-nasal nerve*, which supplies the vomero-nasal organ, and in the domestic animals joins the olfactory nerve itself to terminate in an accessory olfactory bulb; in Man the vomero-nasal organ (p. 1208) is rudimentary after birth, and the nerve is absent; (2) the terminal nerve (Fig. 886).

The **terminal nerve** (*nervus terminalis*) has been found present in all groups of vertebrates, including Man. It is a very fine plexiform nerve consisting of non-medullated fibres with small groups of ganglion-cells, and may be discovered in the cranial cavity as two or three strands in the pia mater covering the gyrus rectus along the medial side of the olfactory tract. Peripherally (anteriorly) its fibres join the olfactory nerve-filaments and have a similar distribution to the nasal mucosa; in some mammals they have been traced to end in the walls of the anterior cerebral artery and in the vascular plexus of the nasal septum up to the region of the vomero-nasal organ. Centrally, the nerve strands pass over the medial root of the olfactory tract towards the anterior perforated substance. The evidence points to the conclusion that the nerve is functional in mammals, and, from the appearance of its fibres and ganglia, among other features, it may eventually be recognized as related in part at least to the autonomic system rather than as representing a separate nerve. (For further details, see Johnston, 1914; Brookover, 1914, 1917; M'Cotter, 1915; Larsell, 1918; Pearson, 1941).

OPTIC NERVE

The **second** or **optic nerve** consists of nerve-fibres which spring from the ganglion-cells of the retina, and converge to the optic disc, where they are grouped together to form the optic nerve. There is no adequate evidence of the presence of centrifugal fibres in the mammalian optic nerve (Bodian, 1937). Composed in this way of connector neurons, the optic nerve differs from other sensory nerves, which are composed of receptor neurons; it is, in reality, a tract of the brain, and the fibres comprising it lack the neurolemmal sheath of ordinary peripheral nerve-fibres, its place being taken by sheaths of neuroglial cells. The nerve pierces the outer layers of the retina, the choroid, and the sclera. Within the eyeball the fibres are non-medullated but acquire a myelin sheath as they penetrate the sclera. It pierces the sclera 3 mm.

(one-eighth of an inch) to the medial side of the posterior pole of the eyeball and slightly *above*[1] the horizontal meridian (Traquair, 1949), the nerve-fibres being divided into bundles by the lamina cribrosa, and enters the orbital fat, surrounded by the ciliary vessels and nerves. It then runs backwards and slightly medially towards the optic foramen, being crossed superiorly by the ophthalmic artery and naso-ciliary nerve, and is pierced on its inferior surface, usually about 1 cm. behind the eyeball, by the central artery and vein of the retina. It is surrounded by sheaths from all three membranes of the brain, that formed by the dura being especially robust, and by prolongations of the subdural and subarachnoid spaces which lie

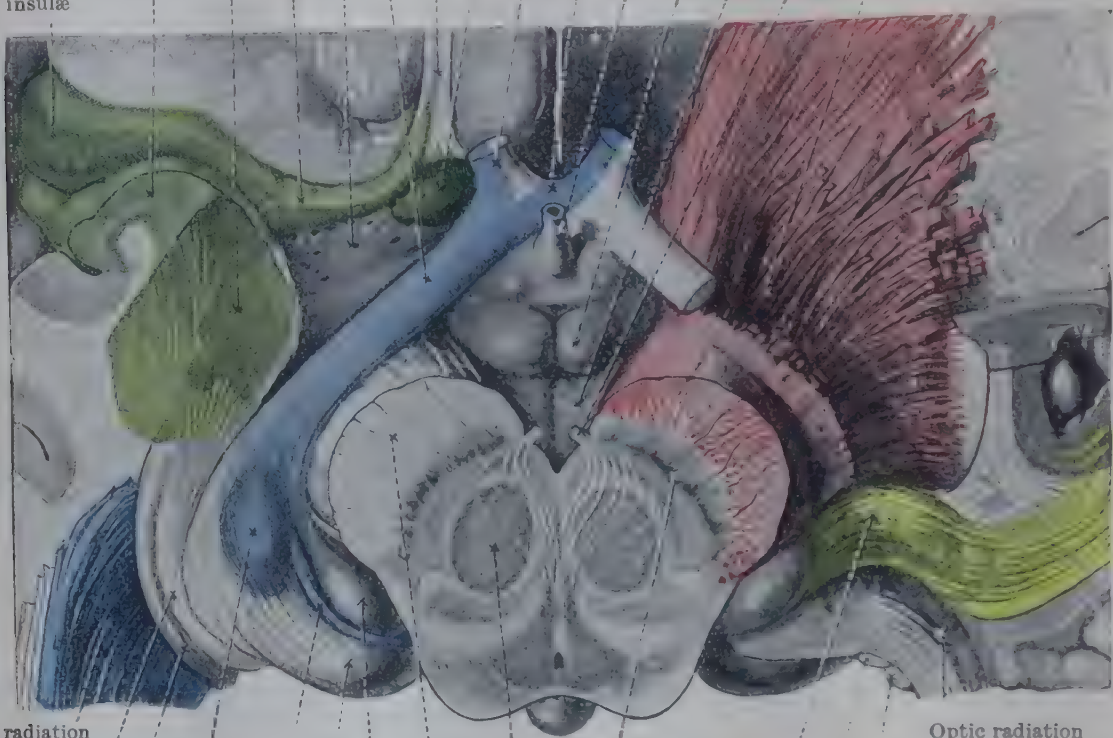

Fig. 887.—Part of Lower Surface of Fore-Brain, showing Olfactory and Optic Tracts. The mid-brain has been cut across. Olfactory area, *green*; optic fibres, *blue*; motor fibres, *red*; auditory fibres, *yellow*.

between them. To enter the optic foramen, it passes through the common tendinous ring from which the four rectus muscles of the eyeball arise. In the foramen it is separated from the sphenoidal air-sinus by only a thin plate of bone, the ophthalmic artery accompanies it on its lower and lateral sides, and the arteria retinæ centralis may enter it in this part of its course. It then enters the middle fossa of the skull and ends in the optic chiasma, which lies in the floor of the third ventricle of the brain, anterior to the interpeduncular area and between the right and left valleculæ of the cerebrum. The chiasma is in close relation on each side to the internal carotid artery (Fig. 889), but is a little distance above the hypophysis cerebri and the diaphragma sellæ.

From each of the two postero-lateral angles of the optic chiasma an optic tract sweeps round to the posterior part of the thalamus and to the mid-brain, between the

[1] It is usually stated that the optic head is below the level of the posterior pole, but Traquair maintains, with reference to the projection of the "blind spot", that it is above. (See also p. 1162.)

cerebral peduncle and the hippocampal gyrus of the corresponding side, and each tract terminates in connexion with the lateral geniculate body. Formerly it was thought that fibres of the optic tract terminated in all three lower visual centres

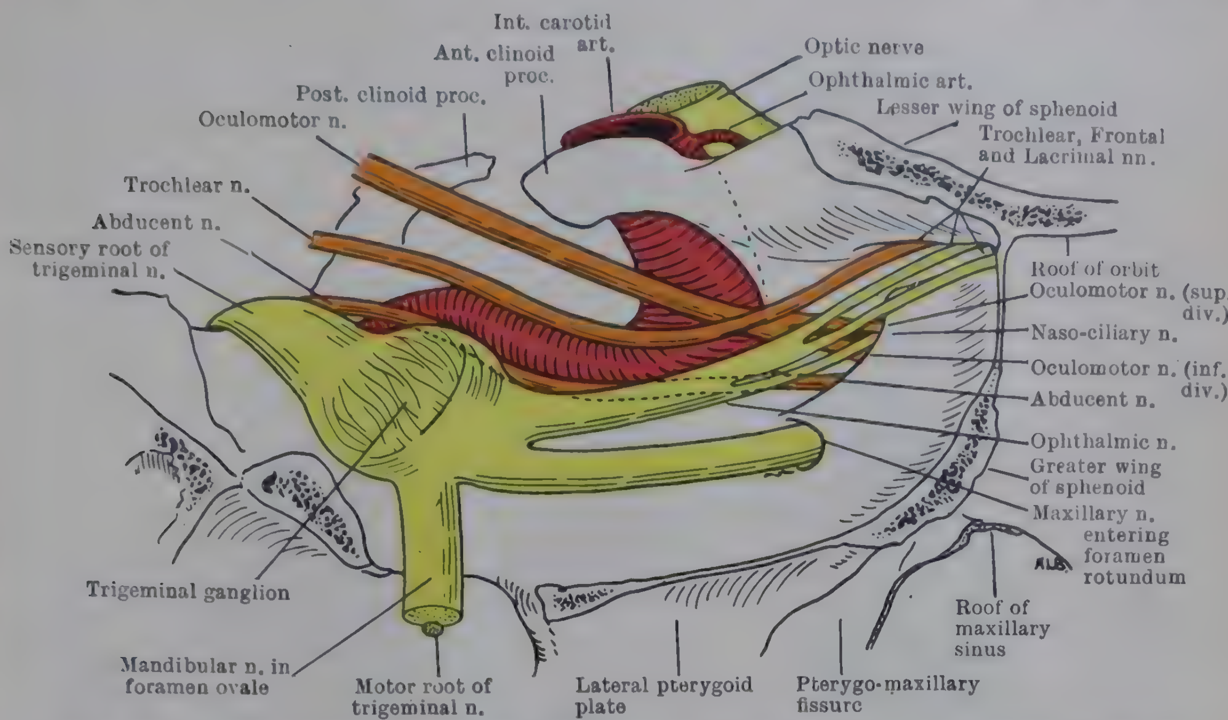

FIG. 888A.—RELATIONS OF STRUCTURES IN CAVERNOUS SINUS AND SUPERIOR ORBITAL FISSURE, VIEWED FROM THE RIGHT SIDE.

The section of the skull passes sagittally through the foramen ovale.

(the lateral geniculate body, pulvinar of thalamus and superior quadrigeminal body), but recent researches have shown that in Man, of the fibres concerned purely with vision, none go to the superior quadrigeminal body and probably none to the pulvinar, a change having been brought about in the arrangement of the fibres in consequence of the development of the macula of the retina and the increased functional importance of the visual cortex, which is connected with all three lower visual centres (Le Gros Clark, 1942). Fibres concerned with visual reflexes, however, do pass directly from the tract to the superior quadrigeminal body and the pretectal nucleus (see p. 952 and Fig. 835).

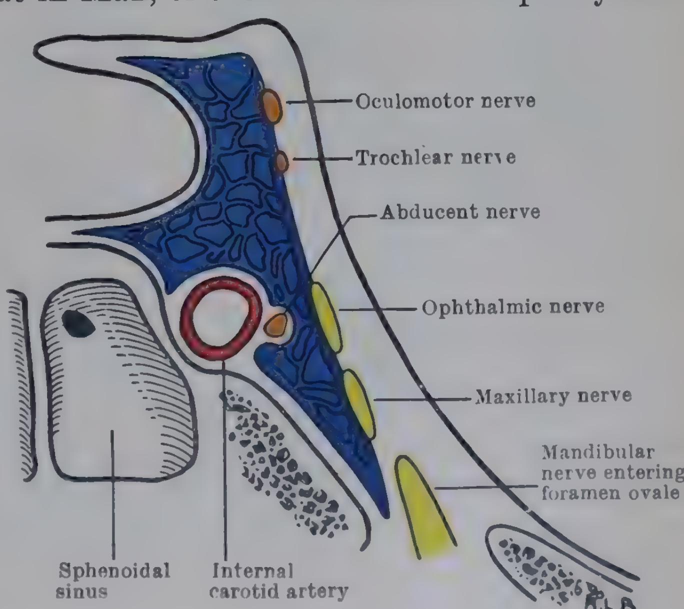

FIG. 888B.—DIAGRAMMATIC OBLIQUE CORONAL SECTION THROUGH THE RIGHT CAVERNOUS SINUS, VIEWED FROM BEHIND.

When the optic nerve reaches the optic chiasma the fibres from the lateral half of each retina, including the corresponding macular fibres, pass to the optic tract of the same side and the fibres from the medial half to the optic tract of the opposite side. Therefore, each optic nerve is connected with both sides of the brain in such a way that ipsilateral retinal areas, and therefore contralateral visual fields, are projected to the optic tracts (see p. 952 in Central Nervous System). Each optic tract, in addition, contains fibres unconnected with the visual apparatus. The connexions of such fibres (which constitute the commissure of Gudden in the chiasma) are not clear, but there are grounds for doubting the correctness of the classical view that Gudden's commissure connects the medial geniculate body and

the inferior quadrigeminal body of opposite sides (Woollard & Harpman, 1939; Magoun & Ranson, 1942).

OCULOMOTOR NERVE

The **third** or **oculomotor nerve** is predominantly a motor nerve and supplies the levator palpebræ superioris, and all the extrinsic ocular muscles, save the

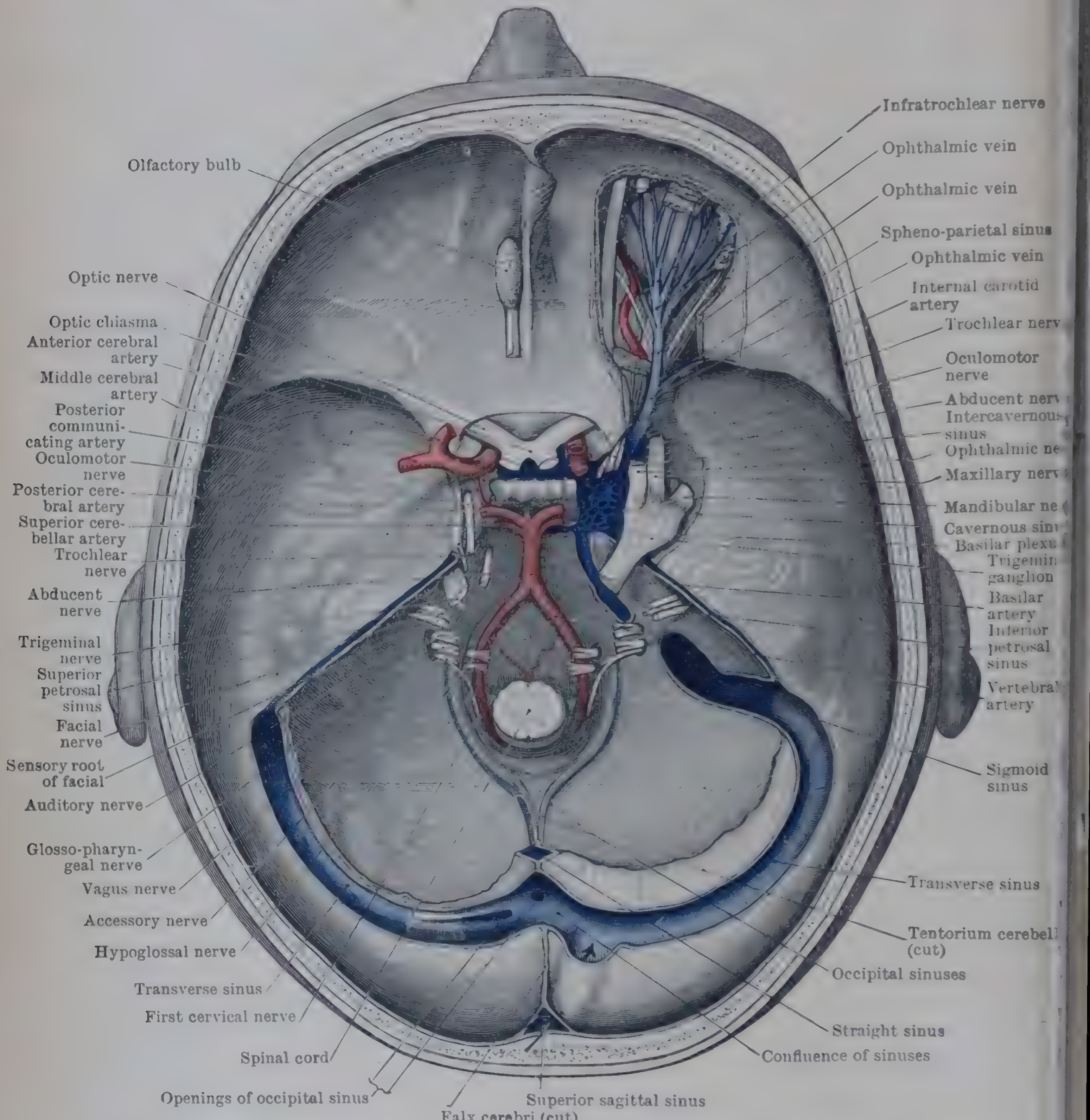

FIG. 889.—BASE OF SKULL, TO SHOW DURA MATER, VENOUS SINUSES, ARTERIES, AND NERVES.

lateral rectus and superior oblique; it supplies also certain intrinsic ocular muscles. Some afferent fibres are present carrying proprioceptive impulses from these muscles—possibly to the mesencephalic nucleus of the fifth nerve (p. 430). It arises from the brain, near the posterior perforated substance, by several rootlets which emerge from the medial sulcus of the cerebral peduncle, just above the pons (Figs. 885 and 813). (For deep origin, see p. 934.) Passing forwards, between and close to the posterior cerebral and superior cerebellar arteries, then along the lateral aspect of the posterior communicating artery through the interpeduncular cistern, the nerve pierces the dura mater antero-lateral to the posterior clinoid

process, in a small triangular space between the free and attached borders of the tentorium cerebelli. Embedded in the dura mater, the nerve courses through the lateral wall of the cavernous sinus, above the trochlear nerve, enters the orbit through the superior orbital fissure, and then lies within the common tendinous ring from which the four rectus muscles arise (Fig. 896). Just before the point of entry into the orbit the nerve divides into upper and lower branches, separated by the naso-ciliary nerve (Fig. 888 A). Sunderland & Hughes (1946) found that fibres concerned with constriction of the pupil were localized about the superior surface of the nerve from its point of emergence from the brain to the middle of the cavernous sinus; thereafter the pupillary fibres did not regularly adopt a fixed position relative to the rest of the third nerve.

Branches.—The **superior branch** of the nerve supplies two muscles of the orbit—the superior rectus and the levator palpebræ superioris.

The **inferior branch** passes forwards, and, after giving branches to the medial and inferior recti, ends in the inferior oblique muscle. From the branch which supplies the inferior oblique a filament (the parasympathetic root) extends to the ciliary ganglion and is concerned with the innervation of the ciliary and sphincter pupillæ muscles of the eyeball (Fig. 890).

Communications.—In the cavernous sinus the oculomotor nerve receives (1) filaments from the sympathetic plexus on the internal carotid artery, and (2) a slender communication from the ophthalmic division of the trigeminal nerve. Such communications are probably of a temporary nature.

Ciliary Ganglion.—This ganglion, which is a component of the cranial parasympathetic system, is a small reddish body about the size of a pin's head placed near the back of the orbit, between the lateral rectus muscle and the optic nerve, and in front of the ophthalmic artery. Some detached ganglionic cells may be found lying above the eyeball—see p. 1122. Joining the ganglion are several groups of fibres :—(1) The *parasympathetic root* derived from the nerve to the inferior oblique muscle. This root contains preganglionic parasympathetic fibres of the third nerve; they are non-medullated and are the only fibres to have synapses in the ciliary ganglion. (2) The *sympathetic root* composed of postganglionic fibres derived from the plexus on the internal carotid artery. These fibres may reach the ganglion independently or by way of the naso-ciliary nerve; and they pass uninterruptedly through the ganglion. (3) The *afferent root*, which is composed of afferent fibres that belong to the naso-ciliary branch of the fifth nerve; they are passing centrally from the eye to the fifth nerve without synaptic relay in the ganglion. It will be noted that the afferent and sympathetic roots have merely a relationship of contiguity with the ganglion cells (Fig. 890).

Passing away from the ciliary ganglion are twelve to fifteen **short ciliary nerves** which reach the eyeball in two groups above and below the optic nerve. These nerves (which are all medullated) convey (*a*) postganglionic parasympathetic fibres from the cells of the ganglion for the innervation of the ciliary muscle and the sphincter pupillæ muscle of the iris; (*b*) vasomotor sympathetic fibres to the vessels of the eye; and (*c*) afferent fibres from all parts of the eyeball. These will later reach the ophthalmic nerve through the sensory root of the ciliary ganglion.

TROCHLEAR NERVE

The **fourth** or **trochlear nerve** supplies only the superior oblique muscle of the eyeball. It arises at the side of the *frenulum veli* from the upper end of the superior medullary velum, just below the inferior quadrigeminal bodies (Fig. 802, p. 915). (For deep origin see p. 933.) It is extremely slender, and, since it emerges through the back of the brain-stem, its intracranial length is considerable. Passing round the lateral side of the cerebral peduncle immediately below the free margin of the tentorium, the nerve appears at the base of the brain behind the optic tract, in the interval between the cerebral peduncle and the temporal lobe of the brain, and between the superior cerebellar and posterior cerebral arteries. Continuing forwards, it then pierces the free border of the tentorium cerebelli,

postero-lateral to the oculomotor nerve, and proceeds forwards, in the lateral wall of the cavernous sinus (Fig. 888), to the superior orbital fissure, lying between the oculomotor nerve and the ophthalmic division of the trigeminal nerve. It enters the orbit above the muscles of the eyeball (Fig. 896), turns medially between the levator palpebræ superioris and the periosteum of the orbital roof, and terminates in the orbital surface of the superior oblique muscle.

Communications.—In the cavernous sinus the nerve communicates by slender branches (1) with the sympathetic plexus on the internal carotid artery, and (2) with the ophthalmic division of the trigeminal nerve. Such communications are probably of a temporary nature.

TRIGEMINAL NERVE

The **fifth** or **trigeminal nerve**, the largest of the cranial nerves, is the nerve of common sensation to the superficial and deep parts of the face, and is motor to the muscles of mastication (see summary of distribution on p. 1010). Proprioceptive impulses from these muscles as well as from the palate and the teeth are conveyed to the mesencephalic nucleus of the fifth nerve (Corbin & Harrison, 1940).

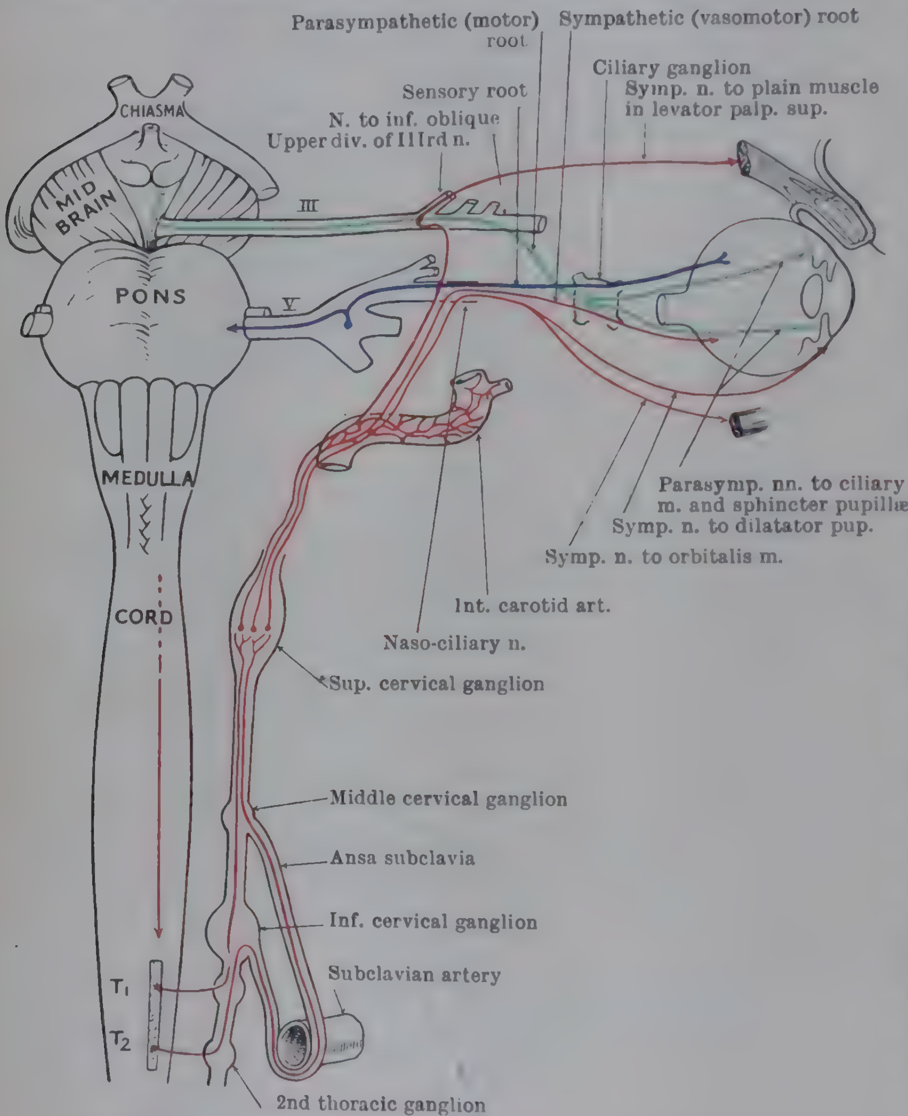

Fig. 890.—Diagram of Ciliary Ganglion and Connexions of Autonomic Nervous System with the Eye.

It is attached to the lateral part of the anterior surface of the pons by two roots—a large **sensory root** and a small **motor root** (Fig. 813, p. 925). (For deep origin see p. 931.) The two roots proceed forwards in the posterior fossa of the skull, and enter the middle fossa by passing beneath the attachment of the tentorium cerebelli to the upper border of the petrous part of the temporal bone; at this point the roots generally lie beneath the superior petrosal sinus. In the middle fossa they occupy a cavity in the dura mater (*cavum trigeminale*) on the anterior surface of the petrous bone. The sensory (afferent) root gradually conceals the motor (efferent) root in its course forwards, and expands within the cavum trigeminale into a large, flattened, and somewhat plexiform ganglion—the **trigeminal ganglion**. That ganglion occupies an impression on the petrous portion of the temporal bone near its apex; and the internal carotid artery and the posterior part of the cavernous sinus are on its medial side. From the ganglion three large trunks arise—the **ophthalmic** or first, the **maxillary** or second, and the **mandibular** or third **divisions** of the nerve. The motor

root of the nerve passes forward beneath the ganglion, and is incorporated wholly with the mandibular division of the nerve; on developmental and functional grounds the motor root is sometimes described as a separate nerve—the *nervus masticatorius*.

In the sensory root adjacent to the ganglion the fibres correspond, from medial to lateral, to the three divisions of the nerve, *i.e.*, ophthalmic, maxillary, and mandibular. Traced towards the pons, this arrangement tends to be obscured by a rotation of the whole nerve and some intermingling of fibres belonging to the three divisions. Nevertheless, at the origin from the pons the fibres of the ophthalmic division are mostly inferior in position and those of the mandibular division in the main superior (Davies & Haven, 1933).

OPHTHALMIC NERVE

The **ophthalmic nerve** passes forwards towards the orbit through the middle fossa of the skull, in the dura mater of the lateral wall of the cavernous sinus, at a lower level than the trochlear nerve. Near the superior orbital fissure it divides into three main branches—lacrimal, frontal, and naso-ciliary (Fig. 888A).

In the wall of the cavernous sinus the ophthalmic nerve gives off (1) a small recurrent branch to the dura mater (*n. to tentorium*, Fig. 878, p. 999), (2) small communicating sensory twigs to the trunks of the oculomotor, trochlear, and abducent nerves, and it receives branches from the sympathetic plexus on the internal carotid artery. Sunderland & Hughes (1946) describe these communicating twigs as being of a temporary nature and not involving the permanent transfer of fibres between the nerves concerned.

The **lacrimal nerve** enters the orbit through the lateral angle of the superior orbital fissure, above the orbital muscles. It passes forwards between the periosteum and the orbital contents to the anterior part of the orbit, and ends by supplying branches (*a*) to the lacrimal gland, (*b*) to the conjunctiva, and (*c*) to the skin of the lateral part of the upper eyelid.

The lacrimal nerve *communicates* in the orbit with the zygomatic branch of the maxillary nerve (Fig. 897) (whereby some secretory fibres are probably conveyed to the lacrimal gland), and on the face, by its terminal branches, with the temporal branches of the facial nerve.

The **frontal nerve** enters the orbital cavity through the superior orbital fissure, courses forwards above the ocular muscles, and divides at a variable point into two branches—a larger supra-orbital and a smaller supratrochlear nerve (Figs. 891 and 892).

The **supra-orbital nerve** passes directly forwards and leaves the orbit through the supra-orbital groove or foramen to reach the forehead. It gives off secondary branches which are distributed to: (1) the forehead and scalp, reaching backwards as far as the vertex; (2) the upper eyelid; and (3) the frontal sinus. On the forehead the supra-orbital nerve communicates with the temporal branches of the facial nerve.

The **supratrochlear nerve** courses obliquely forwards and medially, above the tendon of the superior oblique muscle, to reach the medial part of the supra-orbital margin, where it leaves the cavity of the orbit; it is distributed to the skin and fascia of the medial part of the forehead and the medial part of the upper eyelid.

It communicates with the infratrochlear branch of the naso-ciliary nerve, either before or after leaving the orbit.

The **naso-ciliary nerve** enters the orbit through the superior orbital fissure, and between the two divisions of the oculomotor nerve (Fig. 896). It crosses the orbital cavity obliquely to reach the anterior ethmoidal foramen, lying in its course below the superior rectus and superior oblique muscles and above the optic nerve and medial rectus muscle. The nerve is transmitted, under the name of *anterior ethmoidal*, through the anterior ethmoidal foramen into the cranial cavity, where it lies embedded in dura mater on the cribriform plate of the ethmoid bone. It enters the nasal cavity through the nasal slit, and terminates by dividing into medial and lateral **internal nasal branches**. The medial division supplies the

mucous membrane over the upper and anterior part of the nasal septum. The lateral branch, after supplying collateral offsets to the lateral wall of the nasal cavity, finally appears on the face, as the **external nasal branch**, between the nasal bone and the upper nasal cartilage, and supplies branches to the skin and fascia of the lower part of the dorsum and the tip of the nose. The anterior ethmoidal nerve supplies, then, the cartilaginous part of the nose, both internally and externally.

The **branches** of the naso-ciliary nerve may be divided into three sets, arising (*a*) in the orbit, (*b*) in the nose, and (*c*) on the face.

In the orbit the branches are given off in three situations—lateral to, above, and

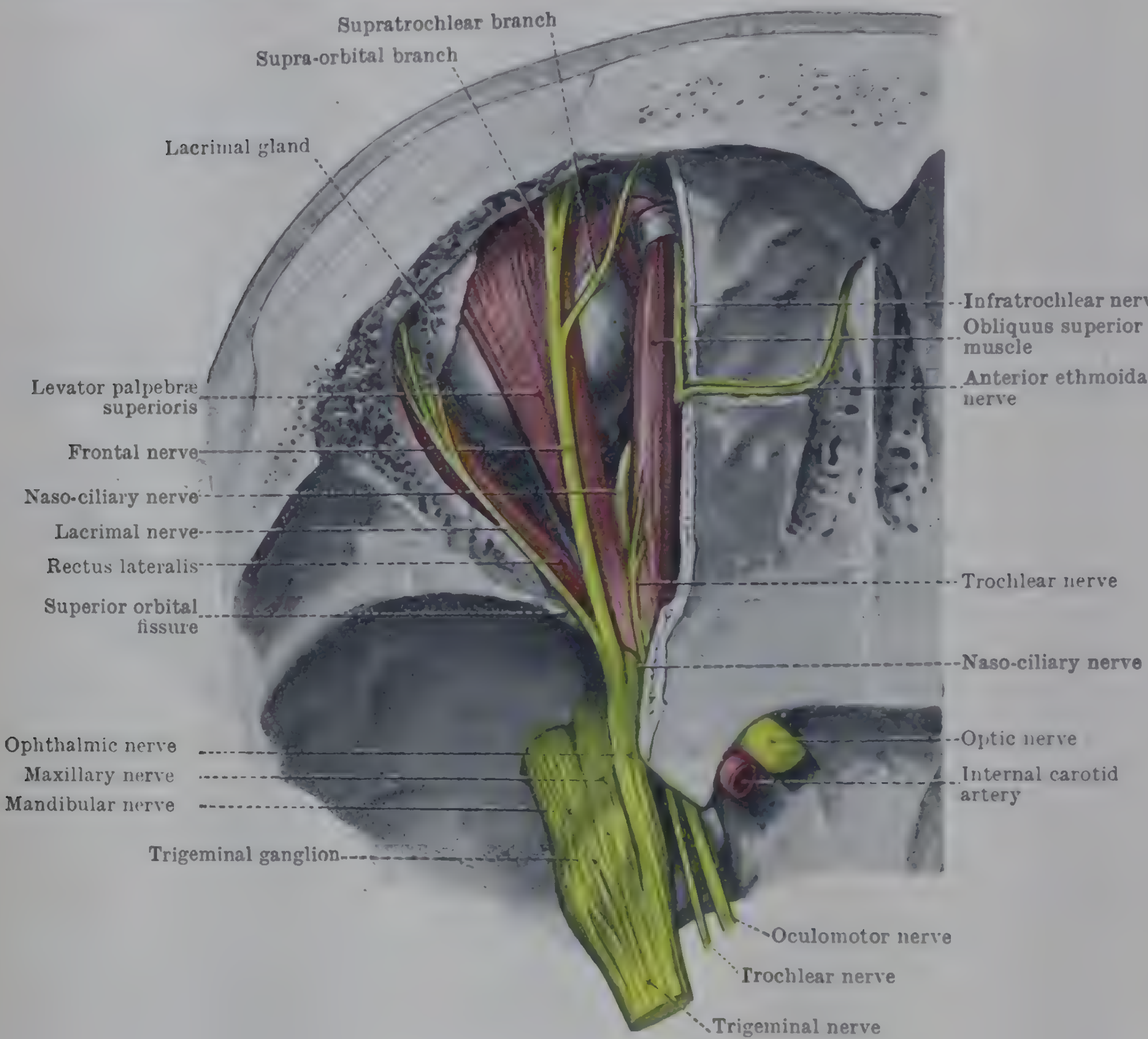

FIG. 891.—NERVES OF ORBIT FROM ABOVE.

medial to the optic nerve. (*a*) As the nerve lies on the lateral side of the optic nerve, it gives off the **ramus communicans** or afferent root to the ciliary ganglion. (*b*) As it crosses above the optic nerve, **two long ciliary nerves** arise and pass forwards alongside the optic nerve to the eyeball. They convey sympathetic fibres to the dilator pupillæ muscle and afferent fibres to the iris and ciliary body. (*c*) On the medial side of the optic nerve the **infratrochlear nerve** arises as a slender branch which courses forwards below the pulley of the superior oblique muscle to the front of the orbit. It ends on the face by supplying the skin of the root of the nose and the eyelids; and it communicates either in the orbit or on the face with the supratrochlear nerve. On the face it also communicates with zygomatic branches of the facial nerve. A minute *posterior ethmoidal branch* may arise from the nerve near the back of the orbit and enter the foramen of the same name to be distributed to the sphenoidal sinus and posterior ethmoidal sinuses.

In the nose the **medial internal nasal branches** supply the mucous membrane of the anterior part of the nasal septum; and **lateral internal nasal branches** supply the anterior part of the lateral wall of the nasal cavity.

In the face the terminal filaments of the **external nasal branch** are distributed to the skin and fascia of the lower half and tip of the nose. The terminal branch communicates with the zygomatic branches of the facial nerve.

MAXILLARY NERVE

The **maxillary nerve** courses forwards from the trigeminal ganglion through the middle fossa of the skull, in the dura mater, and in relation to the lower part of the cavernous sinus (Fig. 888, p. 1015). It passes through the foramen rotundum, traverses the pterygo-palatine fossa, and enters the orbit as the infra-orbital nerve through the inferior orbital fissure. In the orbit it occupies successively the infra-orbital groove and canal, and it finally appears on the face through the infra-orbital foramen (Fig. 898).

The branches and communications of this nerve occur (*a*) in the cavity of the cranium, (*b*) in the pterygo-palatine fossa, (*c*) in the infra-orbital canal, and (*d*) in the face.

(*a*) *In the cavity of the cranium* the nerve gives off a minute **meningeal branch** to the dura mater of the middle fossa of the skull (Fig. 878, p. 999).

(*b*) *In the pterygo-palatine fossa* the nerve gives off—(1) two short thick **ganglionic branches** to which the spheno-palatine ganglion is closely related. These nerves have, however, only a relationship of contiguity with the ganglion, for the fibres pass either close by it or through it without having any synaptic relation with the cells of the ganglion. As the fibres pass away from the ganglion or its vicinity they are commonly accompanied by the axons of cells within the ganglion (*i.e.*, parasympathetic fibres). In this way a number of small nerves appear to proceed from the ganglion and have commonly been called " branches of the ganglion "; but it must be understood that they are predominantly fifth nerve branches with only an admixture of fibres derived from the cells of the ganglion. A description of the spheno-palatine ganglion will be found on p. 1033 with the seventh nerve. These numerous branches (so-called branches of the ganglion) pass backwards to the pharynx, downwards to the palate, medially to the nasal cavity, and upwards to the orbit.

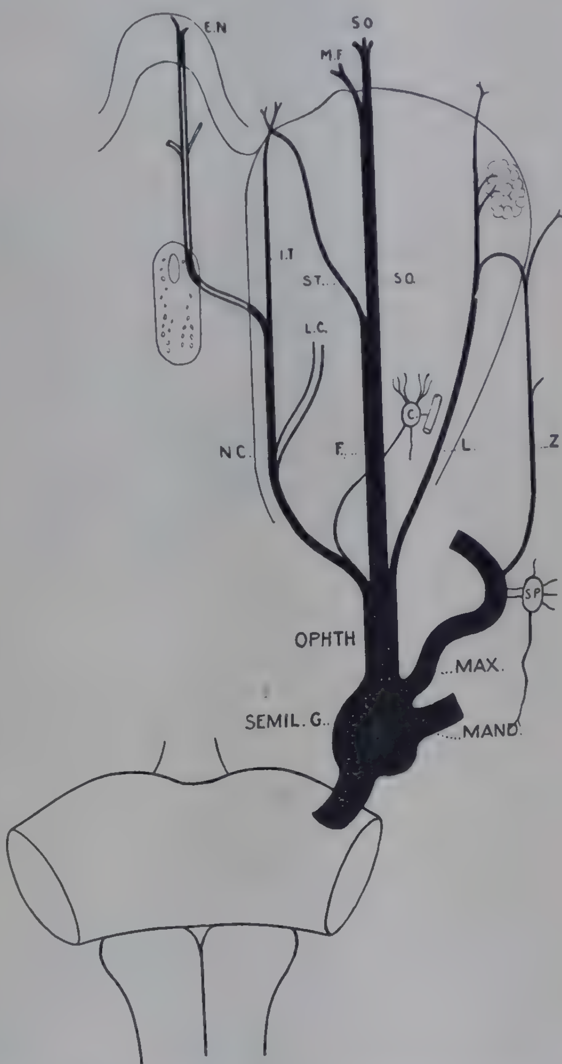

FIG. 892.—SCHEME TO SHOW THE DISTRIBUTION OF THE OPHTHALMIC NERVE.

F., frontal nerve, giving off supratrochlear branch (S.T.) and proceeding as supra-orbital (S.O.), which may divide before leaving orbit into a medial frontal branch (M.F.) and a lateral frontal or supra-orbital proper.

N.C., naso-ciliary nerve; gives off afferent root to ciliary ganglion (C.), two long ciliary nerves (L.C.) to eyeball, and, just before leaving the orbit through the anterior ethmoidal canal, the infratrochlear nerve (I.T.); the rest of its course up to its termination on the nose as the external nasal nerve (E.N.) illustrates the description given in the text.

L., lacrimal nerve, communicating with zygomatico-temporal branch of zygomatic nerve (Z.).

S.P., spheno-palatine ganglion.

(i) The **pharyngeal branch** passes backwards through the palatino-vaginal canal to supply the mucous membrane of the roof of the pharynx and the sphenoidal sinus.

(ii) The **palatine nerves**, three in number, are directed downwards to the palate through the palatine canals.

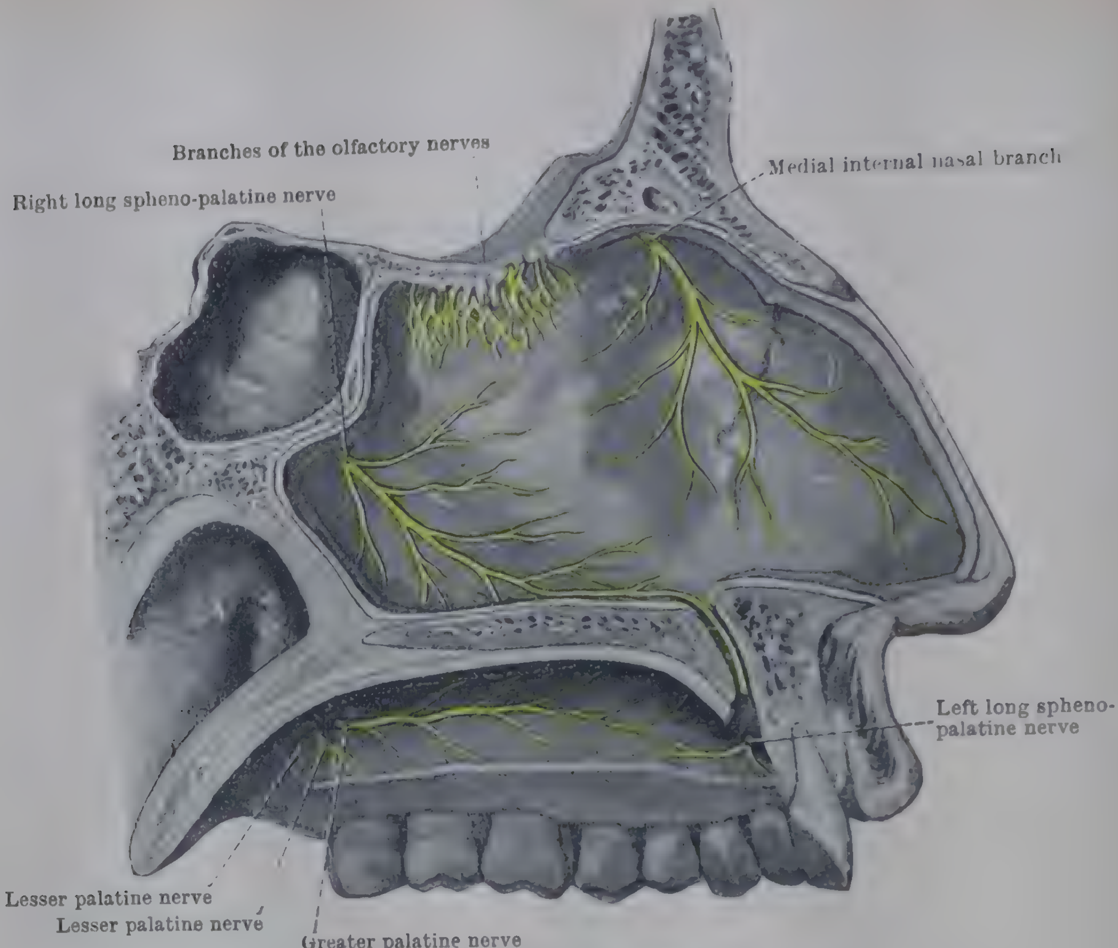

FIG. 893.—INNERVATION OF NASAL SEPTUM AND PALATE.

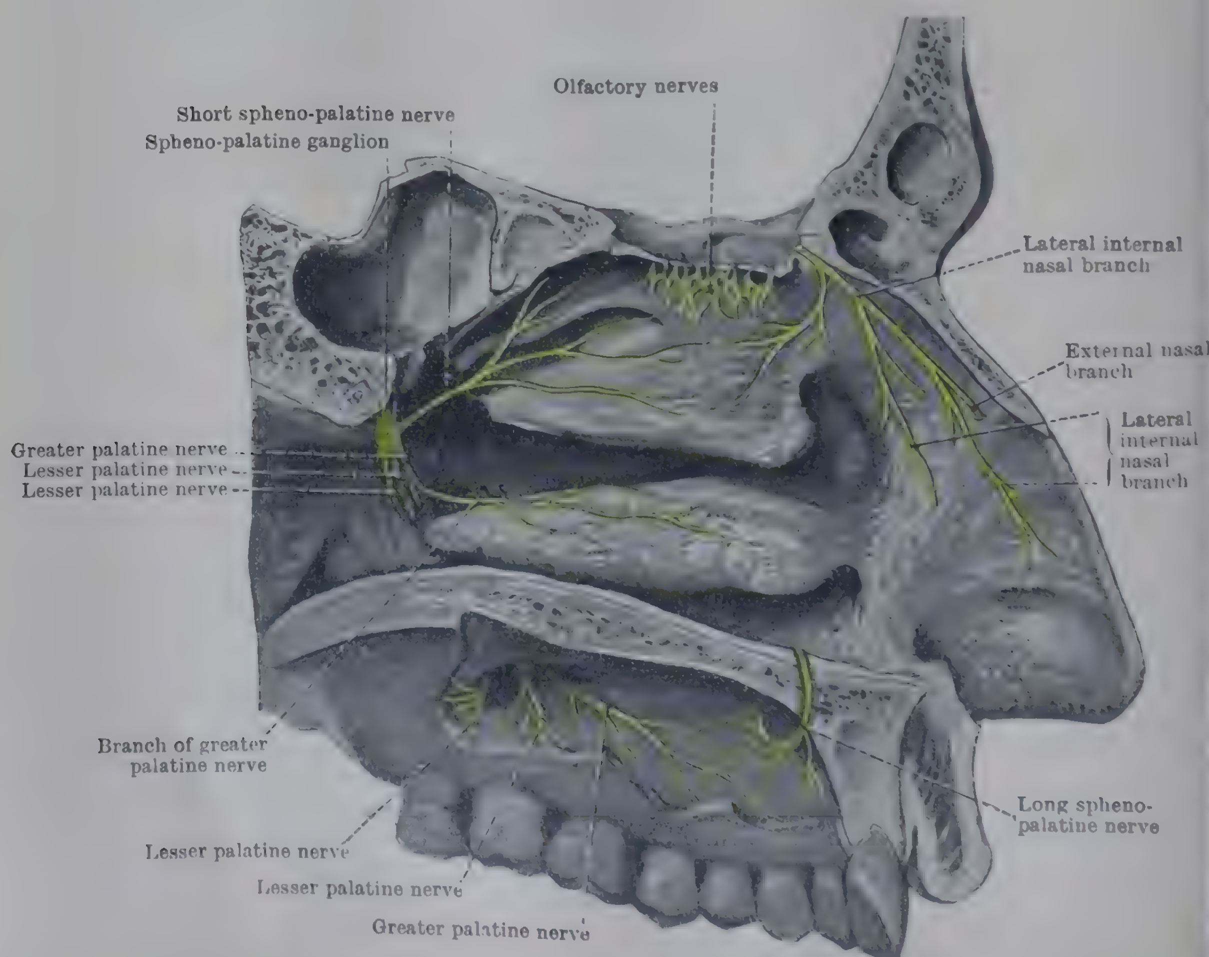

FIG. 894.—INNERVATION OF LATERAL WALL OF NASAL CAVITY AND PALATE.

The **greater palatine nerve** emerges on the under surface of the palate through the greater palatine foramen, and at once separates into numerous branches for the supply of the mucous membrane of the soft palate and the muco-periosteum of the hard palate, which they groove. Its anterior filaments reach to the incisor sockets and communicate with branches of the long spheno-palatine nerve. The main nerve gives off, as it lies in the palatine canal, small **nasal branches** which enter the nasal cavity and supply the mucous membrane of the inferior concha.

The **lesser palatine nerves** descend through the lesser palatine canals. The more medial emerges immediately behind the palatine crest and supplies branches to the soft palate. The more lateral is distributed to the soft palate and the adjacent part of the tonsil.

(iii) The branches directed medially from the spheno-palatine ganglion enter the nasal cavity through the spheno-palatine foramen. They are the long and short spheno-palatine nerves. (*a*) The **long spheno-palatine nerve**, after passing through the spheno-palatine foramen, crosses the roof of the nasal cavity, and extends obliquely downwards and forwards along the nasal septum, grooving the vomer in its course between the mucous membrane and periosteum, to reach the incisive fossa near the front of the hard palate. The nerves pass through the median incisive foramina, the left nerve in front of the right. In the incisive fossa the two nerves communicate. They then turn backwards and supply the mucous membrane of the hard palate. They communicate posteriorly with terminal filaments of the greater palatine nerves. In its course through the nasal cavity each long spheno-palatine nerve furnishes collateral branches to the mucous membrane of the roof and septum of the nose (Fig. 893). (*b*) The **short spheno-palatine nerves** are small branches distributed to the mucous membrane of the superior and middle conchæ, and to the postero-superior part of the nasal septum.

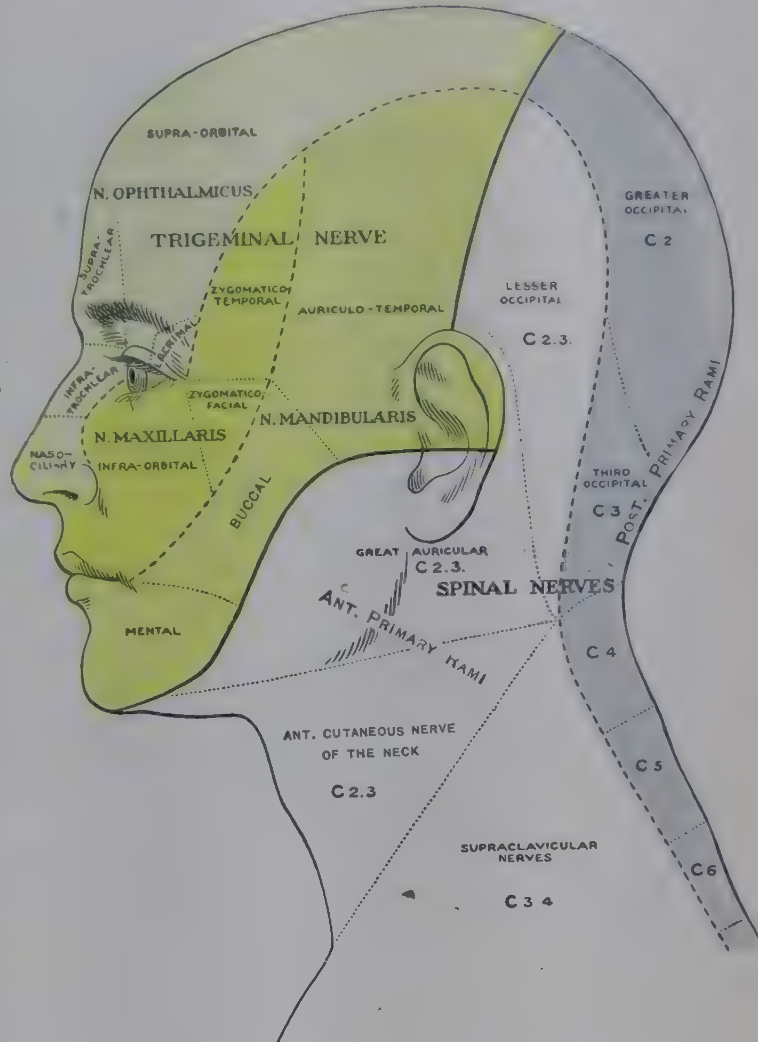

Fig. 895.—Distribution of Cutaneous Nerves to Head and Neck.

(iv) The **orbital branches**, one or more minute branches, pass upwards to supply the periosteum of the orbit and possibly convey some secreto-motor fibres to the lacrimal gland.

(2) **Posterior superior dental nerves**, generally three in number, descend through the pterygo-maxillary fissure to the posterior surface of the maxilla. One branch proceeds downwards to reach the gum and adjacent part of the cheek, while the other two branches enter fine canals in the bone and proceed with accompanying vessels to supply the teeth as far forwards as the canine (Wood Jones, 1939). The two canals run more or less horizontally round the maxillary sinus, the upper and smaller at the level of the zygomatic process and the lower and larger between this and the alveolar margin. They also supply branches to the mucous membrane of the sinus.

(3) A small orbital branch—the **zygomatic nerve**—enters the orbital cavity through the inferior orbital fissure, and, proceeding along the lateral wall, divides

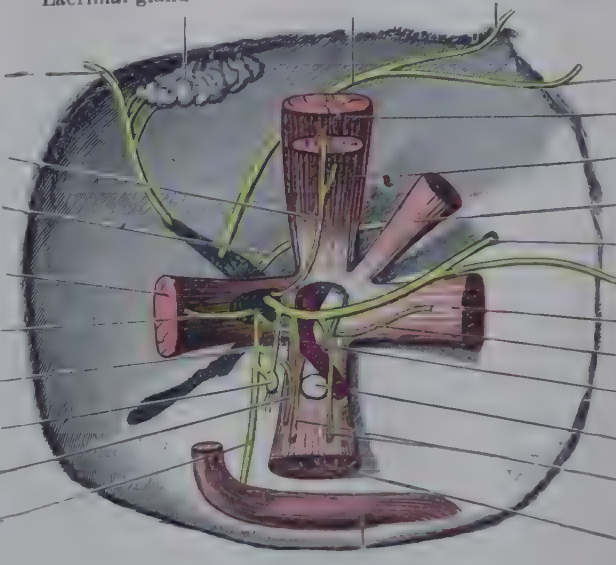

FIG. 896.—SCHEMATIC REPRESENTATION OF NERVES WHICH TRAVERSE THE CAVITY OF THE ORBIT.

Note that the lacrimal, frontal, and trochlear nerves, after entering the orbit through the superior orbital fissure, pass outside the common tendinous ring from which the recti muscles arise; whilst the oculomotor, abducent, and naso-ciliary nerves, together with the optic nerve and ophthalmic artery, enter the orbit within the ring, and therefore lie at first within the cone formed by the ocular muscles as they diverge forwards from it.

into two branches—(i) a *zygomatico-facial branch*, which appears on the face through the zygomatic foramen, after traversing the zygomatic bone, and supplies

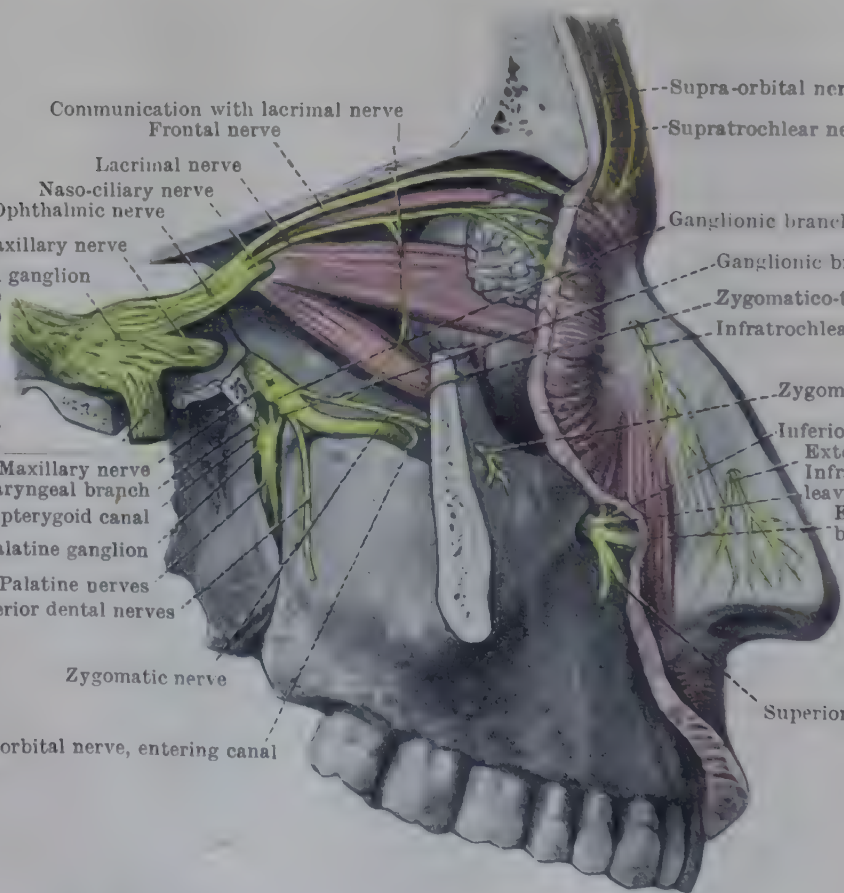

FIG. 897.—COURSE OF THE OPHTHALMIC AND MAXILLARY NERVES.

the skin and fascia over that bone; it communicates with the zygomatic branches of the facial nerve. (ii) A *zygomatico-temporal branch* perforates the temporal

surface of the zygomatic bone, or passes through the spheno-zygomatic suture, and is distributed, after piercing the temporal fascia, to the skin and fascia over the anterior part of the temple. In the orbit it communicates with the lacrimal nerve, and on the face with the temporal branches of the facial nerve. The filament which communicates with the lacrimal nerve probably contains some of the parasympathetic fibres from the spheno-palatine ganglion to the lacrimal gland. The zygomatico-temporal branch may be very minute, and not pass farther than the temporal fascia, between the two layers of which it may form a communication with the facial nerve.

The **infra-orbital nerve** is the terminal branch of the maxillary nerve, which

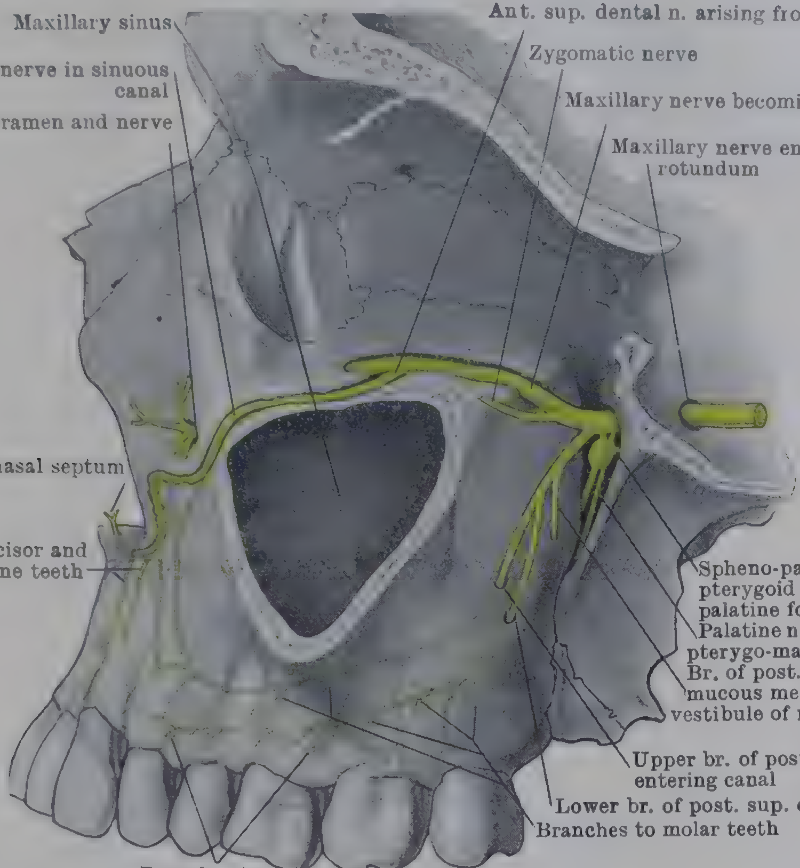

FIG. 898.—COURSE AND BRANCHES OF MAXILLARY NERVE.

enters the orbit through the inferior orbital fissure and traverses the infra-orbital canal to reach the face.

(*c*) About the middle of *the infra-orbital canal* the nerve gives off from its lateral side a stout branch—the **anterior superior dental nerve**. This nerve enters a sinuous canal (Wood Jones, 1939) which conveys it to the root of the anterior nasal spine. It first proceeds forwards to the orbital margin, which it reaches a short distance lateral to the infra-orbital nerve. Here it bends medially and runs in the anterior wall of the maxillary sinus below the infra-orbital foramen to reach the wall of the nose at the level of the anterior end of the inferior concha (Fig. 898). The canal now turns sharply downwards, conveying the nerve to the floor of the nose. The terminal branches of the nerve emerge from a small foramen close to the septum. During its descending course the nerve gives branches to the canine and incisor teeth, and nearer its termination to the lateral wall and floor of the nose and to part of the nasal septum. A branch of the infra-orbital artery accompanies the nerve in its canal. Within the maxillary sinus a bony ridge may be raised by the canal; but the most prominent ridge—in the angle between the roof and the anterior wall of the sinus—is due to the infra-orbital canal itself.

(*d*) *In the face*, after emerging from the infra-orbital foramen, the infra-orbital nerve divides into a number of radiating branches arranged in three sets—(1) **palpebral** for the skin and conjunctiva of the lower eyelid; (2) **nasal**, for the

skin and fascia of the side of the nose; and (3) **labial**, for the cheek and upper lip. These branches form communications with the zygomatic branches of the facial nerve, and form with them the *infra-orbital plexus* (Fig. 902).

MANDIBULAR NERVE

motor

sensory

The **mandibular nerve** is formed by the union of two roots; a large **afferent root** from the trigeminal ganglion, and the small **efferent root** of the trigeminal nerve, which is wholly incorporated with the mandibular trunk. The two roots pass together, in the dura mater of the middle fossa of the base of the skull, to the foramen ovale, through which they emerge into the infratemporal fossa. As they leave the skull they combine to form a single, short trunk which separates into anterior and posterior divisions immediately below the foramen ovale.

At its emergence from the skull the nerve lies deeply between the lateral

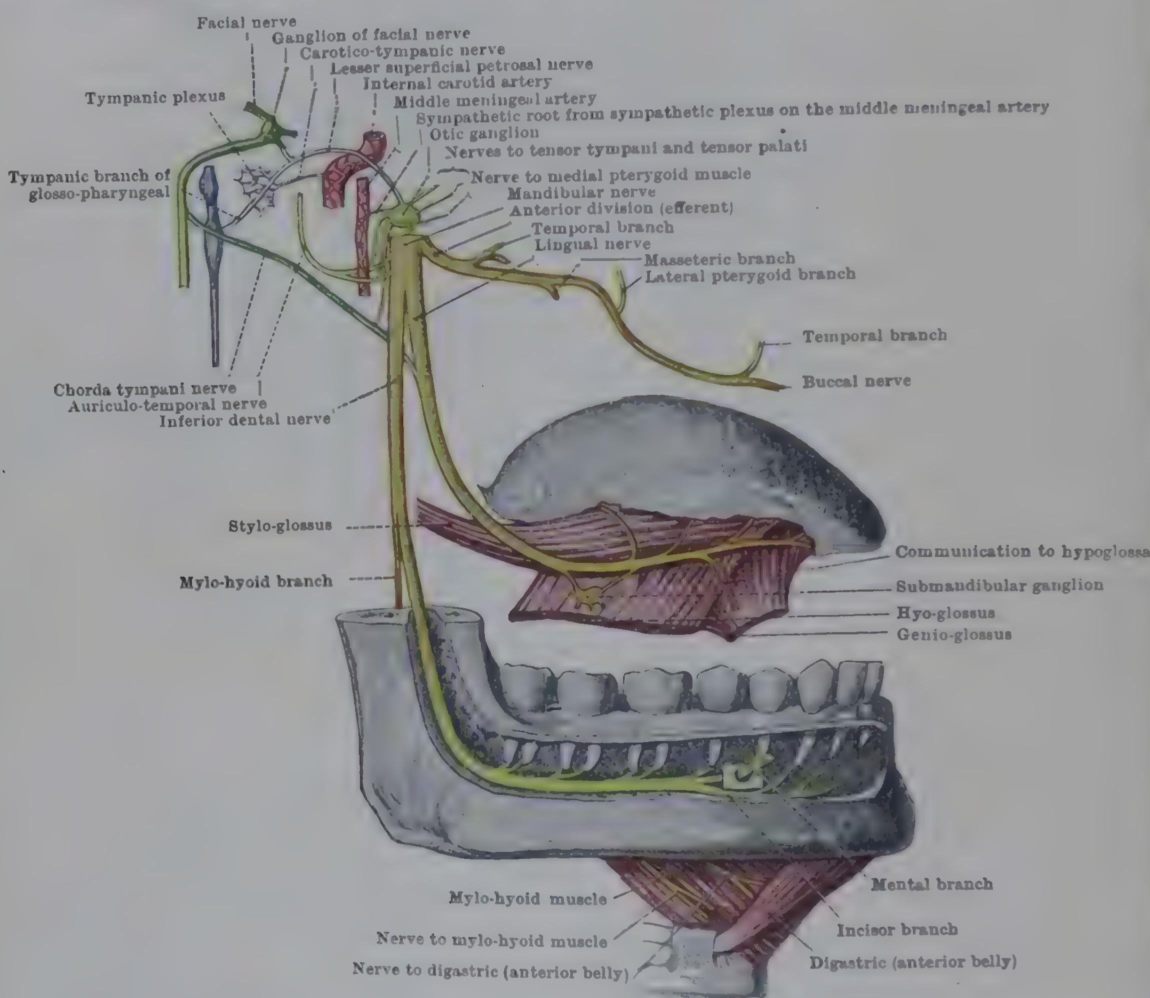

FIG. 899.—SCHEME OF DISTRIBUTION AND CONNEXIONS OF MANDIBULAR NERVE.

pterygoid and the tensor palati muscles; behind it lies the middle meningeal artery.

The branches of the nerve may be divided into two series—(1) those derived from the undivided nerve, and (2) those derived from its terminal divisions.

The branches of the undivided nerve are two in number; they arise from its medial aspect. (*a*) A small **nervus spinosus** arises just outside the skull. It accompanies the middle meningeal artery through the foramen spinosum, and supplies the dura mater and the mastoid cells. (*b*) A small branch for the supply of the **medial pterygoid muscle** and the **tensor tympani** and **tensor palati muscles.** As it passes medially this branch is in close contiguity with the otic ganglion.

The terminal divisions of the nerve are a small anterior and a large posterior trunk.

The small **anterior trunk** passes downwards and forwards medial to the lateral pterygoid muscle, and separates into the following branches: (1) A branch for the **lateral pterygoid muscle** which supplies it on its deep surface. (2) A branch to the **masseter muscle** which passes over the upper border of the lateral pterygoid and through the mandibular notch behind the temporalis muscle; it gives a filament to the mandibular joint. (3) and (4) Two **deep temporal branches**, an anterior (which often accompanies the buccal branch) and a posterior (with sometimes a third, the middle) to the temporal muscle, which also pass laterally above the lateral pterygoid muscle. (5) The **buccal nerve**, which passes obliquely forwards and laterally between the two heads of the lateral pterygoid and then runs downwards to reach the cheek. In the latter part of its course the nerve is closely associated with the anterior and medial aspect of the tendon of the temporalis muscle, being bound to it by fascia or occupying a groove in the tendon, or even piercing the tendon. Here the nerve is quite closely related to the posterior wall of the vestibule of the mouth where surgical approach may be effected. On reaching the cheek, the nerve divides, some of the branches being distributed to the skin and fascia of the cheek and there communicating with the facial nerve, while others perforate the buccinator muscle to supply mucous membrane of the cheek and gum and to assist in the supply of the premolar and the first molar teeth of the lower jaw. Though the buccal nerve penetrates the buccinator muscle, it takes no part in the motor supply of the muscle, which is by the seventh nerve.

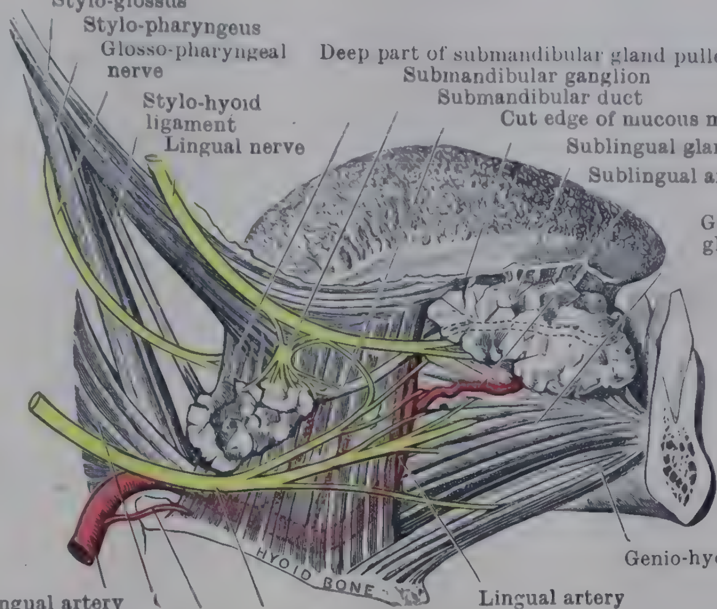

FIG. 900.—LINGUAL AND HYPOGLOSSAL NERVES IN THE SUBMANDIBULAR REGION.

The large **posterior trunk** extends a short way downwards medial to the lateral pterygoid muscle. After giving off, by two roots, the auriculo-temporal nerve, it ends by dividing into two—the lingual and the inferior dental nerves.

The **auriculo-temporal nerve** is formed by the union of two roots which embrace the middle meningeal artery. The nerve passes backwards and laterally medial to the lateral pterygoid muscle and between the spheno-mandibular ligament and the neck of the mandible. After passing through the uppermost part of the parotid gland or its fascia, it is directed upwards to the temple over the zygoma, immediately behind the superficial temporal artery. It is finally distributed as a cutaneous nerve of the temple and scalp, and reaches almost to the vertex of the skull (Fig. 895).

The auriculo-temporal nerve gives off the following branches: (1) A small branch to the mandibular joint. (2) Branches to the parotid gland. (3) A twig for the supply of the skin of the external auditory meatus and tympanic membrane. (4) Auricular branches to the upper half of the auricle on its lateral aspect. (5) Terminal temporal branches to the skin and fascia of the temple and scalp.

It has the following **communications** with other nerves: (1) Important communications are effected by the roots of the nerve, which are separately joined by small branches from the otic ganglion; these convey secretory fibres (parasympathetic) from the glosso-

pharyngeal nerve and sympathetic fibres to the parotid gland. The otic ganglion is described on p. 1037 with the ninth nerve. (2) The parotid and temporal branches of the nerve are connected with branches of the facial nerve in the substance of the parotid gland.

The **lingual nerve** is the smaller of the two terminal branches of the posterior division of the mandibular trunk. It proceeds downwards in front of the inferior dental nerve, medial to the lateral pterygoid muscle, and then between the medial pterygoid and the mandible. After emerging from between the medial pterygoid muscle and the ramus of the mandible the nerve passes beneath those fibres of the superior constrictor which are attached to the mandible and the pterygo-mandibular ligament. It now lies beneath the mucous membrane of the mouth; and, about half an inch below and behind the last molar, it may be palpated as it lies on the bone near the origin of the most posterior fibres of the mylo-hyoid muscle (Fig. 500, p. 583). In this region it is separated from the tongue by the alveolo-lingual groove, but as it proceeds forwards it loops downwards and medially beneath the groove and below the submandibular duct and so comes to lie on the hyo-glossus muscle medial to the duct. It then sends numerous terminal branches upwards and forwards to the mucous membrane over the anterior two-thirds of the tongue.

Three nerves communicate with the lingual nerve in its course to the tongue: (1) The **chorda tympani branch** of the facial nerve joins it from behind at an acute angle medial to the lateral pterygoid muscle, and is incorporated with it in its distribution to the tongue. The chorda tympani (p. 1032) contains parasympathetic preganglionic fibres and also gustatory fibres from the anterior two-thirds of the tongue. (2) At a lower level it usually communicates with the inferior dental nerve. (3) The **hypoglossal nerve** forms larger or smaller loops of communication with the lingual nerve as they course forwards over the hyo-glossus muscle.

Besides supplying the aforesaid branches to the mucous membrane over the sides and dorsum of the tongue in its anterior two-thirds, the lingual nerve supplies the mucous membrane of the floor of the mouth including the lingual aspect of the lower gum and the mucosa overlying the sublingual gland. Branches also assist in the supply of the premolar and first molar teeth. It supplies an afferent root to the submandibular ganglion and also, by virtue of parasympathetic fibres derived entirely from the chorda tympani branch of the seventh nerve, it supplies the parasympathetic root of the ganglion. This ganglion is described on p. 1034, with the facial nerve.

The **inferior dental nerve** is larger than the lingual nerve. It passes from beneath the inferior border of the lateral pterygoid muscle to reach the interval between the ramus of the mandible and the spheno-mandibular ligament. It enters the mandibular canal through the mandibular foramen in company with the inferior dental artery, traverses the substance of the ramus and body of the mandible, distributing branches to the teeth in its course, and it terminates by dividing into a mental and an incisor branch.

Branches.—(1) The **mylo-hyoid nerve** is a small branch that arises just before the inferior dental nerve enters the mandibular foramen. It pierces the spheno-mandibular ligament and grooves the ramus as it descends into the submandibular region, where it lies on the inferior surface of the mylo-hyoid muscle, deep to the submandibular gland. It is distributed to the mylo-hyoid muscle and the anterior belly of the digastric muscle. (2) The **dental branches** arise from the nerve in the mandibular canal, and form fine plexuses from which filaments supply the teeth; the molars and premolars receive their supply from an alveolar plexus, the incisors from an incisor plexus and the canine from either (Starkie & Stewart, 1931). Usually the lingual and the buccal nerves also assist in the innervation of the premolar and first molar teeth (Stewart & Wilson, 1928). (3) The **mental nerve** is a trunk of considerable size which arises from the inferior dental in the mandibular canal. It emerges from the mandible through the mental foramen, and is distributed by many branches to the skin of the chin and lower lip. It communicates, under cover of the facial muscles, with the mandibular branch of the facial nerve (Fig. 902). (4) The **incisor**

branch is the terminal part of the inferior dental nerve remaining after the origin of the mental branch. It forms a fine incisor plexus and supplies the canine tooth and the incisor teeth ; a few fibres may cross the median plane and take part in the innervation of the medial incisor of the opposite side.

Summary.—The trigeminal is the largest and most complex of the cranial nerves. (1) It is the chief afferent nerve for the face, the anterior half of the scalp, the orbit and eyeball, the nose and nasal cavity and paranasal sinuses, the lips, teeth, mouth, and anterior two-thirds of the tongue. (2) Its efferent fibres supply the muscles of mastication, the mylo-hyoid and anterior belly of the digastric, and the tensor tympani and tensor palati muscles. (3) It gives branches to the mandibular joint and the dura mater.

In its distribution to the skin of the face the branches of the fifth nerve present certain noteworthy features : (1) While the branches to the skin reach the surface at many points and in diverse ways, the three main divisions are severally, by their branches, responsible for the supply of three clearly demarcated cutaneous areas (Fig. 895, p. 1023). Moreover, since in embryonic life the general distribution of the nerve is outlined by the outgrowth from the trigeminal ganglion of the three main divisions (ophthalmic, maxillary, and mandibular) into the fronto-nasal, maxillary, and mandibular processes respectively, each nerve-trunk supplies, broadly speaking, the deeper structures of the face lying opposite its own area of cutaneous distribution. (2) In the face there are numerous communications with the seventh nerves, possibly for the distribution of proprioceptive fibres to the muscles of expression (p. 426). (3) The cutaneous branches of the fifth nerve receive sudomotor (sympathetic) fibres from the external carotid plexus for distribution to the sweat-glands (Wilson, 1936).

Though the **ganglia associated with the fifth nerve**, namely, the ciliary, spheno-palatine, otic, and submandibular, are frequently mentioned in their relations to its branches, it should be realized that functionally that nerve has less to do with them than any of the other cranial nerves with which they are connected, for the ganglia properly belong to the parasympathetic system. In structure they largely consist of the stellate or multipolar neurons characteristic of the autonomic system elsewhere ; and developmentally they are formed by cell-bodies which have migrated from the trigeminal ganglion along the branches of the trigeminal nerve—an origin paralleled by that of the ganglia of the sympathetic trunks. Moreover, the fibres they receive from other nerves (the ciliary ganglion from the oculomotor, the submandibular and spheno-palatine ganglia from the facial, and the otic ganglion from the glosso-pharyngeal) may be likened to the splanchnic efferent fibres received by the ganglia of the sympathetic trunk through the white rami communicantes of the spinal nerves. Their development is described together with that of the autonomic system on p. 1146.

Each of the ganglia contains three varieties of fibres: (1) afferent ; (2) parasympathetic efferent, derived from one of the cranial nerves ; and (3) sympathetic, which are derived from the superior cervical ganglion. Many of the so-called roots and branches are mixed, though they are generally named according to the predominating kind of fibres they contain. Lastly, it is to be noted that *only the parasympathetic paths have a cell-station in the ganglia* ; all the other fibres pass uninterruptedly through them. Each of these ganglia is described with the cranial nerve which conveys its preganglionic parasympathetic fibres to it.

ABDUCENT NERVE

The **sixth** or **abducent nerve** supplies only the lateral rectus muscle of the eyeball. It issues from the brain at the inferior border of the pons, just above the pyramid of the medulla oblongata (for the deep origin, see p. 931). It is directed forwards and upwards and usually lies behind the anterior inferior cerebellar artery but may be in front of it. It pierces the dura mater in the posterior fossa of the skull and crosses dorsal to, or may run through, the inferior petrosal sinus to reach the apex of the petrous temporal bone. Here it lies under the petro-clinoid ligament and presents a bend as it runs forward into the middle cranial fossa to enter the cavernous sinus (Fig. 888, p. 1015). In the sinus it is placed close to the lateral side of the internal carotid artery. After traversing the sinus it enters the orbit through the superior orbital fissure below the oculomotor and naso-ciliary nerves. At this point it lies within the tendinous ring from which the four rectus muscles arise. (Fig. 896, p. 1024). In the cavity of the orbit it supplies the lateral rectus muscle on its deep (ocular) surface.

Communications.—In the cavernous sinus the sixth nerve receives two communicating filaments : (1) from the carotid plexus of the sympathetic, and (2) from the ophthalmic division of the trigeminal nerve. Such communications are probably temporary and do not involve the permanent transfer of fibres from one nerve to another (Sunderland & Hughes, 1946).

FACIAL NERVE

The **seventh** or **facial nerve** is a mixed nerve and consists of two parts. The larger part or **motor root** supplies all the superficial muscles of the scalp, face, and neck (muscles of expression), and some of the deep ones. The smaller part is called the **sensory root**, but it contains not only afferent taste-fibres for the anterior two-thirds of the tongue but also efferent parasympathetic fibres connected with the spheno-palatine and submandibular ganglia for the supply of the lacrimal and some of the salivary glands. The ganglion of the facial nerve (see p. 1031) is the cell-station for the afferent fibres. The **motor root** emerges from the brain at the inferior border of the pons, medial to the auditory nerve (for the deep origin, see p. 930). Between it and the auditory nerve is the much smaller **sensory root** (Fig. 885, p. 1012). The facial nerve enters the internal auditory meatus, passes through the facial canal in the petrous portion of the temporal bone, emerges at the base of the skull by the stylo-mastoid foramen, and passes forwards through

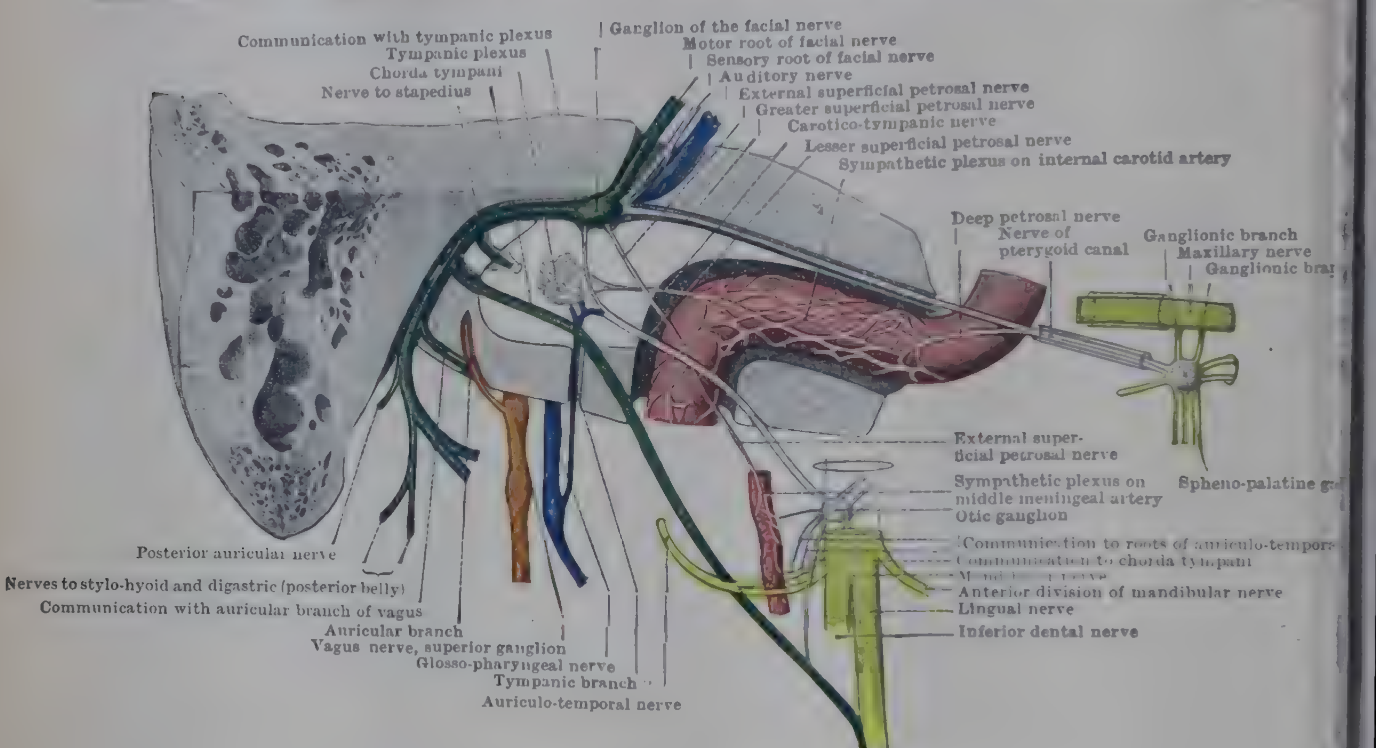

FIG. 901.—CONNEXIONS OF FACIAL NERVE IN THE TEMPORAL BONE.

the parotid gland to supply the muscles of the face. *In the internal auditory meatus* the nerve is placed above the auditory nerve, the sensory root intervening, and all three are surrounded by sheaths of the dura, arachnoid, and pia. *In the facial canal* the nerve first runs laterally between the cochlea and the bony vestibule to the hiatus in the canal for the greater superficial petrosal nerve, then abruptly backwards in the upper part of the medial wall of the tympanum above the fenestra vestibuli, and finally downwards behind the tympanum, lying in the bony septum that separates the middle ear from the tympanic antrum and mastoid air-cells. On emerging from the stylo-mastoid foramen the nerve lies under cover of the mastoid process and is therefore more exposed in the child, in whom this process is incompletely developed. The nerve then runs laterally and forwards between the styloid process and the digastric muscle (Fig. 1079, p. 1265) to enter the parotid gland on its postero-medial surface. *In the parotid gland* (see p. 582) it crosses the external carotid artery and the posterior facial vein superficially and breaks up into its terminal branches, which emerge through the ends and anterior border of the gland. In the face the branches radiate to the various facial muscles, which they supply on their deep surfaces (Fig. 902).

Branches and Communications.—(i) *In the internal auditory meatus* the sensory root lies between the motor root and the auditory nerve and sends communicating

branches to both of them. The branch to the auditory nerve probably separates from it again to join the ganglion of the facial nerve (Fig. 904).

(ii) *In the facial canal* the **ganglion of the facial nerve** is formed at the point where the nerve bends backwards at the 'genu'. It is an oval swelling on the nerve, from which three small branches arise. (1) The **greater superficial petrosal nerve** passes forwards through the hiatus in the canal for the facial nerve to the middle fossa of the skull and runs in the dura mater to the foramen lacerum, where it is

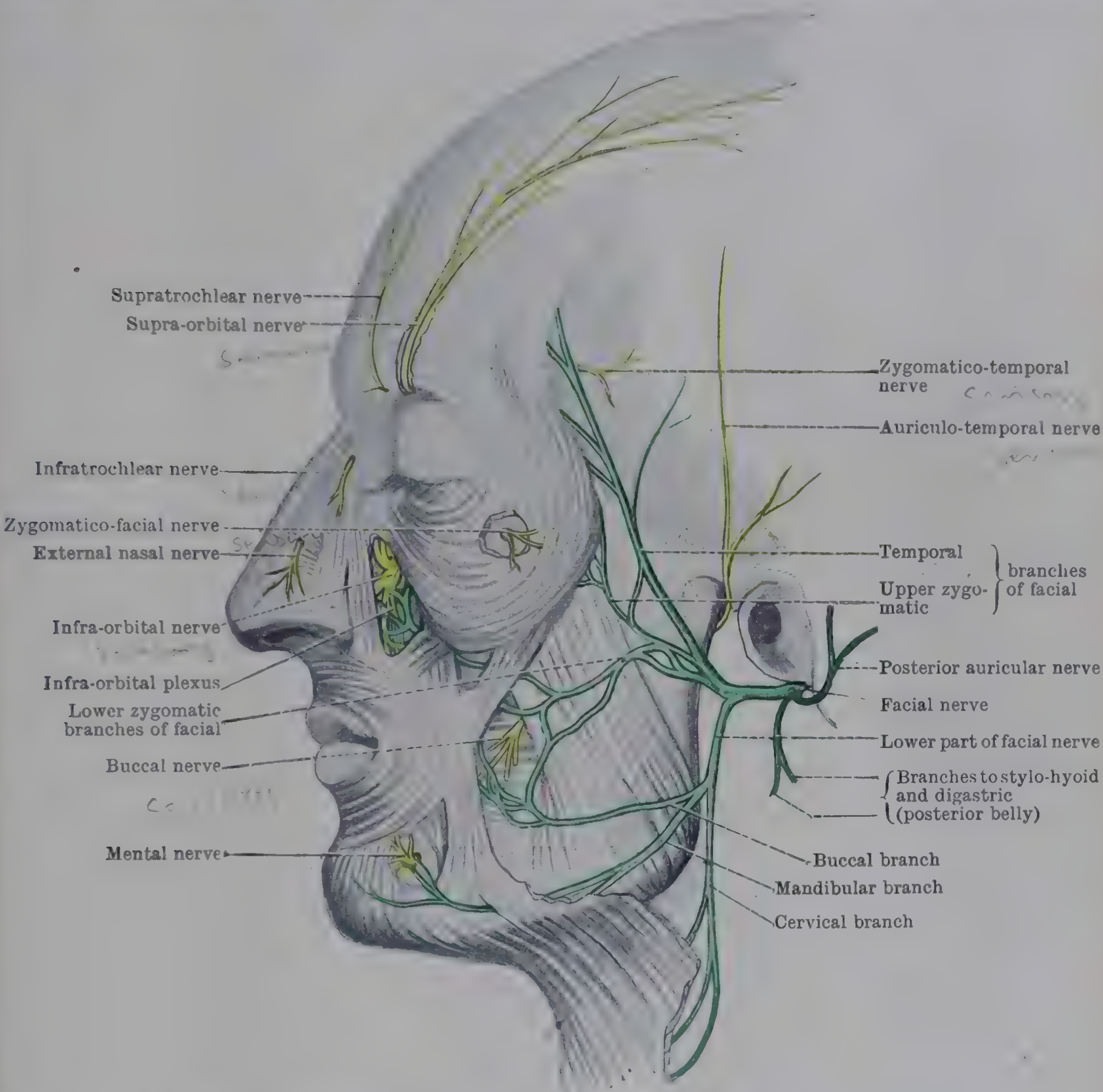

FIG. 902.—DISTRIBUTION OF TRIGEMINAL AND FACIAL NERVES ON THE FACE.

joined by the deep petrosal nerve—a sympathetic branch derived from the plexus on the internal carotid artery. The combined nerve—**the nerve of the pterygoid canal**—then runs forwards in the pterygoid canal of the sphenoid bone to reach the spheno-palatine ganglion (Fig. 903). (2) A minute filament which pierces the temporal bone and joins the much larger tympanic branch of the glosso-pharyngeal to form the **lesser superficial petrosal nerve**, which lies in the dura mater of the middle cranial fossa lateral to the greater superficial petrosal nerve. The lesser superficial petrosal nerve finally leaves the middle fossa by a small foramen medial to the foramen ovale and joins the otic ganglion. It is to be regarded essentially as a parasympathetic branch of the ninth nerve, and it will be discussed in connexion with the otic ganglion (p. 1037). (3) The **external superficial petrosal nerve** is a minute inconstant branch which joins the sympathetic plexus on the middle meningeal artery.

From the facial nerve in the descending part of its canal behind the tympanum, three branches arise: (1) The small **nerve to the stapedius** passes

forwards to that muscle. (2) A fine communicating branch which arises from the facial just before it leaves its canal and joins the auricular branch of the vagus. (3) The **chorda tympani** (containing taste and parasympathetic fibres) arises between these two smaller branches, enters the tympanic cavity through a *posterior canaliculus*, passes across the membrana tympani and the handle of the malleus, leaves the cavity by an *anterior canaliculus* and reaches the infratemporal fossa through the *petro-tympanic fissure*; medial to the lateral pterygoid muscle, after receiving a fine communication from the otic ganglion, it becomes incorporated with the lingual branch of the mandibular nerve, and in its further course is intimately associated with that nerve; it supplies the parasympathetic root to the submandibular ganglion, and is finally distributed to the side and dorsum of the tongue in its anterior two-thirds (excluding the vallate papillæ); it largely consists of afferent (taste) fibres derived from the ganglion of the facial nerve, but also contains some secreto-motor parasympathetic fibres which enter the submandibular ganglion and undergo synapse with postganglionic neurons which then supply the submandibular, sublingual, and lingual glands (Fig. 903).

(iii) *In the neck*, before it enters the parotid gland, the facial nerve gives off three muscular branches: (1) and (2) small branches, frequently arising together, supply the **stylo-hyoid** and the posterior belly of the **digastric**; the latter nerve sometimes communicates with the glosso-pharyngeal. (3) The **posterior auricular nerve** bends backwards and upwards over the anterior border of the mastoid process along with the posterior auricular artery. It divides into two branches—an *auricular branch* for the posterior auricular muscle and the intrinsic muscles of the auricle, and an *occipital branch* for the occipital belly of the epicranius muscle. The posterior auricular nerve, in its course, communicates with the great auricular, lesser occipital, and with the auricular branch of the vagus nerve.

(iv) *In the parotid gland* the facial nerve spreads out in an irregular series of branches which communicate in the substance of the gland with branches of the great auricular and auriculo-temporal nerves.

1. The **temporal branches** are of large size, and, sweeping out of the parotid gland over the zygomatic arch, are distributed to the orbicularis oculi, frontal belly of occipito-frontalis, auriculares anterior and superior. The temporal branches communicate in their course with the auriculo-temporal, zygomatico-temporal, lacrimal, and supra-orbital branches of the trigeminal nerve.

2. The **zygomatic branches** are in two sets. The **upper** are small, and sometimes are inseparable from the temporal or lower zygomatic branches. Extending forwards across the zygomatic bone, they supply the orbicularis oculi and zygomatic muscles, and communicate with the zygomatico-facial branch of the maxillary nerve.

The **lower** are of considerable size. Passing forwards over the masseter muscle, in company with the parotid duct, they supply the orbicularis oculi, the zygomaticus major, buccinator, and the muscles of the nose and upper lip. The **infra-orbital plexus** is formed by the union of these nerves with the infra-orbital branch of the maxillary nerve below the lower eyelid. Smaller communications occur with the infratrochlear and external nasal branches of the naso-ciliary nerve on the side of the nose.

3. The **buccal branch** (or branches) extends forwards to the angle of the mouth to supply the muscles converging on the mouth, including the buccinator. It communicates with the buccal branch of the mandibular nerve in front of the masseter muscle.

4. The **mandibular branch** passes along the mandible to the interval between the lower lip and chin, and supplies the depressor anguli oris, depressor labii inferioris, and orbicularis oris. It communicates with the mental branch of the inferior dental nerve.

5. The **cervical branch** emerges from the parotid gland near its lower end, and sweeps forwards below the angle of the mandible to the front of the neck. It runs deep to the platysma, supplying it and forming loops of communication with the anterior cutaneous nerve of the neck.

No mention has been made of cutaneous afferent fibres in the seventh nerve, but clinical evidence is suggestive of the fact that some sensory fibres—with their cell-bodies in the facial ganglion—reach the skin in the mastoid region and the external auditory meatus.

When inflammation attacks the ganglion, a herpetiform eruption (similar to "shingles", see p. 1053) may affect this area. It is not suggested, however, that the cutaneous area mentioned is exclusively supplied by the seventh nerve. Some consider that proprioceptive afferent fibres from the facial musculature travel in the seventh nerve, but it is possible, and perhaps more probable, that they do so through the fifth.

Though the facial nerve is commonly described as above, as a mixed nerve, the sensory root can be considered, on the basis of its origin and distribution, as well as on the really mixed nature of its fibres, as a separate nerve, the **glosso-palatine**. Under this term are included the sensory root of the facial, the ganglion of the facial nerve, chorda tympani, and part of the greater superficial petrosal nerve. Its central connexions and peripheral distribution resemble those of the glosso-pharyngeal nerve, and suggest that it is an aberrant part of the latter.

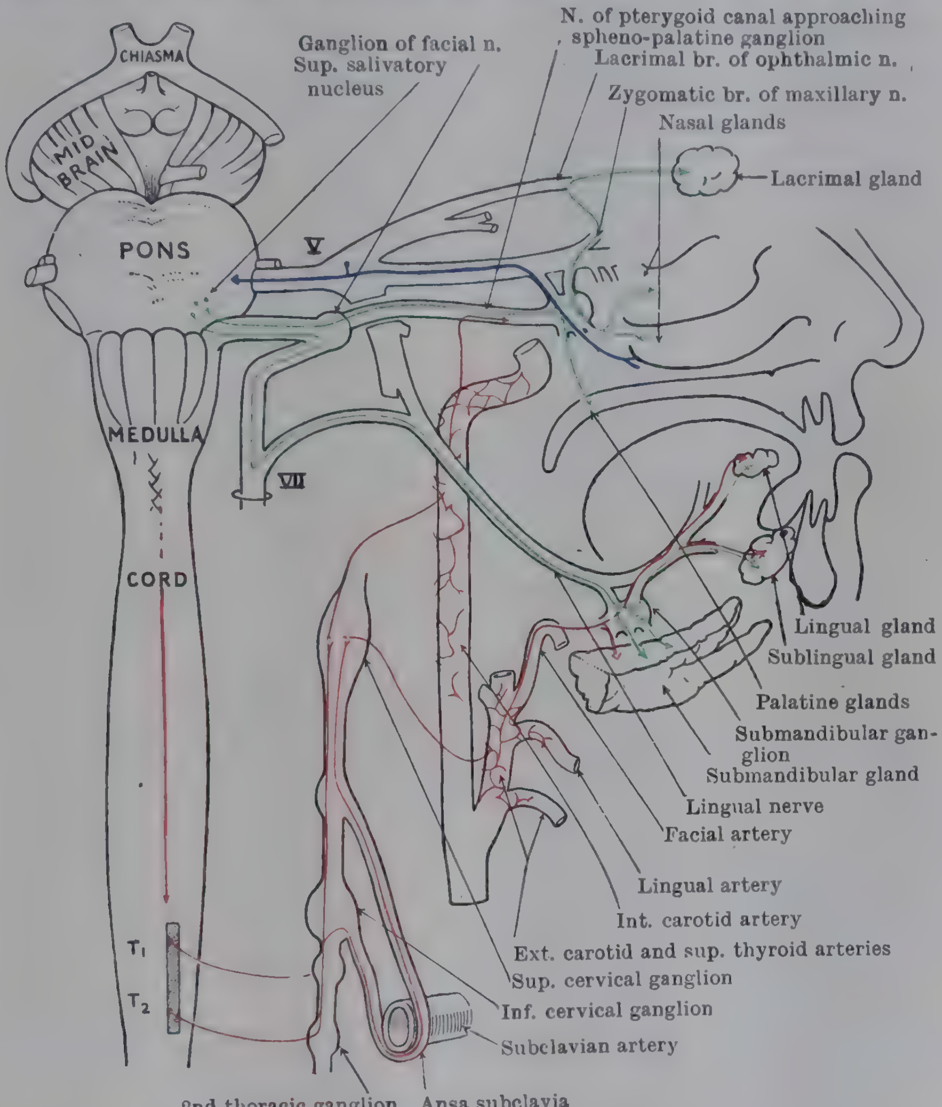

Fig. 903.—Diagram of Connexions of Spheno-Palatine and Submandibular Ganglia with Distribution of Parasympathetic Components of Seventh Cranial Nerve.

Spheno-Palatine Ganglion.—This ganglion is a component of the cranial parasympathetic system. It is situated deeply in the upper part of the pterygo-palatine fossa close to the spheno-palatine foramen and is a small reddish body lying in close relationship with the ganglionic branches of the maxillary nerve. Various groups of nerve-fibres have an association with this ganglion :—(*a*) The *parasympathetic root*, composed of preganglionic fibres from the seventh nerve, reaches it by way of the greater superficial petrosal nerve and the nerve of the pterygoid canal. (*b*) The *sympathetic root* contains fibres derived from the internal carotid plexus which reach the ganglion by way of the nerve of the pterygoid canal, but are already postganglionic fibres of the superior cervical sympathetic ganglion and do not therefore have any synaptic relation with the cells of the spheno-palatine ganglion. (*c*) Fibres derived from the maxillary nerve reach the ganglion in the ganglionic branches of that nerve and constitute an *afferent root.* These fibres likewise are merely passing by or through the ganglion

and have no relationship with it other than one of contiguity. They leave the ganglion in the form of numerous branches which pass upwards to the orbit, downwards to the palate, and medially to the nasal cavity and thus serve as pathways along which the postganglionic neurons may reach the lacrimal, palatine, and nasal glands (a detailed account of these branches of the fifth nerve is given on pp. 1021-1023). Thus, the lacrimal gland receives its secreto-motor supply by fibres which accompany the zygomatic nerve and later the lacrimal nerve, and possibly by some fibres that run with the orbital branches of the maxillary nerve. The glands of the palate and the nasal cavity are supplied by fibres which accompany palatine, nasal, and naso-palatine branches (Fig. 903).

Some afferent fibres—presumably gustatory—proceed centrally through the palatine nerves, the spheno-palatine ganglion and the greater superficial petrosal nerve to reach the facial ganglion where their cell-bodies are situated.

Submandibular Ganglion (see note on p. 1029).—This ganglion is a small reddish structure placed on the hyo-glossus muscle, between the lingual nerve and the duct of the submandibular gland (Fig. 900). It is suspended from the lingual nerve by two **communicating branches**, consisting for the most part of fibres of the lingual and chorda tympani nerves which at that point separate from the lingual nerve and pass to the ganglion. The **roots** of the submandibular ganglion are: (1) an *afferent root*, from the lingual nerve; (2) a *parasympathetic root*, from the chorda tympani; and (3) a *sympathetic root*, from the sympathetic plexus on the facial artery. Only parasympathetic fibres are relayed in the ganglion (Fig. 903).

The **glandular branches from the ganglion** are distributed to the submandibular gland and duct and, by fibres which become reunited with the trunk of the lingual nerve, to the sublingual gland and the glands of the anterior part of the tongue; they are secreto-motor and vaso-motor to the glands. Small detached portions of the submandibular ganglion are not uncommonly found along the course of its branches or buried in the glands (*e.g.*, the ganglion described by Langley, 1921).

AUDITORY NERVE

The **eighth** or **auditory nerve** is entirely sensory and consists of two functionally quite different parts—the *vestibular nerve* concerned with equilibra-

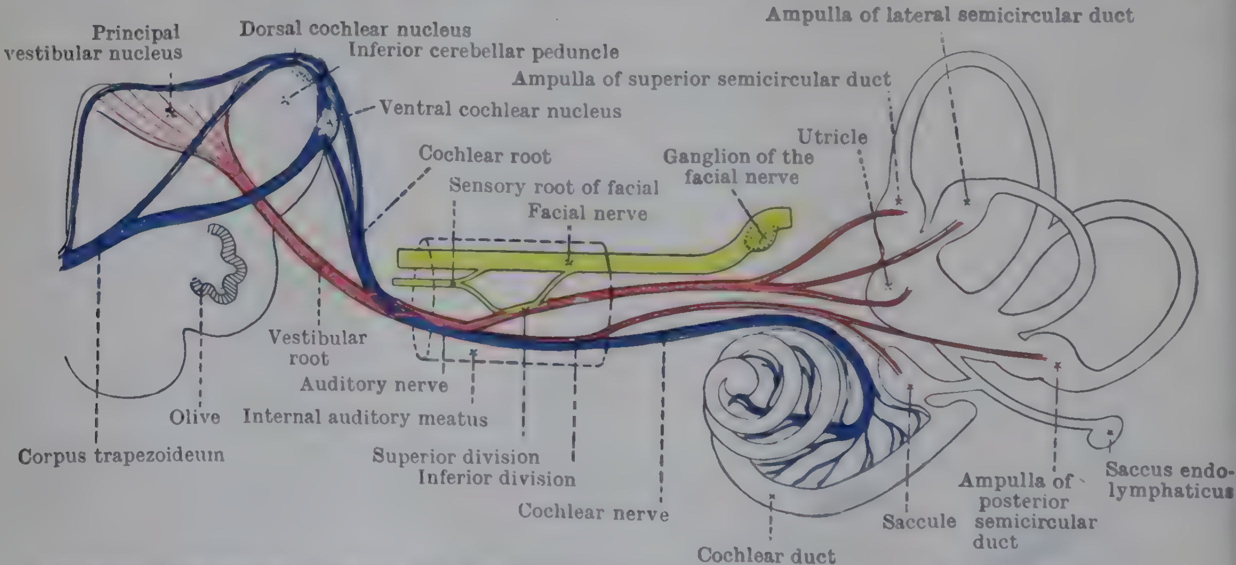

FIG. 904.—SCHEME OF ORIGIN AND DISTRIBUTION OF AUDITORY NERVE (cf. Fig. 1027, p. 1201).

The bundle of fibres (blue) shown coursing across the floor of the fourth ventricle are not auditory; they are the striæ medullares (p. 887) and are probably aberrant ponto-cerebellar fibres.

tion, and the *cochlear nerve*, the true nerve of hearing; they differ also in their peripheral endings and central connexions. (See also p. 1200.)

The combined trunk is attached to the brain by two roots, medial and lateral. The **medial, vestibular root** emerges between the olive and the inferior cerebellar peduncle. The **lateral, cochlear root**, is attached to the brain-stem on the lateral side

of the inferior cerebellar peduncle where two accumulations of nerve-cells give rise to the dorsal and ventral cochlear nuclei. (For deep connexions, see p. 903.) The two roots unite with each other to form the trunk of the auditory nerve, which is attached to the brain on the lateral side of the roots of the facial nerve, at the lower border of the pons (Fig. 813, p. 925).

The nerve passes laterally through the internal auditory meatus, lying below the roots of the facial nerve (Fig. 901). In the meatus the trunk separates into two divisions, an upper consisting of vestibular fibres only, and a lower which consists mainly of cochlear fibres but contains also some vestibular fibres. The divisions subdivide, and their branches pierce the fundus of the internal auditory meatus to supply the several parts of the labyrinth (Fig. 1027, p. 1201).

The **superior division** usually receives fibres in the meatus from the sensory root of the facial nerve, and gives off a communicating branch to the ganglion of the facial nerve. It then separates into three terminal branches which pierce the lamina cribrosa. (1) The **utricular nerve** supplies the macula of the **utricle.** (2) and (3) The **superior** and **lateral ampullary nerves** supply the ampullæ of the **superior** and **lateral semicircular ducts.**

The **inferior division** gives off (1) a **saccular nerve** to the macula of the **saccule** which pierces the inferior vestibular area, (2) an **inferior ampullary nerve** to the ampulla of the **posterior semicircular duct** which pierces the foramen singulare, and (3) is continued as the **cochlear nerve**, which is distributed through the modiolus and osseous spiral lamina to the spiral organ in the cochlea.

Both the vestibular and cochlear nerves contain among their fibres collections of bipolar nerve-cells, forming in each nerve a distinct ganglion —the **vestibular ganglion** on the vestibular trunk at the bottom of the internal auditory meatus, and the **spiral ganglion** on the cochlear trunk within the modiolus. The cells of these ganglia give origin to the fibres of the vestibular and cochlear parts of the nerve respectively.

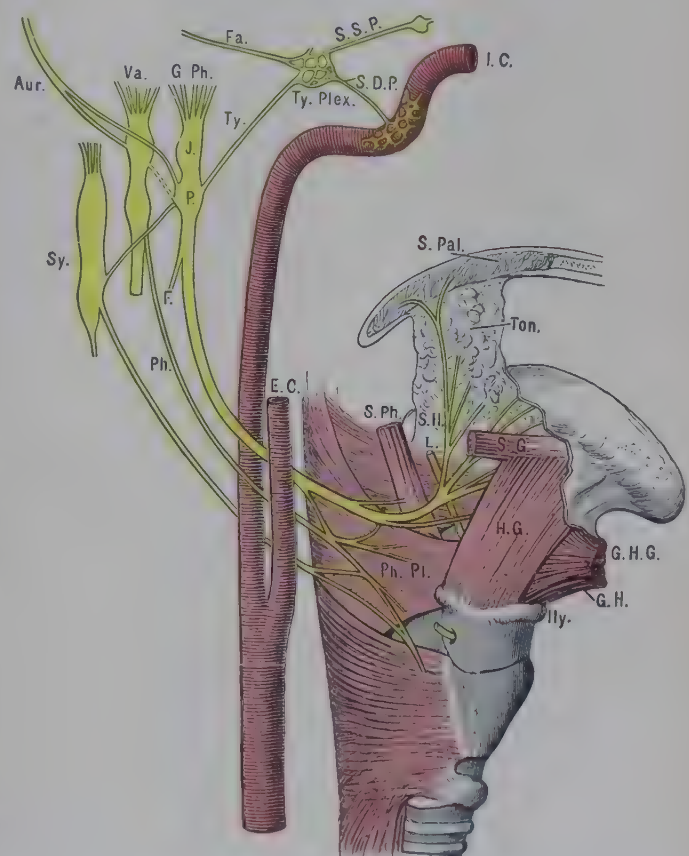

Fig. 905.—Scheme of Connexions and Distribution of Glosso-Pharyngeal Nerve.

G.Ph., Glosso-pharyngeal nerve; J., Superior, and P., Inferior ganglia; Ty., Tympanic nerve; Ty.Plex., Tympanic plexus; Fa., Root from ganglion of facial nerve; S.S.P., Lesser superficial petrosal nerve to the otic ganglion; S.D.P., Carotico-tympanic nerve; I.C., Internal carotid artery; Va., Vagus nerve; Aur., Auricular branch of vagus; Sy., Superior cervical sympathetic ganglion; F., Communicating branch to facial nerve; Ph., Pharyngeal branch of vagus; E.C., External carotid artery; Ph.Pl., Pharyngeal plexus; S.Ph., Stylo-pharyngeus muscle; S.H.L., Stylo-hyoid ligament; H.G., Hyo-glossus; S.G., Stylo-glossus; S.Pal., Soft palate; G.H.G., Genio-glossus; G.H., Genio-hyoid; Hy., Hyoid bone.

GLOSSO-PHARYNGEAL NERVE

The **ninth** or **glosso-pharyngeal nerve** is a mixed nerve, consisting of a large afferent part which supplies the pharynx and tongue and also the carotid sinus and body, and a smaller efferent part which supplies the stylo-pharyngeus muscle (branchial efferent fibres) and also sends preganglionic parasympathetic fibres to the otic ganglion.

It is attached to the brain by five or six fine rootlets which are attached to the side of the medulla oblongata, close to the facial nerve above, and in series with the rootlets of the vagus nerve below (Fig. 813, p. 925; for the deep connexions, see p. 927). The rootlets combine to form a nerve which

passes through the jugular foramen along with the vagus and accessory nerves but enveloped in a separate sheath of dura mater (Fig. 889, p. 980). In the neck, the nerve first descends medial to the styloid process and between the internal carotid artery and the internal jugular vein; it then curves forwards to the side of the pharynx above the level of the hyoid bone. As it runs forwards it curves round the posterior border of the stylo-pharyngeus muscle and passes superficial to that muscle and usually deep to the stylo-hyoid ligament, to the posterior border of the hyo-glossus muscle, and then onwards deep to the hyo-glossus. The terminal branches are distributed to the region of the oro-pharyngeal isthmus, the tonsil, and the pharyngeal part of the dorsum of the tongue (Fig. 905).

The **branches** of the nerve may be classified in three series according to their origin—(i) in the jugular foramen, (ii) in the neck, (iii) in relation to the tongue.

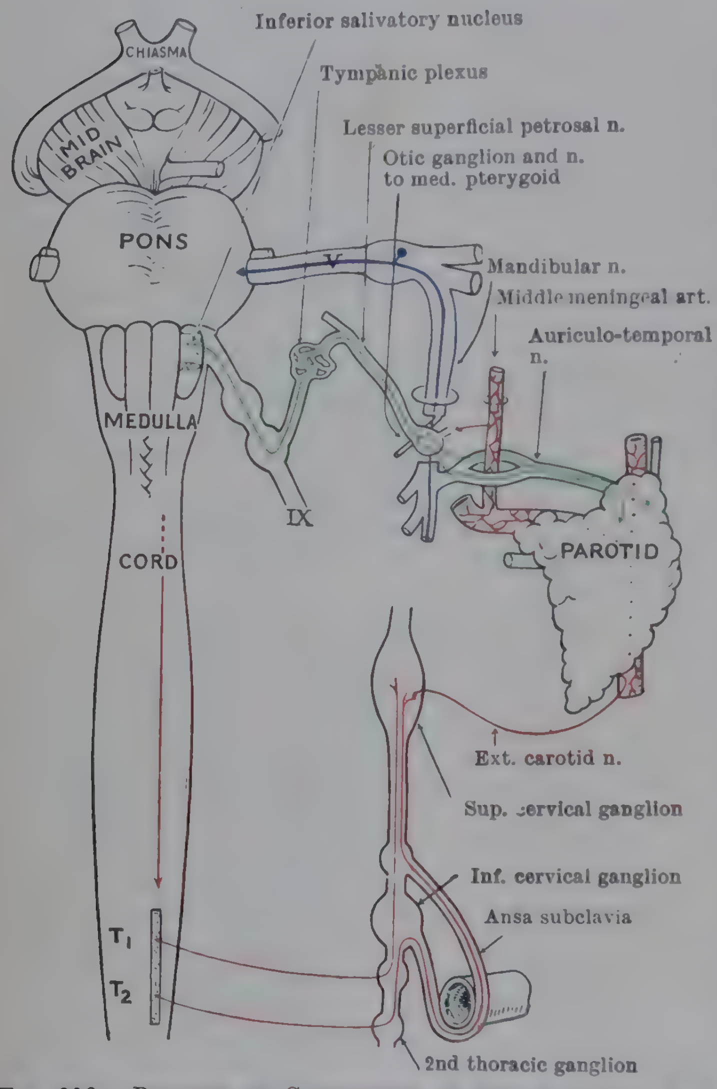

FIG. 906.—DIAGRAM OF CONNEXIONS OF OTIC GANGLION WITH DISTRIBUTION OF PARASYMPATHETIC COMPONENTS OF NINTH CRANIAL NERVE.

In the jugular foramen there are two enlargements on the trunk of the nerve — the superior and inferior ganglia—which contain the cell-bodies of the afferent fibres. The **superior ganglion** is small, and does not implicate the whole width of the nerve; it may be fused with the inferior ganglion, or even be absent altogether. No branches arise from it.

The **inferior ganglion** is distinct and constant. It is placed on the nerve at the lower part of its course through the jugular foramen.

Branches and Communications of Inferior Ganglion.—The **tympanic branch** is the most important offset from this ganglion. It passes through a small canal in the bridge of bone between the jugular foramen and the carotid canal to reach the cavity of the tympanum, where it breaks up into branches to help to form the **tympanic plexus**, in which they are associated with the superior and inferior carotico-tympanic branches from the internal carotid plexus of the sympathetic, and a twig from the ganglion of the facial nerve. The plexus lies on the promontory of the medial wall of the middle ear, and supplies the mucous lining of the tympanum, mastoid air-cells, and pharyngo-tympanic tube (Fig. 901). Some fibres of the tympanic branch of the glosso-pharyngeal nerve become reunited and, in the substance of the temporal bone, they join with a small branch from the ganglion of the facial nerve to form the **lesser superficial petrosal nerve**, which emerges from the temporal bone and pierces the base of the skull to join the otic ganglion (Fig. 906).

Besides its communications by the tympanic branch, the inferior ganglion of the glosso-pharyngeal nerve communicates with three other nerves: (1) with the superior cervical ganglion of the sympathetic; (2) with the auricular branch and sometimes with the superior ganglion of the vagus; and (3) sometimes with the facial nerve.

In the neck the glosso-pharyngeal nerve gives off the following branches:—(1) As it crosses over the **stylo-pharyngeus muscle** it supplies the nerve to that muscle, some fibres of which pierce the muscle to reach the mucous membrane of the pharynx. (2) The **pharyngeal branches** supply the mucous membrane of the pharynx either directly after piercing the superior constrictor muscle, or indirectly after joining with the pharyngeal offsets from the vagus and the superior cervical ganglion of the sympathetic to form the **pharyngeal plexus** (Fig. 905). (3) The *ramus caroticus* consists of afferent fibres which innervate the carotid sinus and body (Fig. 689, p. 808). It runs downwards in front of the internal carotid artery and in its course has communications with vagal and sympathetic branches which lie rather behind the artery (Sheehan, Mulholland & Shafiroff, 1941).

The **terminal branches** of the nerve supply the mucous membrane of the tongue and adjacent parts. A **tonsillar branch** forms a plexus to supply the mucous membrane covering the tonsil, the adjacent part of the soft palate, and the palatine arches. The **lingual branches** contain taste-fibres, as well as ordinary sensory fibres, for the posterior third of the tongue including the circumvallate papillæ.

Otic Ganglion.—The otic ganglion is a small body situated medial to the mandibular nerve just below the foramen ovale at the posterior border of the medial pterygoid muscle. It is a component of the cranial parasympathetic system. Various groups of fibres come into relationship with it and are generally described as the roots of the ganglion:—(1) A *parasympathetic root* composed of preganglionic fibres derived from the ninth nerve through its tympanic branch, the tympanic plexus, and the lesser superficial petrosal nerve. Some parasympathetic fibres from the 'genu' of the facial nerve join the tympanic plexus and proceed to the otic ganglion in the lesser superficial petrosal nerve. The parasympathetic root—composed predominantly of fibres of the ninth nerve—contains the only fibres which form synapses with the cells of the otic ganglion. (2) A *sympathetic root* composed of fibres derived from the plexus on the middle meningeal artery. These are already postganglionic fibres derived from the cervical sympathetic chain and have no synaptic association with the cells of the ganglion. (3) A so-called *efferent root* composed of motor fibres of the mandibular nerve on their way to supply the medial pterygoid muscle and the tensor palati and tensor tympani muscles. It must be clearly understood that these mandibular fibres have merely a relationship of contiguity with the ganglion.

Passing away from the ganglion are its postganglionic parasympathetic fibres as well as the sympathetic fibres which have traversed the ganglion. The most important group consists of those fibres which join the auriculo-temporal nerve (Fig. 906) to be carried in it to the parotid gland as its secreto-motor and vasomotor supply. Other small twigs from the ganglion communicate with the nerve of the pterygoid canal and the chorda tympani nerve.

VAGUS NERVE

The **tenth** or **vagus nerve** is a mixed nerve. It contains a large number of parasympathetic fibres (afferent as well as efferent), and is the most widely distributed of the cranial nerves, for it passes through the neck and thorax into the abdomen. It supplies afferent fibres chiefly to the pharynx, œsophagus, stomach, larynx, trachea, and lungs; efferent fibres to the plain musculature of the same series of organs; and special fibres to the heart and abdominal viscera. The cranial portion of the eleventh cranial nerve contributes efferent fibres to the vagus for the innervation of most of the voluntary muscles of the larynx and pharynx. Each nerve is connected with the seventh, ninth, eleventh, and twelfth cranial nerves, with the first and second cervical spinal nerves, and with the sympathetic system.

It is attached by numerous rootlets to the side of the medulla oblongata, in series with the glosso-pharyngeal nerve above and the accessory nerve below it (for the deep connexions, see p. 927). The rootlets unite to form a single trunk which emerges into the neck through the jugular foramen.

In the jugular foramen the nerve occupies the same sheath of dura mater as the accessory nerve; it is placed behind the glosso-pharyngeal nerve and a small ganglion—the **superior ganglion**—is developed on it.

In the neck the vagus nerve pursues a vertical course in front of the vertebral column. It occupies the carotid sheath, lying between and behind the internal and common carotid arteries and the internal jugular vein. It enters the thorax behind the large veins: *on the right side*, after crossing in front of the first part of the subclavian artery; *on the left side*, in the interval between the left common carotid and subclavian arteries. In the upper part of the neck, immediately below the jugular foramen, a second and larger ganglion—the **inferior ganglion**—is developed on the trunk of the nerve. Both ganglia give origin to afferent fibres.

In the thorax the nerves pass through the superior and posterior mediastina, and their relations are different on the two sides. (*a*) *In the superior mediastinum* the *right nerve* continues its course alongside the trachea, and behind the right innominate vein and superior vena cava, to the posterior surface of the root of the lung. The *left nerve* courses downwards between the left common carotid and subclavian arteries, and behind the left innominate vein and the phrenic nerve. It passes across the left side of the aortic arch and then proceeds to the posterior surface of the root of the left lung. (*b*) *In the posterior mediastinum* the vagi nerves are concerned in the formation of two great plexuses—the pulmonary and the œsophageal. Behind the root of the lung each vagus nerve breaks up to form the **posterior pulmonary plexus**, from the lower part of which two nerves emerge. Those two nerves on the right side pass anterior to the vena azygos; on the left side anterior to the descending thoracic aorta. Both series reach the œsophagus and divide into small communicating branches which form the **œsophageal plexus**, which lies mainly *on* the œsophagus, though some branches may descend within its wall. At the œsophageal opening of the diaphragm two single nerves (the anterior and posterior gastric nerves) become separated from the plexus, and, having entered the abdomen, they terminate by supplying the stomach and other abdominal organs. Fibres from the vagi of both sides enter into the formation of each nerve which extends from the œsophageal plexus into the abdomen (M'Crea, 1924; Jackson, 1949).

The **communications** and **branches** of the vagus nerve may be described as (i) ganglionic, (ii) cervical, (iii) thoracic, and (iv) abdominal (Fig. 907).

Superior Ganglion.—The **superior ganglion** of the vagus is small and spherical. It lies in the jugular foramen, and gives off two branches—meningeal and auricular.

The **meningeal branch** passes backwards to supply the dura mater of the posterior fossa of the skull.

The **auricular branch** enters the mastoid canaliculus through the lateral wall of the jugular fossa, and, escaping from it through the tympano-mastoid fissure, it is distributed to the back of the auricle, the floor of the external auditory meatus, and the lower part of the tympanic membrane. It receives, near its origin, a twig from the tympanic branch of the glosso-pharyngeal nerve, and, as it traverses the temporal bone, usually communicates with the facial nerve by a branch which arises from that nerve in its canal; it communicates superficially with the posterior auricular nerve.

Communications.—Besides supplying the meningeal and auricular branches, this ganglion receives communications from: (1) the superior cervical ganglion of the sympathetic; (2) the accessory nerve; and (3) (sometimes) the inferior ganglion of the glosso-pharyngeal nerve.

Inferior Ganglion.—The **inferior ganglion** of the vagus, placed immediately below the preceding, is large and fusiform. Like the superior ganglion, it has two branches—the pharyngeal and superior laryngeal nerves.

The **pharyngeal branch** (often double) receives its efferent fibres (through the ganglion) from the accessory nerve. It passes obliquely downwards and medially to the pharynx between the internal and external carotid arteries, and combines with the pharyngeal branches from the glosso-pharyngeal and superior cervical ganglion of the sympathetic to form the **pharyngeal plexus**, which lies on the wall

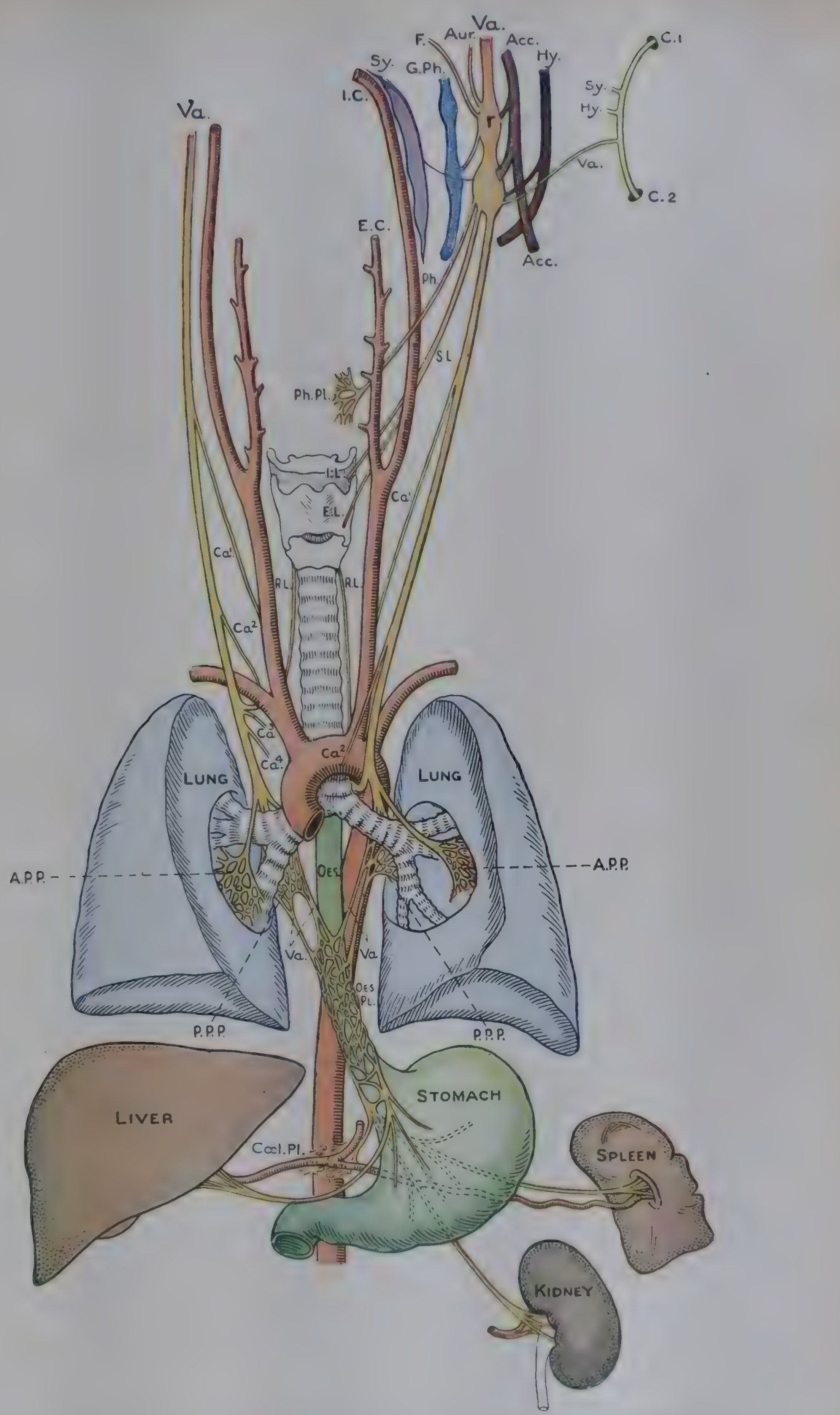

FIG. 907.—SCHEME OF CONNEXIONS AND DISTRIBUTION OF VAGUS NERVES.

Acc., Accessory nerve.
A.P.P., Anterior pulmonary plexus.
Aur., Auricular branch.
C.1, C.2, Loop between first and second cervical nerves.
Ca.[1], Ca.[2], Upper and lower cervical cardiac branches.
Ca.[3], Cardiac branches of recurrent laryngeal.
Ca.[4], Thoracic cardiac br. (rt. vagus).
Cœl.Pl., Cœliac plexus.
E C., External carotid artery.
E.L., External laryngeal branch.
F., Meningeal branch.
G.Ph., Glosso-pharyngeal nerve.
Hy., Hypoglossal nerve.
Hy., Cerv. commun. to hypoglossal n.
I.C., Internal carotid artery.
I.L., Internal laryngeal branch.
Oes.Pl., Œsophageal plexus.
Ph., Pharyngeal branch.
Ph.Pl., Pharyngeal plexus.
P.P.P., Posterior pulmonary plexus.
R.L., Recurrent laryngeal nerve.
r., Superior ganglion of vagus.
S.L., Superior laryngeal nerve.
Sy., Superior cervical ganglion of sympathetic.
Sy., Grey ramus communicans.
Va., Right and left vagi.
Va., Cervical commun. with inferior ganglion of vagus.

of the pharynx at the level of the middle constrictor (Fig. 905). From this plexus the muscles of the pharynx and soft palate (except the stylo-pharyngeus and tensor palati) are supplied. The **lingual branch** is a minute nerve which separates itself from the plexus and joins the hypoglossal nerve in the anterior triangle of the neck.

The **superior laryngeal nerve** passes obliquely downwards and medially, medial to the external and internal carotid arteries, towards the thyroid cartilage. It is joined by twigs from the sympathetic and the pharyngeal plexus, and is said to give a filament to the internal carotid artery. It ends by dividing in its course into two unequal parts—a larger internal and a smaller external laryngeal branch.

The **internal laryngeal nerve** passes medially into the pharynx. It pierces the thyro-hyoid membrane, in company with the corresponding branch of the superior laryngeal artery under cover of the thyro-hyoid muscle, and divides into three branches. These supply the mucous membrane of the larynx, reaching upwards to the epiglottis and the posterior part of the dorsum of the tongue. The lowest branch forms communications on the medial side of the lamina of the thyroid cartilage with the branches of the recurrent laryngeal nerve.

The **external laryngeal nerve** passes downwards deep to the infrahyoid muscles and upon the inferior constrictor muscle of the pharynx. It supplies branches to that muscle, and ends in the **crico-thyroid** muscle.

Communications.—Besides supplying the pharyngeal and laryngeal nerves, the ganglion has the following communications with other nerves: (1) with the superior cervical ganglion of the sympathetic; (2) with the hypoglossal; (3) with the loop between the first and second cervical nerves; and (4) with the accessory nerve, which applies itself to the ganglion, and thereby supplies to the vagus nerve the efferent fibres for the muscles of the larynx, except the crico-thyroid.

Beevor & Horsley (1888), on the basis of a series of experiments on monkeys, came to the conclusion: (1) that the glosso-pharyngeal nerve supplies the stylo-pharyngeus and the middle constrictor; (2) that the vagus supplies no muscles in the head and neck; (3) that the cranial portion of the accessory nerve supplies the levator palati and the muscles of the pharynx and larynx.

Branches of Vagus in the Neck.—In the neck the vagus nerve supplies cardiac branches and (on the right side) the recurrent laryngeal nerve (Fig. 907).

The **cervical cardiac branches** are **upper** and **lower.** *On the right side* both cardiac branches pass downwards into the thorax behind the subclavian artery, and along the side of the trachea to the deep cardiac plexus. *On the left side* the two nerves separate on reaching the thorax. The *upper nerve* passes deeply alongside the trachea to join the deep cardiac plexus. The *lower nerve* accompanies the vagus nerve across the aortic arch, along with the cardiac branch of the superior cervical ganglion of the sympathetic, to end in the superficial cardiac plexus.

The **right recurrent laryngeal nerve** arises at the root of the neck as the vagus crosses in front of the first part of the subclavian artery. It hooks round the artery, and passes obliquely upwards and medially behind the subclavian and the common carotid, and either in front of or behind the inferior thyroid artery; it then ascends in the groove between the œsophagus and trachea, along the medial side of the corresponding lobe of the thyroid gland. It finally disappears under cover of the inferior border of the inferior constrictor muscle to end in **laryngeal branches** which supply all the intrinsic muscles of the larynx except the crico-thyroid.

In its course it gives off the following branches:—

(1) **Cardiac branches** arise as the nerve winds round the subclavian artery, and descend alongside the trachea to end in the deep cardiac plexus.

(2) **Communicating branches** to the inferior cervical ganglion of the sympathetic arise from the nerve behind the subclavian artery.

(3) **Muscular branches** supply the trachea, œsophagus, and the inferior constrictor of the pharynx.

(4) **Terminal branches** supply the muscles of the larynx (except the crico-thyroid)

and communicate medial to the lamina of the thyroid cartilage with branches of the internal laryngeal nerve (p. 696). Sensory fibres are supplied to the mucous membrane of the larynx below the level of the vocal folds.

Branches of Vagus in the Thorax.—In the thorax the vagi form the great pulmonary and œsophageal plexuses. The right nerve, in addition, furnishes cardiac branches; and the left nerve gives off the recurrent laryngeal nerve.

The **left recurrent laryngeal nerve** differs from the nerve of the right side mainly in its point of origin and in the early part of its course. It springs from the vagus as it crosses the aortic arch, and, after hooking below the arch, behind the *ligamentum arteriosum*, it passes upwards in the superior mediastinum to the neck, where its course and relations are similar to those of the nerve of the right side. The branches of the nerve are the same as those of the right nerve. The **cardiac branches** are larger; they arise below the aortic arch and pass to the deep cardiac plexus.

The **thoracic cardiac** branches on the right side are derived from the trunk of the vagus as it lies beside the trachea; on the left side they arise from its recurrent branch. All join the deep cardiac plexus.

Branches of Vagus in the Abdomen.—From the lower end of the œsophageal plexus two gastric nerves (each containing fibres from both vagi) pass on the walls of the gullet through the diaphragm into the abdomen. The **posterior gastric nerve** is distributed to the posterior surface of the stomach and sends communicating offsets to the cœliac, splenic, and renal plexuses of the autonomic system. The **anterior gastric nerve** applies itself to the anterior surface and lesser curvature of the stomach, to which it is distributed. It sends communicating offsets between the layers of the lesser omentum to the hepatic plexus, and fine filaments from these offsets pass in the omentum to the pylorus and first part of the duodenum.

Vagal fibres are thus distributed either directly to viscera (*e.g.*, the stomach from the gastric nerves) or indirectly through the great plexuses in the abdomen. All vagal fibres which enter the abdomen, although largely non-medullated, are to be regarded as preganglionic; they meet their postganglionic neurons in the intramural or terminal plexuses situated in the walls of the gut and other viscera (*e.g.*, myenteric and submucous plexuses of intestine, p. 625). The distribution in the abdomen extends as far as the descending colon, at which level the area of distribution of the sacral parasympathetic begins. The terminal branches of distribution are generally associated with sympathetic fibres and both sets commonly run alongside blood-vessels to the gut or other viscus supplied. Besides innervating the muscular walls of the hollow abdominal viscera, vagal fibres are also secreto-motor to the glands of the stomach and intestine.

Certain **asymmetrical features** of the two vagus nerves are explained by a reference to the process of development. The course of the recurrent laryngeal nerves is explained by the absence of neck in the early embryo, and by the primitive aortic arches between which they passed, having occupied a higher position before the heart descended into the thorax, when it dragged these branches of the nerves down with it. The corresponding arches (the fourth pair), beneath which they originally passed, develop into the subclavian artery on the right side, the aorta on the left (see Fig. 1133, p. 1373). Variations in the pattern of arterial development may impose corresponding alterations in the course of the recurrent nerve.

Thoracic Plexuses

Of the plexuses formed by the vagus nerves in the thorax—cardiac, pulmonary, and œsophageal—the **cardiac plexuses** are described under the autonomic system, on p. 1138. The fibres of the vagus which take part in the formation of thoracic and abdominal plexuses belong to the parasympathetic system.

Pulmonary Plexuses.—As already stated, the vagus nerve on each side, on reaching the back of the root of the lung, breaks up into numerous plexiform branches for the formation of the posterior pulmonary plexus. From each nerve a few fibres pass to the front of the root of the lung, above its upper border, to form the much smaller anterior pulmonary plexus. These plexuses communicate freely with each other, fibres connect the plexuses of the two sides, they

are intimately connected with the cardiac plexuses, and they receive branches from the sympathetic. Reference is made to the pulmonary plexuses in the section dealing with the autonomic system (see p. 1138).

The **anterior pulmonary plexus** on each side is joined by a few fibres from the corresponding part of the deep cardiac plexus, and on the left side from the superficial cardiac plexus as well. It surrounds and supplies the constituents of the root of the lung anteriorly.

The **posterior pulmonary plexus**, placed behind the root of the lung, is formed by the greater part of the vagus nerve, reinforced by fine branches from the second, third, and fourth thoracic ganglia of the sympathetic.

Numerous branches extend from the anterior and posterior pulmonary plexuses into the substance of the lung. The entering fibres, arranged in a plexiform manner, form three groups. One accompanies the bronchi, another the vessels, and a third is distributed to the pulmonary pleura.

Œsophageal Plexus.—The œsophagus in the thorax is supplied by the vagus nerves both in the superior and posterior mediastina. *In the superior mediastinum* it receives branches from the vagus nerve on the right side, and from the recurrent laryngeal nerve on the left side.

In the posterior mediastinum the gullet is surrounded by the œsophageal plexus, formed from the trunks of the vagus nerves emerging from the posterior pulmonary plexuses. That part of the œsophagus also receives fibres from the greater splanchnic nerve and the splanchnic ganglion. From the œsophageal plexus branches supply the muscle and mucous membrane of the wall of the œsophagus.

A few filaments also pass from the plexus to the posterior surface of the pericardium.

The thoracic plexuses described above are to be regarded as predominantly vagal, *i.e.*, parasympathetic. The ganglion-cells found in them are the cell-bodies of postganglionic neurons whose fibres innervate the heart, its coronary vessels, and the tissues of the lung. Afferent fibres are present whose cell-bodies are located in the vagal ganglia. Impulses carried from the heart, the great veins, and the aorta (including the glomus aorticum, p. 1145) by such afferent fibres have considerable importance in vasosensory reflex mechanisms.

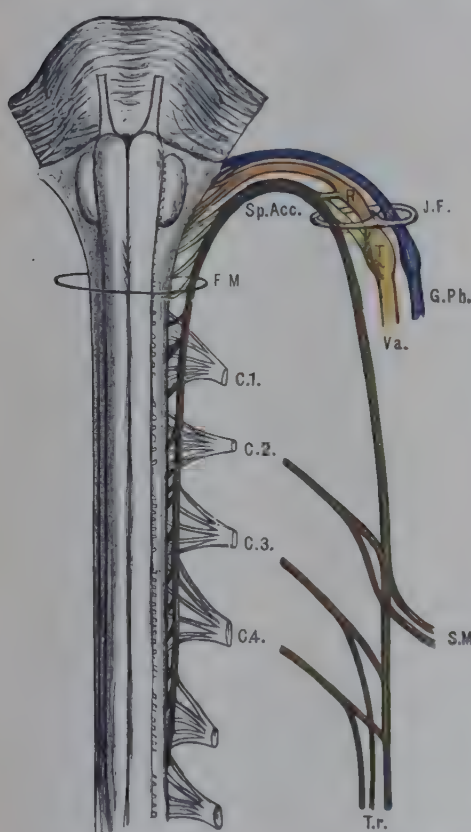

Fig. 908.—Scheme of the Origin, Connexions, and Distribution of the Accessory Nerve.

Sp.Acc., Accessory nerve; C.1-4, First four cervical nerves (posterior roots); Va., Vagus nerve; R, Superior ganglion; T, Inferior ganglion; G.Ph., Glosso-pharyngeal nerve; S.M., Nerves to sterno-mastoid; Tr., Nerves to trapezius; F.M., Foramen magnum; J.F., Jugular foramen.

ACCESSORY NERVE

The **eleventh** or **accessory nerve** consists of two essentially separate parts, different both in origin and in distribution. One, the **bulbar portion, is accessory to the vagus nerve**, and arises by the *cranial root* in series with the rootlets of that nerve, from the side of the medulla oblongata; its fibres are contributed to the pharyngeal and laryngeal branches of the vagus for the supply of the constrictors of the pharynx and the intrinsic muscles of the larynx. The other, the **spinal portion**, arises by the *spinal root* from the side of the spinal cord between the anterior and posterior roots of the spinal nerves, its origin extending from the level of the cranial root as low as the origin of the fifth or sixth cervical nerve (for the deep origin, see p. 927). This portion of the nerve supplies the sterno-mastoid and trapezius muscles. Successively joining together, the rootlets form a trunk which ascends in the subarachnoid

space of the vertebral canal, behind the ligamentum denticulatum, to the foramen magnum. Approaching the jugular foramen, the spinal and cranial roots unite into a single trunk which leaves the cranial cavity through the jugular foramen in the same compartment of dura mater as the vagus nerve (Fig. 889, p. 1016).

In the jugular foramen the part **accessory to the vagus** (after furnishing a small branch to the superior ganglion of the vagus) applies itself to the inferior ganglion. At this point some fibres join the ganglion and the rest become incorporated in the trunk of the vagus beyond the ganglion. Its fibres are distributed in certain branches of the vagus indicated above. See also p. 1040.

The **spinal portion** of the nerve extends into the neck, where at first it lies along with other nerves in the interval between the internal carotid artery and the internal jugular vein. It then passes obliquely downwards and laterally superficial (sometimes deep) to the vein, under cover of the posterior belly of the digastric; still descending, it pierces the deep part of the sterno-mastoid muscle or lies close to its deep surface, and it supplies the muscle. It appears at the posterior border of the sterno-mastoid at or below the junction of the upper and middle thirds, and about the level of the upper border of the thyroid cartilage. It runs obliquely downwards and backwards in the fascial roof of the posterior triangle to reach the anterior border of the trapezius muscle, under which it passes and which it helps to supply in conjunction with branches of the cervical plexus. The accessory nerve communicates with nerves from the cervical plexus in three situations: (1) in or under cover of the sterno-mastoid, with the branch for the muscle derived from the second cervical nerve; (2) in the posterior triangle, with branches to trapezius from the third and fourth cervical nerves; (3) deep to the trapezius, with the same branches.

In its course beneath the sterno-mastoid and in the posterior triangle the accessory nerve has important and intimate relations with lymph-glands.

HYPOGLOSSAL NERVE

Motor Nv

The **twelfth** or **hypoglossal nerve** is a predominantly efferent nerve, which supplies all the muscles of the tongue, both intrinsic and extrinsic, except the palato-glossus. It arises by numerous rootlets from the front of the medulla oblongata between the pyramid and the olive (Fig. 885, p. 1012; for the deep origin, see p. 926). The rootlets arrange themselves in two bundles which separately pierce the dura mater, and unite in the anterior condylar canal, or after emerging from the skull. Immediately below the base of the skull it is closely associated with the glosso-pharyngeal, vagus, and accessory nerves, and lies, with them, medial to and between the internal carotid artery and the internal jugular vein, and deep to the posterior belly of the digastric and the stylo-hyoid muscle. In this part of its course it is joined by fibres of the first and second cervical nerves. As it descends it becomes more superficial and, winding round the vagus nerve, it is closely attached to the lateral surface of its inferior ganglion. Midway between the posterior belly of the digastric and the greater horn of the hyoid bone it turns forwards, through the angle between the occipital artery and its sterno-mastoid branch, and passes to the floor of the mouth. In its course forwards it lies superficial to the internal carotid artery, the occipital artery, the external carotid artery, and to the loop of the lingual artery (which separates it from the middle constrictor muscle). Farther forward it lies between the posterior belly of the digastric muscle laterally and the hyo-glossus medially and then between the mylo-hyoid laterally and the hyo-glossus medially, where it breaks up into terminal branches which continue onwards between the mylo-hyoid and genio-glossus muscles. The terminal branches communicate with filaments of the lingual nerves.

Communications.—Near the base of the skull the hypoglossal nerve is connected by small branches with: (1) the superior cervical ganglion of the sympathetic; (2) the inferior ganglion of the vagus; (3) by a larger branch, with the loop between the first two cervical nerves; (4) as it crosses the external carotid artery it receives a communication from the pharyngeal plexus (*lingual branch of the vagus*); and (5) medial to the mylo-hyoid

muscle, at the anterior border of the hyo-glossus, it forms loops of communication with the lingual branch of the mandibular nerve.

The **branches** of the nerve are: (1) Meningeal; (2) Descending; (3) Thyro-hyoid; and (4) Terminal.

The **meningeal branch** passes from the nerve near its origin to supply the

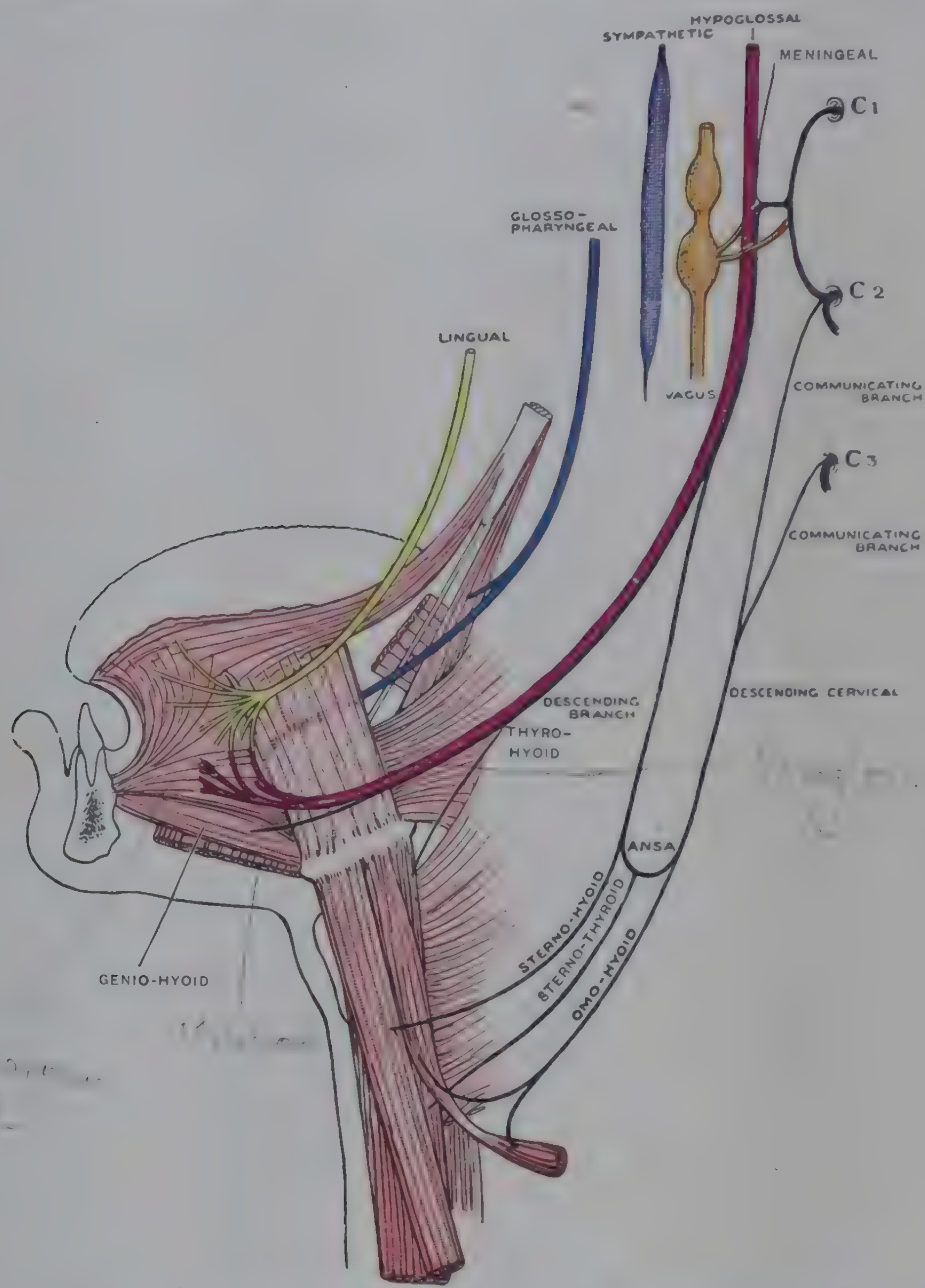

FIG. 909.—MUSCLES OF HYOID BONE AND STYLOID PROCESS, AND EXTRINSIC MUSCLES OF THE TONGUE, SHOWING CONNEXIONS AND DISTRIBUTION OF HYPOGLOSSAL NERVE.

dura mater of the posterior fossa of the skull. It probably derives its fibres from the communication with the first and second cervical nerves.

The **descending branch of the hypoglossal nerve** is the chief branch given off in the neck. It arises from the hypoglossal nerve as it crosses the internal carotid artery, and descends in the anterior triangle superficial to the carotid sheath. It is joined about the middle of the neck by the **nervus descendens cervicalis** (from the second and third cervical nerves). By their union the **ansa hypoglossi (hypoglossal loop)** is formed, from which branches are distributed to both bellies of the omo-hyoid, the sterno-hyoid, and the sterno-thyroid. The descending branch of the hypoglossal nerve derives its fibres from the communication to the hypoglossal nerve from the loop between the first and second cervical nerves; the ansa hypoglossi therefore is made up of fibres of the first three cervical nerves.

The **nerve to the thyro-hyoid muscle** is a small branch which arises from the

hypoglossal nerve before it leaves the carotid triangle. It descends behind the greater horn of the hyoid bone to reach the muscle. When traced backwards this nerve is found associated with the loop between the first and second cervical nerves.

The **terminal branches** of the hypoglossal nerve are distributed to the hyoglossus, stylo-glossus, genio-hyoid, and genio-glossus, and to all the intrinsic muscles of the tongue. The nerve to the genio-hyoid is said to be derived from the loop between the first and second cervical nerves.

COMPONENT FIBRES OF CRANIAL NERVES

The third, fourth, sixth, eleventh, and twelfth pairs are composed of large and small medullated fibres; non-medullated fibres have been found in the fifth, sixth, ninth, eleventh, and twelfth, of which those in the sixth, eleventh, and twelfth are probably all derived from the sympathetic system. As regards the function of the fibres, although the cranial nerves are usually broadly classified as efferent and afferent, as well as mixed nerves, it is now recognized that few of them consist exclusively of one or the other order of fibres. The optic nerve, though long supposed to contain some centrifugal fibres, is to be regarded as purely afferent in the mammal (Bodian, 1937). The third, fourth, and sixth nerves are not purely efferent in function, but contain also some afferent (somatic afferent, *proprioceptive*) fibres (Tozer & Sherrington, 1910), as well as fibres from the sympathetic system, and the same may prove true for the eleventh and twelfth nerves. Indeed the cranial nerves vary greatly in their functional composition, and, moreover, no nerve, save the olfactory, optic and auditory, is made up of one functional order of fibres.

The animal body is naturally divided into two different areas or regions—the **somatic** area, forming the body-wall and limbs, and the **splanchnic** or visceral area, comprising the chief viscera contained within the body cavity. In the head and neck an additional factor has to be considered owing to the presence of the series of pharyngeal or branchial arches, for in connexion with that series there have been developed not only an additional set of visceral muscles, requiring motor innervation (*e.g.*, the muscles of mastication, and of the face, palate, and pharynx), but also visceral sense-organs (taste-buds). In a regional classification of the nerves on these lines those that supply the derivatives of the branchial region may be termed *special* in contrast with the *general* nerves of the rest of the visceral area; similarly in the somatic area the introduction of the ear as a specialized sensory area results in the presence of a special set of somatic afferent fibres. Combining the regional distribution with the function of the fibres (*efferent* and *afferent*) the nerve-fibres may be tabulated as follows (after Herrick, 1938):—

Sensory: General somatic afferent (sensory from the skin).
Special somatic afferent (cochlear and vestibular nerves).
General splanchnic afferent (from visceral mucous membrane).
Special splanchnic afferent (from organs of taste).
Motor: General splanchnic efferent (to plain musculature).
Branchial efferent (to branchial muscles).
General somatic efferent (to skeletal muscles).

It is worthy of note that such a classification serves rightly to emphasize the central connexion, practical continuity, and function of the peripheral nervous system as a whole, since many of the fibre-paths designated under this nomenclature traverse both the cerebro-spinal and autonomic systems on their way to their destinations.

DEVELOPMENT AND MORPHOLOGY OF CRANIAL NERVES

In the early human embryo, when the neural plate is folded in to form the neural tube, the cells that form its lateral margins are left as a **neural crest**, lying above the tube and connecting it with the surface ectoderm. From the cells of the crest there are developed not only all of the cerebro-spinal and sympathetic ganglia, together with the chromaffin bodies, but all of the *afferent* fibres of the cerebro-spinal system (except those of the first and second cranial nerves and a few fibres in connexion with the seventh, ninth, and tenth nerves to be mentioned later), whilst from the walls of the **neural tube** all of the *efferent* fibres arise.

At a later stage the lateral walls of the neural tube become differentiated into three layers—the **ependymal**, **mantle**, and **marginal zones**—and the neural canal is more or less rhomboidal in transverse section, its lateral angles marking the division of the walls into a dorsal part (the **alar lamina**) and a ventral part (the **basal lamina**). Into the alar lamina grow the central processes of the cells situated in the cerebro-spinal ganglia, which have been derived from the neural crest, and it may, therefore, be considered *afferent* in function, whilst the basal lamina, from whose cells there grow out long peripheral fibres, may be termed *efferent*. Furthermore, in the middle or mantle zone (grey matter) of each lamina the developing neuroblasts become arranged in two longitudinal columns, one having **somatic** (body-wall) and the other **splanchnic** (visceral) peripheral connexions. Thus, the grey matter of each lateral wall of the neural tube shows four longitudinal cell-columns (Figs. 730, 910), which, from their presence throughout the whole length of the neural tube, their peripheral connexions, and their functions, may be called:

1. General somatic afferent cell-column } in the Alar lamina,
2. General splanchnic afferent cell-column }
3. General splanchnic efferent cell-column } in the Basal lamina,
4. General somatic efferent cell-column }

corresponding to Gaskell's four primary functional divisions of the activities of the organism.

In the hind- and mid-brain regions, however, other cell-columns are added, consequent upon the presence of (1) the great **special sense organs** (nose, eye, ear) which demand specialized somatic afferent connexions, and (2) the **branchial system** and its derivatives, which, as a specialized part of the visceral area, demand special splanchnic connexions, both afferent and efferent. In the developing brain-stem, therefore, three additional cell-columns are to be found (Fig. 911) :—

1. Special somatic afferent cell-column } in the Alar lamina,
2. Special splanchnic afferent cell-column }
3. Branchial efferent cell-column in the Basal lamina.

As is pointed out above in the discussion of their components, few of the cranial nerves are composed exclusively of fibres of one functional order; in most, however, there is such a preponderance of one type that we are justified in grouping them into three series :—

Somatic Afferent.	Somatic Efferent.	Branchial and Splanchnic (Afferent and Efferent)
I. Olfactory.	III. Oculomotor.	V. Trigeminal.
II. Optic.	IV. Trochlear.	VII. Facial.
VIII. Auditory.	VI. Abducent.	IX. Glosso-pharyngeal.
	XII. Hypoglossal.	X. Vagus.
		XI. Accessory.

Though this grouping is purely *functional*, it is, as we might expect, reflected anatomically in development, for the somatic afferent group of nerves (I, II, and VIII) is connected with the alar lamina, corresponding in this respect to the posterior roots of the spinal nerves, whilst the somatic efferent group (III, IV, VI, and XII) arises from the medial part of the basal lamina in line with the anterior roots of the spinal nerves. The splanchnic group (V, VII, IX, X, and XI), which is composed of afferent and efferent nerves specialized in connexion with the branchial system, forms an intermediate series between the other two. It must be said, however, that though there is some degree of correspondence between cranial and spinal nerves, any attempt to show a strict homology leads to insuperable difficulties.

Somatic Afferent Group

Of the three cranial nerves in this group, the eighth only is developed from the neural crest, and is to that extent comparable to the posterior root of a spinal nerve. It is quite probable, however, that some of its fibres come from cells developed from the ectoderm of the auditory vesicle, and, moreover, its distribution is limited to a specialized sensory area of the ectoderm. The first and second nerves are developed in connexion with outgrowths of the brain; and it is obvious that neither of them is strictly comparable to any of the other nerves, cranial or spinal.

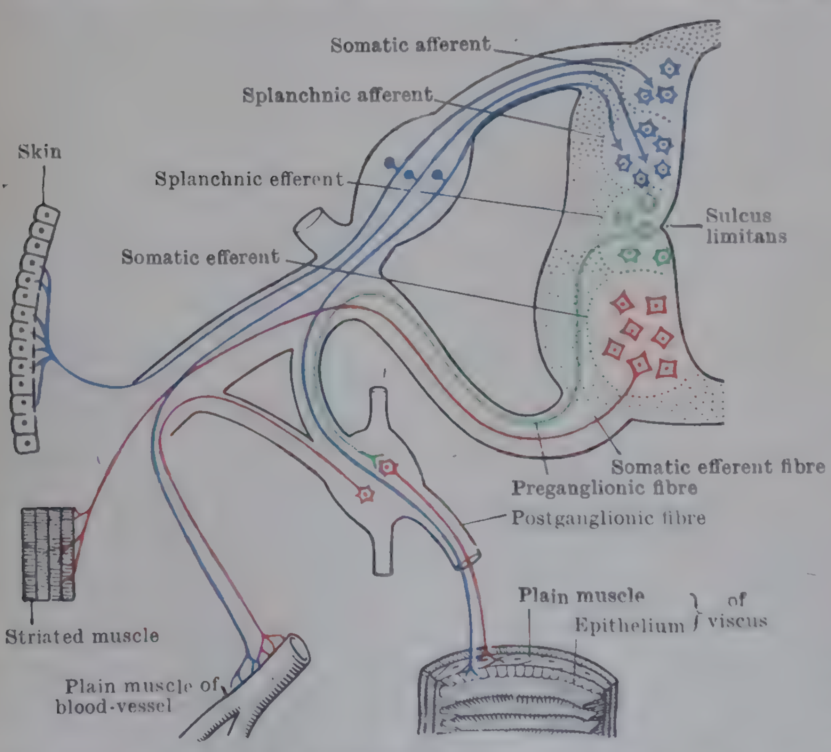

Fig. 910.—Diagram of Components of Spinal Nerve and their Relation to Nuclei of Origin or Termination in Section of Embryonic Spinal Cord. Compare with components of cranial nerves in Fig. 911 and also with Fig. 963, p. 1129.

I. Olfactory Nerve.—At the end of the fourth week an olfactory plate becomes differentiated in the ectoderm lying under the fore-brain on each side. By the growth of the medial and lateral nasal processes around it, the plate comes to form the roof of the olfactory pit. The sensory cells of the plate now take on the character of true nerve-cells, and send in basal fibres which arborize around the cells of the olfactory bulb. At first the olfactory plates are directly in contact with the bulb, which is developed from the fore-brain, but later, by the development of the cribriform plate and meninges, they become pushed apart, and the fibres

connecting them are lengthened to form the true olfactory nerves. These nerves are peculiar in that the cell-bodies, which are bipolar, lie in the mucous membrane and are not aggregated into ganglia. The fibres proceeding to the olfactory bulb are non-medullated.

II. Optic Nerve.—The optic nerve is developed in the stalk of the optic vesicle—an outgrowth from the fore-brain, and, morphologically, is a part of the central nervous system. When the optic cup is formed (see under Development of the Eye) its inner or retinal layer becomes differentiated into the rods and cones (the true neuro-sensory cells, corresponding to the olfactory cells) and nerve-cells, the processes of which grow back along the optic stalk to form the optic nerve, chiasma, and tract. These nerve-cells are true intercalated neurons, corresponding to those of the grey matter of the central nervous system, and their fibres, lacking the typical neurolemmal sheath of peripheral nerves, are supported by neuroglia.

VIII. Auditory Nerve.—The internal ear first arises as an ectodermal plate lying dorsal to the

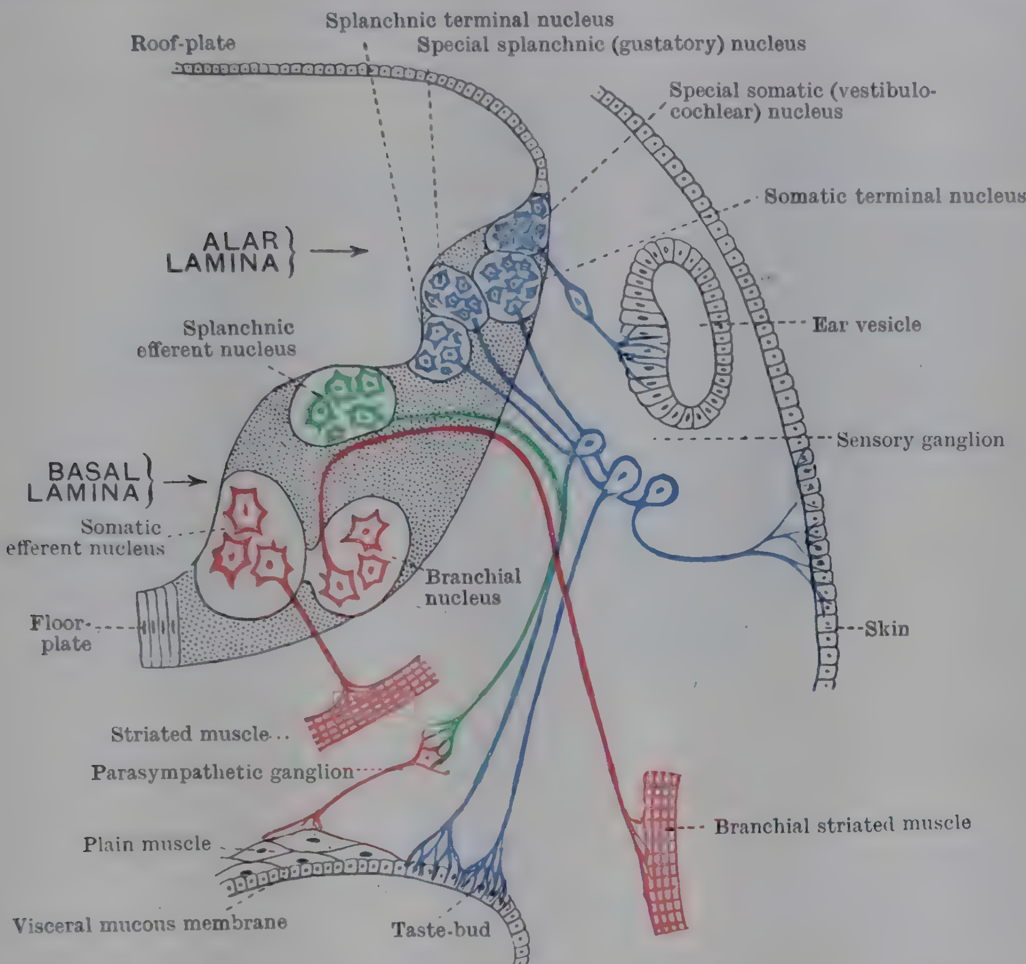

FIG. 911.—DIAGRAM OF COMPONENTS OF CRANIAL NERVES AND THEIR RELATION TO NUCLEI OF ORIGIN OR TERMINATION IN SECTION OF EMBRYONIC HIND-BRAIN.

Compare with components of spinal nerve in Fig. 910 and also with Fig. 730, p. 845.

first pharyngeal groove. That plate invaginates to form a flask-like auditory vesicle (otocyst) from the lining cells of which patches of neuro-epithelium are later differentiated. The vestibular and cochlear ganglia develop between the vesicle and the hind-brain in close association with the ganglion of the seventh nerve. Although the origin of the common mass is usually said to be from the neural crest, it is probable that some at least of the cells of the auditory ganglia are derived from the neuro-epithelium of the auditory vesicle. The ganglia, composed of bipolar cells, grow in direct proportion to the vestibular and cochlear outgrowths of this vesicle, and their central and peripheral fibres form the vestibular and cochlear nerves.

SOMATIC EFFERENT GROUP

The hypoglossal nerve and the three nerves to the muscles of the eyeball all arise from the somatic efferent cell-column in the basal lamina of the neural tube, and on that account, as well as by reason of the fact that they innervate somatic muscles, are usually considered as being in series with the anterior roots of the spinal nerves.

Though the primitive vertebrate head undoubtedly was segmental, little reliable evidence remains upon which to base a reconstruction of its segmentation, and various investigators have placed the number of the primitive cephalic segments between eight and nineteen. No distinct myotomes are visible in the head of the human embryo, but a study of the lower vertebrates leads to the conclusion that the premuscle mass from which the extrinsic ocular muscles are developed represents the first three cephalic myotomes. The first myotome forms the superior,

inferior, and medial recti and the inferior oblique, supplied by the oculomotor nerve; the second myotome forms the superior oblique, supplied by the trochlear nerve; and the third forms the lateral rectus, supplied by the abducent (see Fig. 478, p. 554).

Similar studies tend to show that the intrinsic muscles of the tongue are derived from the last three cephalic myotomes. Between those two sets of persisting myotomes (ocular and lingual) there is a gap which probably represents three or more myotomes which have disappeared.

III. Oculomotor Nerve.—This nerve arises from neuroblasts in the basal lamina of the mid-brain. The fibres emerge in small bundles from the anterior surface of the lamina and converge to form the trunk of the nerve, which runs to the premuscle mass from which the extrinsic muscles of the eye (with the exception of the superior oblique and lateral rectus) are formed.

IV. Trochlear Nerve.—The neuroblasts from which this nerve arises lie just caudal to and in line with the nucleus of the third nerve. Instead of leaving the basal lamina by its anterior

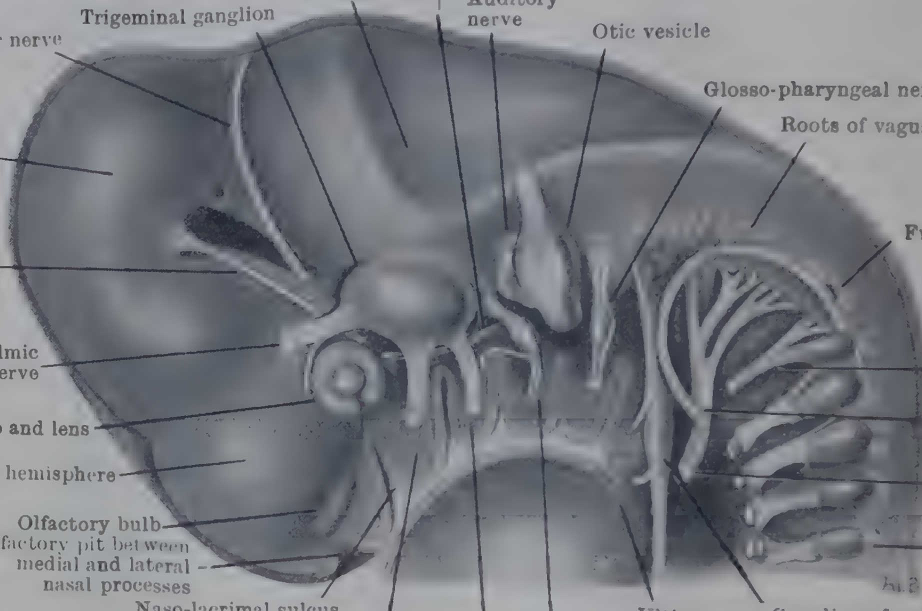

Fig. 912.—Developmental Arrangement of the Cranial Nerves. (After Streeter, 1908.)

surface, however, the fibres grow backwards, curve round the neural canal (aqueduct), and, after crossing behind it, emerge on the opposite side at the junction of the mid-brain and hind-brain.

VI. Abducent Nerve.—The nucleus of origin lies in the basal lamina of the hind-brain under the floor of the fourth ventricle. The fibres emerge at a point caudal to the future pons and run to the rudiment of the lateral rectus muscle.

XII. Hypoglossal Nerve.—The twelfth is a compound nerve representing the fused efferent nerves of three, or possibly more, precervical neural segments. Its fibres take origin from neuroblasts in the somatic efferent cell-column and emerge from the walls of the basal lamina in several groups; they then converge anteriorly to form the trunk of the nerve and grow forwards to end in the muscle-rudiment of the tongue. The occasional presence of a ganglion (Froriep, 1882) on the hypoglossal nerve (human and other mammalian embryos and some adult mammals) suggests that this nerve has carried sensory fibres earlier in phylogeny. The presence of sensory components in the adult human hypoglossal has been disputed; but Pearson (1945) has described sensory-type ganglion-cells in the intra-medullary part of the nerve in human fœtal and adult material, and Tarkhan & Abou-el-Naga (1947) claim to have demonstrated the presence of afferent fibres in the dog.

Branchial and Splanchnic (Afferent and Efferent) Group

The nerves of this group are essentially related to the **pharyngeal arches** (see p. 66). In the embryo each of these arches contains a muscle-plate which differs from the myotomes in that it is developed from splanchnic mesoderm but resembles the myotomes in producing striated muscle. Associated with each arch is a nerve which contains both afferent and efferent fibres, and runs along the upper or cephalic border of the arch; that nerve sends a small branch (*pretrematic*) round the dorsal end of the pharyngeal pouch to run along the lower, or caudal, border of the arch in front of the one from which it arises. The nerve of the first or mandibular arch is the mandibular division of the trigeminal nerve; the nerve of the second arch is the

facial, and that of the third is the glosso-pharyngeal; the nerves of the remaining arches are fused to form the vagus and accessory nerves.

The nerve of each arch supplies branchial efferent fibres to the muscle-plate; and it has a ganglion on its root from which afferent (general splanchnic afferent) fibres pass to the pharyngeal mucosa on the inner surface of the arch and the pharyngeal pouch in front of it.

Furthermore, in connexion with the branchial system there are in the human embryo vestiges of a series of sense organs which have been lost by the higher vertebrates. They are small areas of modified ectoderm which are found at the dorsal end of each external pharyngeal groove or branchial cleft and are known as epibranchial **placodes**. During the fifth week of embryonic development the placodes are in contact with the ganglia of the facial, glosso-pharyngeal, and vagus nerves—and contribute cells to the formation of these ganglia.

Whilst the nerves of the splanchnic group typically do not possess somatic afferent fibres, the trigeminal, in conformity with the large part taken by the first arch in the formation of the face, receives a preponderance of that type of fibre. In reality, however, the trigeminal is a double nerve, and the present tendency is to regard its efferent (branchial) part as a separate nerve (the masticator); and the remainder as a somatic afferent nerve. The vagus nerve also contains a limited number of somatic afferent fibres which supply the skin around the persistent dorsal part of the first pharyngeal groove—that is, the external auditory meatus.

V. Trigeminal Nerve.—The trigeminal ganglion arises very early from the neural crest at the extreme cranial end of the hind-brain. Central processes from its cells form the afferent root of the nerve, and, reaching the hind-brain at the level of the pontine flexure, divide to run up and down in the alar plate, where the descending fibres form the spinal tract of the fifth nerve. The peripheral fibres separate into three large divisions which grow out into the three processes that take part in the formation of the face (the fronto-nasal, maxillary, and mandibular processes) and form the three divisions of the fully developed nerve.

The efferent fibres arise from the branchial efferent column of the basal lamina, where the cell-bodies form a dorsal nucleus opposite the point at which the afferent fibres enter the brain. The efferent fibres emerge as a distinct trunk in the embryo, and, after coursing along the medial side of the trigeminal ganglion, run to the muscle-plate of the first arch, which later forms the muscles of mastication.

VII. Facial Nerve.—The facial is composed mainly of efferent fibres which arise from a nucleus in the branchial efferent column of the basal lamina. Growing out from that nucleus they emerge from the hind-brain just medial to the auditory ganglion and run to the muscle-plate of the second or hyoid arch from which the platysma group of muscles is later developed. At first the fibres run directly from their nucleus of origin to the lateral surface of the hind-brain, passing above the nucleus of the abducent nerve. Later, however, the facial nucleus shifts downwards (caudally) and ventro-laterally towards the afferent nuclei of the solitary tract and the spinal tract of the trigeminal nerve, following the general law of neurobiotaxis that the chief dendrite and body of a neuron tend to move towards the source of the majority of their afferent impulses (p. 890). General splanchnic efferent fibres (parasympathetic) also leave the brain in the seventh nerve.

The afferent fibres are developed from the ganglion of the facial nerve, which is derived from the neural crest and lies in close association with the ganglia of the auditory nerve. It is probable that certain cells are also contributed to this ganglion by the epibranchial placode of the first pharyngeal groove. The central fibres enter the alar lamina and form, together with fibres from the glosso-pharyngeal nerve, the solitary tract. Pearson (1947) suggests that some central fibres also run to the descending root of the trigeminal nerve and a few possibly to the mesencephalic tract of the same nerve. The peripheral fibres run in front of the pharyngeal groove and form the chorda tympani and greater superficial petrosal nerves, which represent the pretrematic branch of the facial nerve.

IX. Glosso-Pharyngeal Nerve.—The efferent fibres arise from the nucleus ambiguus, which is a common nucleus of origin for the efferent fibres of the glosso-pharyngeal, vagus, and accessory nerves and lies in the branchial efferent column in line with the efferent nuclei of the fifth and seventh nerves. Emerging from the hind-brain they grow out ventrally to meet the muscle-plate of the third arch, and eventually supply the pharyngeal muscles derived from that element. General splanchnic efferent fibres (parasympathetic) also leave the brain in the ninth nerve.

The afferent fibres, which form the larger part of the nerve, are derived from two ganglia—the superior ganglion, developed from the neural crest, and the inferior ganglion, formed in part from the neural crest and in part from an epibranchial placode with which it is in contact. Centrally the fibres enter the alar lamina and join fibres from the facial and vagus to form the solitary tract. Most of the peripheral fibres from the ganglia run ventrally to enter the third arch, passing, as a lingual branch, to that part of the tongue which is later developed from it. Some of the peripheral fibres, however, form a pretrematic branch in front of the second pharyngeal pouch, and, as the tympanic nerve, supply the structures derived from the dorsal extremity of the first and second pouches (tympanum, etc., see p. 67).

X. Vagus.—The vagus is a composite nerve representing, with the accessory, the union of the nerves of all the pharyngeal arches behind the third. Its afferent fibres, therefore, grow out from several root-ganglia developed from the neural crest. The superior ganglion is the most cephalic of those; the others are vestigial and are called accessory ganglia. The ganglion inferior, like the inferior ganglion of the glosso-pharyngeal, is developed in contact with an epibranchial placode, and in all probability receives cells from that source as well as from the neural crest. The central fibres grow towards the alar lamina, and, after entering it, turn downwards

to form, in conjunction with fibres from the facial and glosso-pharyngeal nerves, the solitary tract. The peripheral fibres grow downward to form the bulk of the vagus nerve.

The efferent fibres arise from two nuclei in the basal lamina—the nucleus ambiguus in the branchial efferent column, and a dorsal efferent nucleus which lies in the general splanchnic efferent column. The fibres from these two sources emerge laterally in two separate bundles and join the afferent fibres to form the trunk of the nerve. Those from the nucleus ambiguus grow out to the muscle-plates of the fourth and succeeding arches, from which the laryngeal and part of the pharyngeal muscles are developed. The fibres from the dorsal nucleus run to the parasympathetic plexuses of the vagus.

XI. Accessory Nerve.—This nerve is closely associated with the vagus; both embryologically and morphologically it may be regarded as the caudal part of the vagus complex which has become specialized because of a new rôle assumed by the branchial muscles which it supplies, these muscles (sterno-mastoid and trapezius) having been pressed into service as muscles of the limb-girdle.

The efferent fibres, of which alone it is composed, arise from two sources. The larger number grow out from cell-groups which are developed in the lateral grey column of the upper four or more cervical segments of the spinal cord (branchial efferent column) in series with the nucleus ambiguus of the tenth. Emerging from the cord laterally, these fibres run upwards along the line of the neural crest as the spinal accessory trunk to join the vagus. Leaving this nerve after a short course, however, they run to their destination. A few fibres of the accessory nerve arise from cells in the dorsal motor nucleus of the vagus and, after pursuing a short course with the accessory proper, rejoin the vagus and are distributed to its plexuses.

SPINAL NERVES

The spinal nerves are characterized by being attached to the spinal cord and by passing from the vertebral canal through the intervertebral foramina.

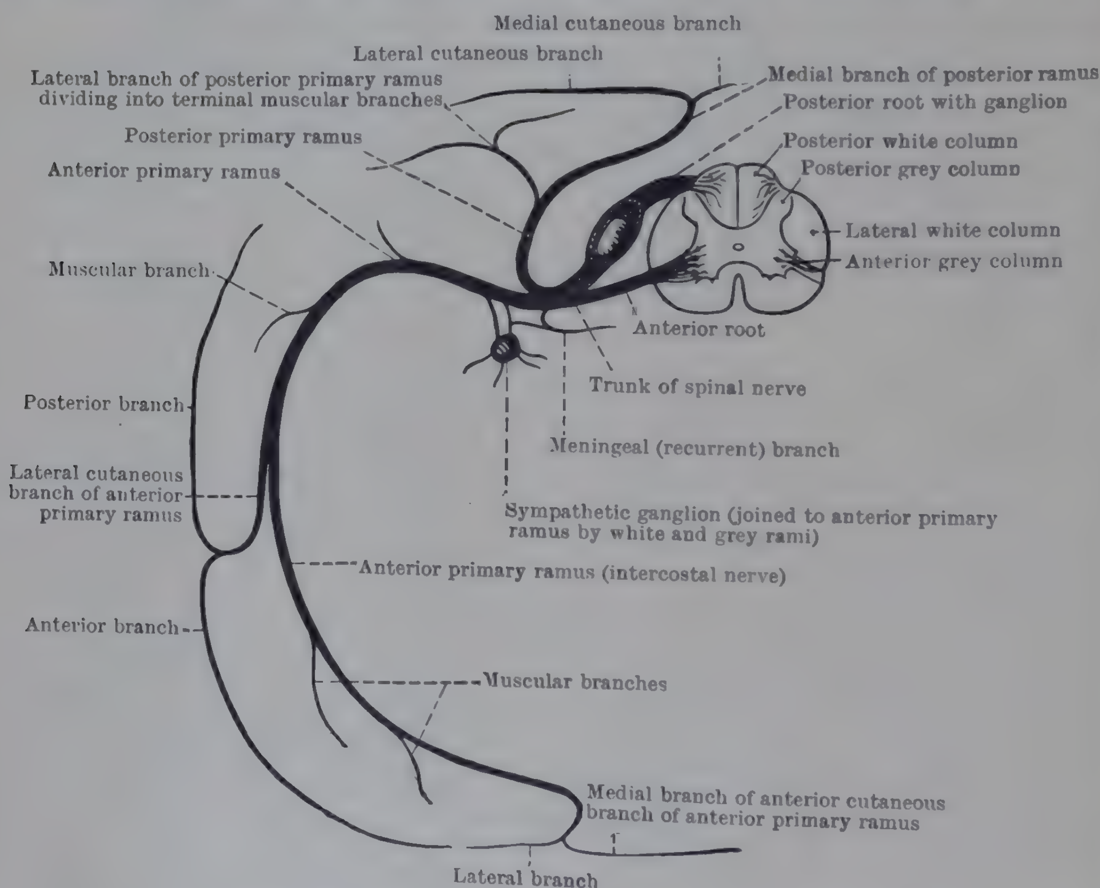

FIG. 913.—DIAGRAM OF ORIGIN AND DISTRIBUTION OF TYPICAL SPINAL NERVE.

Note that the medial branch of the posterior primary ramus is represented as distributed to skin, whilst the lateral branch terminates at a deeper level in muscle. Both branches, however, supply muscles; and in the lower half of the body it is the lateral branch that supplies the skin.

There are usually thirty-one pairs, which are grouped as cervical, thoracic, lumbar, sacral, and coccygeal, in relation to the vertebræ between which they emerge. There are eight cervical nerves, the first passing out of the vertebral canal between the occipital bone and the atlas, and the last appearing between the seventh cervical and first thoracic vertebræ; the other cervical nerves are numbered in corre-

spondence with the vertebræ *above* which they emerge from the canal. There are twelve thoracic, five lumbar, five sacral nerves, and one coccygeal nerve, all appearing *below* the corresponding vertebræ.

The thirty-first nerve is occasionally absent; and there are sometimes one or two additional pairs of minute filaments below the thirty-first, which, however, do not emerge from the vertebral canal. They are the vestigial caudal nerves.

The size of the spinal nerves varies. The largest are those which take part in the formation of the great nerve-trunks of the limbs (lower cervical and first thoracic, and lower lumbar and upper sacral nerves); and of these the nerves destined for the lower limbs are the larger. The coccygeal nerve is the smallest of the spinal nerves; the thoracic nerves (except the first) are more slender than the limb nerves; and the cervical nerves diminish in size from below upwards.

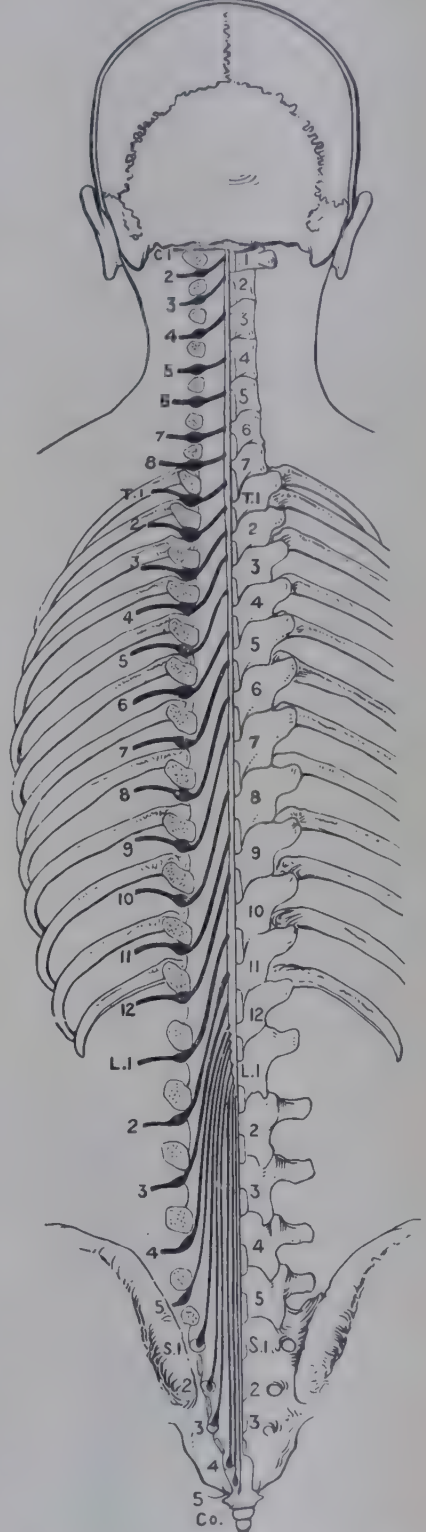

Fig. 914.—Diagram of Origin of Spinal Nerves, showing Position of Roots and Ganglia in Relation to Vertebral Column. The nerves are shown as thick black lines on the left side.

Origin of Spinal Nerves.—Each nerve is attached to the spinal cord by two roots, one of which is ganglionic and the other not; they are called respectively **posterior** (dorsal or afferent) and **anterior** (ventral or efferent).

The **posterior root** is larger than the anterior root; it contains a larger number of radicular fibres, and the individual fibres are of larger size than in the anterior root. It has a vertical linear attachment to the postero-lateral sulcus of the spinal cord. The fibres of contiguous posterior roots are in close relation, and, in some instances, overlap. As the radicles of the posterior root pass away from the spinal cord, they form two bundles, both of which become connected with the proximal end of a **spinal ganglion.** From the distal end of the ganglion the posterior root proceeds to its junction with the anterior root in the intervertebral foramen.

The **spinal ganglia** are found on the posterior roots of all the spinal nerves. (In the case of the first cervical nerve, the posterior root, with its ganglion, is not infrequently reduced or absent.) They occupy the intervertebral foramina, except (1) the ganglia of the sacral and coccygeal nerves, which lie *within* the vertebral canal, and (2) the ganglia of the first and second cervical nerves, which lie upon the vertebral arches of the atlas and axis respectively. With the exception of the coccygeal ganglia they are outside the dura mater, but are invested by a prolongation of that membrane. The ganglia are of ovoid form, bifurcated in some cases at their proximal ends. They consist of unipolar nerve-cells, whose axons, after a very short course, divide into central (root) fibres and peripheral (trunk) fibres. The central fibres form the portion of the root which enters the spinal cord; the peripheral fibres are continued in a lateral direction from the ganglion into the spinal nerve.

There is no adequate evidence to support the view that the dorsal roots contain efferent fibres; they are entirely afferent (Westbrook & Tower, 1940).

Aberrant Spinal Ganglia.—Between the spinal ganglion and the spinal cord small collections of cells are occasionally found on the posterior roots, either as scattered cells or distinct ganglia. They are most frequently met with on the posterior roots of the lumbar and sacral nerves.

The **anterior root** is smaller than the posterior root and has no ganglion. It arises from the anterior surface of the spinal cord (*anterior root-zone*) by means of scattered bundles of nerve-fibres, which occupy a greater horizontal area and are more irregular in their arrangement than the fibres of the posterior root. The rootlets sometimes overlap, and are not infrequently connected with neighbouring radicular fibres above and below.

The posterior and anterior roots proceed laterally in the vertebral canal from their attachment to the spinal cord towards the intervertebral foramina, where they unite to form the spinal nerve. The direction of the roots of the first two nerves is upwards and laterally; the roots of the remaining nerves course obliquely downwards and laterally, the obliquity gradually increasing until the course of the lower lumbar, the sacral and coccygeal nerve-roots is vertically downwards in the vertebral canal. This increasing obliquity of the roots is due to the fact that the spinal cord extends down only as far as the lower border of the first lumbar vertebra, and results in the length of the roots being steadily augmented from cervical to sacral region (Fig. 914). The collection of nerve-roots which occupies the lower part of the canal, below the first lumbar vertebra, and comprises all the nerve-roots below those of the first lumbar nerve, is designated the **cauda equina.** They arise from the lumbar enlargement and the conus medullaris, and surround the filum terminale of the spinal cord.

Within the vertebral canal the nerve-roots are in relation with the **meninges** of the spinal cord, and the anterior are separated from the posterior by the ligamentum denticulatum, and, in the neck, by the spinal part of the accessory nerve also. Each receives on leaving the cord an investment of pia which becomes continuous with the arachnoid where the roots pierce the dura. The two roots are thereafter enclosed in a single tubular sheath of dura mater, in which the spinal ganglion is included. The spinal nerve thus ensheathed occupies the intervertebral foramen (except the first two cervical and the sacral and coccygeal nerves). In the region of the intervertebral foramen the nerve is in relation to the postero-lateral aspect of the intervertebral disc; protrusion or herniation of the nucleus pulposus may compress the adjacent nerve and induce sensory and motor symptoms.

Primary Rami of Spinal Nerve.—After emerging from the intervertebral foramen the nerve immediately divides into two main branches, named the **posterior and anterior primary rami**. Just before its division each nerve gives off a minute **meningeal branch**, which re-enters the vertebral canal after effecting a junction with a branch from the sympathetic trunk, and is distributed to the membranes and vessels of the spinal cord.

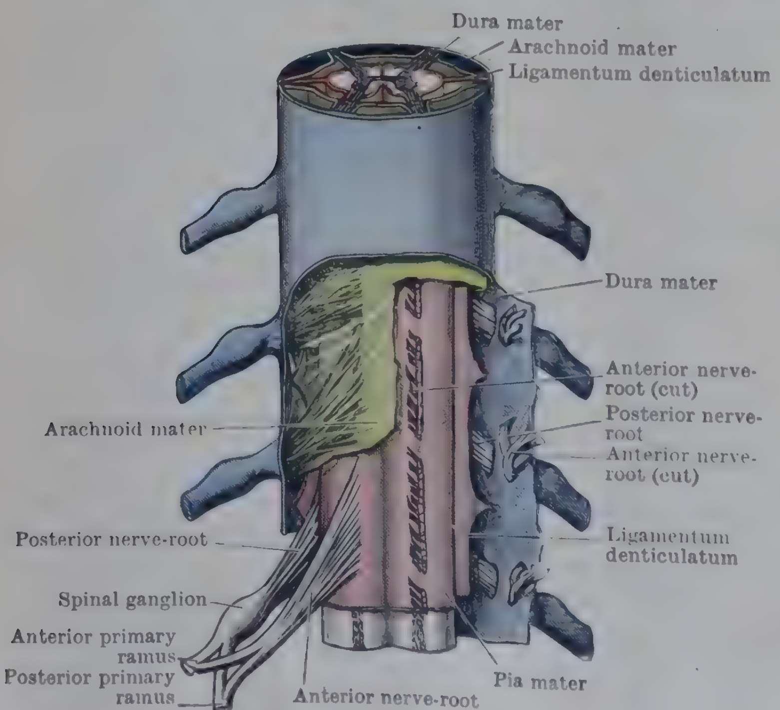

FIG. 915.—MODE OF ORIGIN OF SPINAL NERVES, SHOWN IN RELATION TO MEMBRANES OF SPINAL CORD.

The **posterior** and **anterior primary rami** of the spinal nerves are mainly somatic in their distribution, and are responsible for the innervation of the skeletal muscles and of the skin and fascia of trunk and limbs.

The primary rami of the nerves contain fibres from both posterior and anterior roots. Indeed, each root can be seen, on removal of its sheath, to divide into two portions, of which one portion enters into the formation of the posterior primary ramus, the other into the

formation of the anterior primary ramus. The posterior primary rami, with the exception of the first two, are smaller than the anterior primary rami. They are responsible for the innervation of the skin, fascia, ligaments, and axial muscles of the back. They do not supply the muscles of the limbs, although in their cutaneous distribution they are prolonged on to the back of the head, the shoulder, and the gluteal region. They form two small plexuses—the **posterior cervical** and the **posterior sacral plexuses**. The anterior primary rami are, with the exception of the first two cervical nerves, much larger than the posterior primary rami. They supply the sides and anterior parts of the body, the limbs, and the perineum. For the most part they have a complicated arrangement. The thoracic or intercostal nerves alone have a simple mode of distribution; the other nerves give rise to the **plexuses—cervical, brachial, lumbar, sacral**, and **coccygeal**.

White Rami Communicantes.—From the anterior primary rami of certain nerves (first thoracic to second or third lumbar inclusive) a series of fine nerves arises which serves to connect the spinal with the sympathetic system. These **white rami communicantes**, through the medium of the gangliated trunk of the sympathetic, have a wide distribution to blood-vessels, viscera, certain glands, and other structures.

A second stream of nerves called **pelvic splanchnic nerves** (parasympathetic), associated with the second and third or third and fourth sacral nerves, connects these spinal nerves with the pelvic plexuses of the autonomic system (pp. 1125 and 1143).

Distribution of Spinal Nerves.—Although the distribution, like the origin of the spinal nerves, presents primarily and essentially a segmental arrangement, that is masked, and in some instances obliterated, by developmental changes in the parts supplied. In no region can an isolated nerve be traced to a complete segment. The nearest approach to a complete girdle of innervation is found in the thoracic region, in such a nerve as the sixth thoracic nerve. Yet even such a nerve is not distributed to any part entirely alone. In its *cutaneous distribution* it supplies a distinctly segmental area of skin, from the median plane posteriorly to the median plane anteriorly; yet at the same time the adjacent nerves overstep, so to speak, the boundaries of the area and assist in its cutaneous nerve supply. Each segmental area will then have its own proper nerve, but it will have also the overlapping innervation of the segmental nerves immediately above and below. The trunk and the limbs may, with the above qualification, be mapped out into segmentally supplied strips of skin called **dermatomes**; these are arranged with some considerable regularity in the trunk where the segmental pattern has not been greatly altered in development. In the limbs, however, distortion of the segmental areas has resulted from the growth of the limb-buds, and the dermatomes (Figs. 929 and 942) no longer show the simplicity they exhibit in the trunk (see M.R.C. War Memo. No. 7, 1942). It must be clearly understood that to denervate a dermatome would necessitate the section of its own nerve and also of those of the immediately adjacent dermatomes above and below. (See Head, 1893; Foerster, 1933; and Keegan & Garrett, 1948.)

In "shingles" [*cingulum* = a girdle] or *herpes zoster*, the cutaneous distribution of a thoracic nerve may be marked out, partially or completely, by a characteristic vesicular eruption which is due to a specific kind of inflammation of the spinal ganglion. Herpes may occur also in the cutaneous areas of distribution of the fifth and seventh cranial nerves (p. 1033).

The *muscular distribution*, also, of a spinal nerve is segmental; the anterior primary ramus supplies the intercostal muscles of the space in which it lies; but in its course it forms communications with adjacent nerves. The posterior primary ramus supplies axial muscles of the back; not, however, in an obviously segmental manner, on account of the fusion of the segmental myotomes in the formation of complex longitudinal muscles, which are together supplied by the series of muscular branches derived from the posterior primary rami of contiguous nerves. In other regions still greater changes of structure are accompanied by deviations from a segmental type of distribution, causing the foundation of the nerve-plexuses by which the trunk and limbs are innervated.

When describing the distribution of nerves, it is important to bear in mind that the descriptions "muscular" and "cutaneous" applied to branches may be misleading. Muscular branches contain afferent as well as efferent fibres, and so-called cutaneous branches are invariably distributed to the neighbouring subcutaneous fascia as well as

skin. In certain regions—for example, the digits—they supply filaments to joints also. Further, efferent fibres of the sympathetic nervous system accompany both muscular and cutaneous nerves.

POSTERIOR PRIMARY RAMI OF SPINAL NERVES

The **posterior primary rami** of the spinal nerves innervate skin, fascia, and muscles: the skin of the trunk posteriorly, the back of the head, the shoulder and the gluteal region; and the longitudinal muscles of the back, but not the muscles of the limbs.

Each posterior ramus divides as a rule into two parts—a **medial** and a **lateral branch** (Fig. 913, p. 1050). In the upper half of the body the medial branches generally supply the cutaneous fibres, while the lateral trunks are purely muscular nerves. In the lower part of the body the opposite is the case: the lateral branches provide the cutaneous nerves and the medial branches are distributed entirely to muscles. The cutaneous nerves have a different course in the two cases. In the upper half of the back they course backwards deep to and among the muscles to within a short distance of the spines of the vertebræ, close to which they become superficial. They then extend laterally in the superficial fascia. In the lower half of the back the cutaneous nerves are directed downwards and laterally among the muscles, and become superficial at a greater distance from the median plane. In both regions the nerves pursue a sinuous course to the surface, and the lower series emerge and become superficial a considerable distance below the level of their origin. There are considerable individual differences in the origin, course, and distribution of the several nerves.

CERVICAL NERVES

First Cervical Nerve.—The posterior root of this nerve may be small or even absent. Its *posterior primary ramus* is larger than the anterior ramus; it does not divide into medial or lateral branches, and it does not directly supply any cutaneous branch.

Passing backwards, in the space between the occipital bone and the posterior arch of the atlas, the nerve enters the suboccipital triangle, and is placed below and behind the vertebral artery, and under cover of the semispinalis capitis muscle. It supplies the following branches:—

(*a*) **Muscular branches** to the semispinalis capitis, rectus capitis posterior major and minor, and obliquus capitis superior and inferior.

(*b*) A **communicating branch** descends to join the second cervical nerve.

The communicating branch may arise in common with the nerve to the obliquus inferior and reach the second cervical nerve by piercing or passing superficial or deep to that muscle; or it may accompany the nerve to the semispinalis capitis and communicate with the greater occipital nerve, under or over that muscle.

Second Cervical Nerve.—The *posterior primary ramus* of this nerve is larger than the anterior primary ramus. It passes backwards between the atlas and axis, in the interval between the obliquus inferior and the semispinalis cervicis muscles, and under cover of the semispinalis capitis muscle. In that situation the nerve gives off several small muscular and communicating branches. The main trunk, after piercing the semispinalis capitis and trapezius muscles, accompanies the occipital artery to the scalp as the **greater occipital nerve**. This is the chief cutaneous nerve for the posterior part of the scalp. It enters the superficial fascia at the level of the superior nuchal line of the occipital bone and about an inch from the external occipital protuberance. Ramifying over the surface, it supplies the skin and subcutaneous tissues of the scalp as far as the vertex. It *communicates* on the scalp with the following nerves: great auricular, lesser occipital, posterior auricular, and third occipital. At the vertex it reaches the area of cutaneous supply of the ophthalmic division of the fifth cranial nerve.

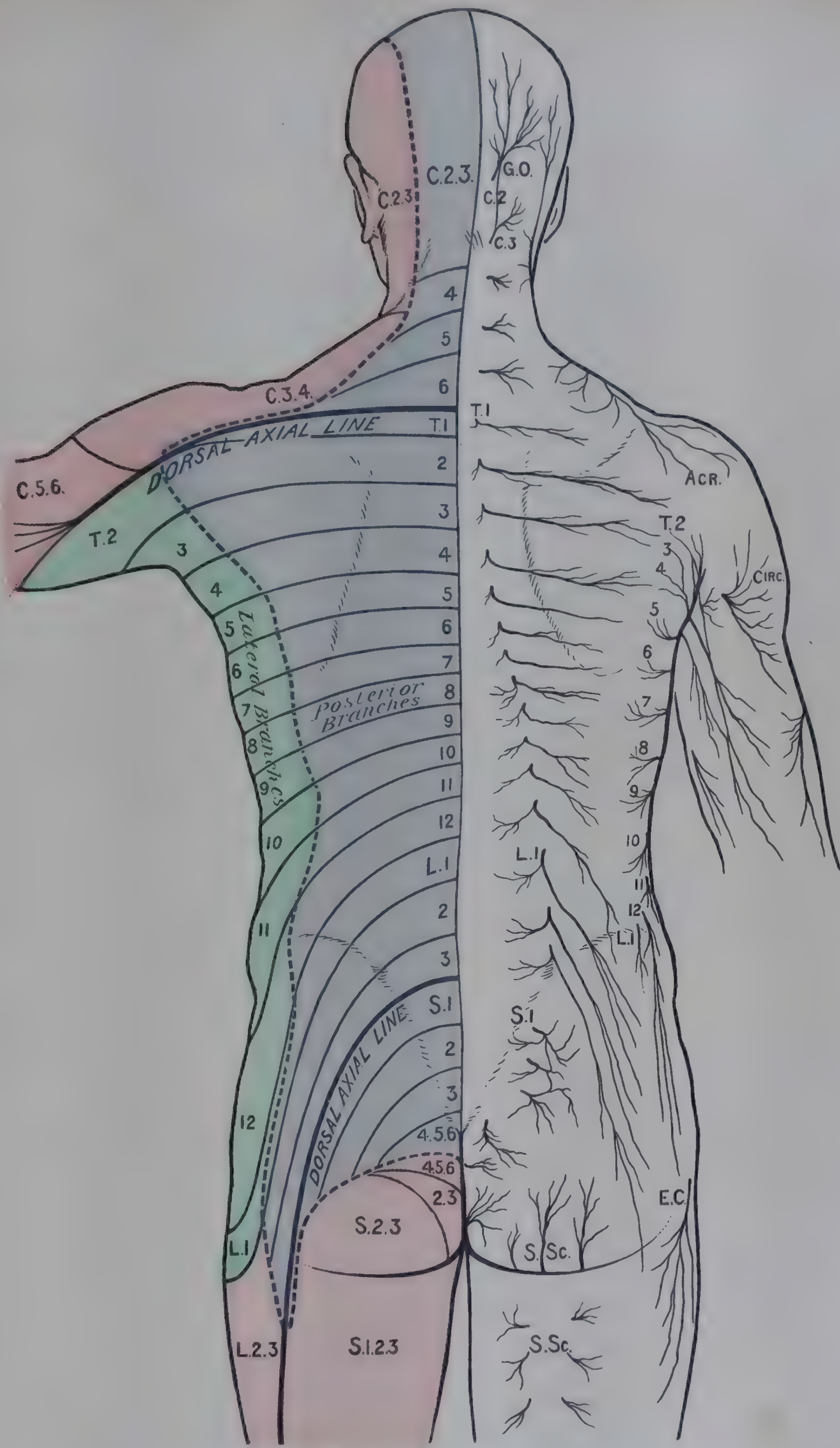

FIG. 916.—DISTRIBUTION OF CUTANEOUS NERVES ON THE BACK OF THE TRUNK.

On the right side of the figure the distribution of the several named nerves is represented.

G.O. (C.2), Greater occipital; C.3, Third occipital; T.1, L.1, S.1 *et seq.*, Posterior primary rami of thoracic, first three lumbar, and sacral nerves; Acr., Supraclavicular branches from cervical plexus; T.2-12. Lateral branches of thoracic nerves; Circ. Cutaneous branches of circumflex nerve; L.1, Lateral cutaneous branch of ilio-hypogastric nerve; E.C., Lateral cutaneous nerve of thigh; S.Sc., Posterior cutaneous nerve of thigh.

On the left side a schematic representation is given of the segmental areas (dermatomes) supplied by the above nerves, the numerals indicating the spinal origin of the branches of distribution to each area. For the lower part of the trunk and upper part of the thigh, cf. Figs. 942 and 945, based on more recent clinical data.

The **muscular branches** of the second cervical nerve are destined for the semispinalis capitis, obliquus inferior, semispinalis cervicis, and multifidus.

Associated with the posterior primary ramus is the **posterior cervical plexus**. Descending over the posterior arch of the atlas is a branch from the first cervical nerve which forms a loop or network with a branch of the second nerve. From that loop twigs are supplied to

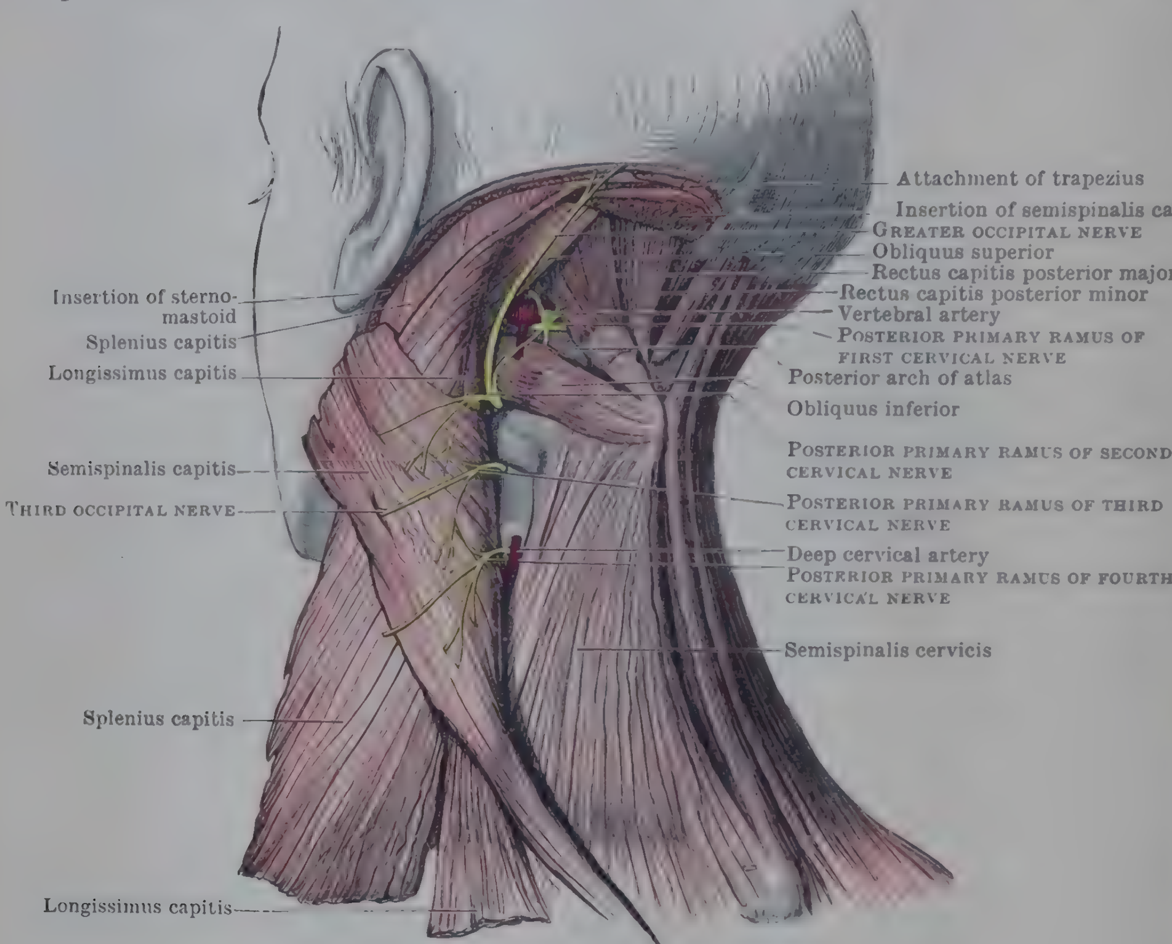

FIG. 917.—POSTERIOR CERVICAL PLEXUS.

the surrounding muscles. A similar loop is formed by a communication between the posterior primary rami of the second and third nerves, from which also muscles are supplied. Occasionally an additional loop is formed between the posterior primary rami of the third and fourth nerves.

Third Cervical Nerve.—This *posterior primary ramus* is much smaller than that of the second nerve. Near its origin it forms a loop of communication with the second, and it may give off a similar communicating branch to the fourth nerve. The main trunk divides into a medial, cutaneous branch, and a lateral, muscular, branch. The lateral branch enters contiguous muscles; the medial branch passes backwards and medially and becomes superficial as the **third occipital nerve** close to the median plane of the neck. It supplies fine branches to the skin and fascia of the neck and scalp, and it communicates with the greater occipital nerve.

The **posterior primary rami** of the **fourth, fifth, and sixth cervical nerves** are still smaller. Deep to the semispinalis capitis each divides into a lateral (muscular) and a medial (cutaneous) branch. The muscular branches supply neighbouring muscles; the cutaneous branches are small nerves which pass backwards and become superficial close to the median plane. They supply the skin of the back of the neck. The sixth is the smallest, and the cutaneous branches of the fifth and sixth nerves may be absent altogether. In certain cases the fourth nerve forms, with the third, a loop of communication from which muscles are supplied.

Seventh and Eighth Cervical Nerves.—These are the smallest of the posterior primary rami of the cervical nerves. They give off ordinarily no cutaneous branches, and they end in the deep muscles of the back. There is occasionally a small cutaneous offset from the eighth nerve.

THORACIC NERVES

The *posterior primary ramus* of each thoracic nerve divides into a **medial** and a **lateral branch.** The medial branches of the upper six or seven thoracic nerves are distributed chiefly as *cutaneous* nerves—their muscular twigs being very small—while the lateral branches are *muscular* in their distribution; in the case of the lower five or six thoracic nerves the opposite is the case. In all of them the muscular branches innervate the longitudinal muscles of the back. The distribution of the cutaneous branches is therefore different in the upper and lower part of the back. The **medial cutaneous branches** of the *upper six* or *seven* thoracic nerves innervate the skin and fascia of the scapular region; after a sinuous, backward course among the dorsal muscles, they reach the surface near the spines of the vertebræ and are directed laterally and almost horizontally over the trapezius muscle. The first is small; the second is very large and reaches the acromion. The rest diminish in size from above downwards, and become more and more oblique in direction. The **lateral cutaneous branches** of the *lower five* or *six* thoracic nerves are directed from their origin obliquely downwards and laterally among the parts of the sacro-spinalis muscle. Becoming cutaneous after piercing the latissimus dorsi at some distance from the median plane, they supply the skin and fascia of the back in the lower part of the chest and loin, the lowest nerves (eleventh and twelfth) passing over the iliac crest into the gluteal region. The lower nerves often divide into two branches before or after they emerge from the latissimus dorsi muscle. Owing to the obliquity of their course, each of those cutaneous branches supplies an area of skin which lies at an increasingly lower level than does the posterior primary ramus from which the branch arises, thus accounting for the change in the disposition of the dermatomes, compared with the more horizontal arrangement in the upper thoracic region (Fig. 916).

LUMBAR NERVES

The *posterior primary rami* of the **first three lumbar nerves** divide into medial and lateral branches in the same way as the lower thoracic nerves. The medial branches are muscular and innervate the deep muscles of the back. The lateral branches are chiefly cutaneous. They are directed obliquely downwards and laterally among the fibres of the sacro-spinalis and become superficial by piercing the lumbar fascia just above the iliac crest and a short distance in front of the posterior superior iliac spine. They are then directed downwards in the superficial fascia of the gluteal region, and supply a lengthy strip of skin, extending from the median plane above the iliac crest to a point distal to and behind the greater trochanter of the femur. There may be only two cutaneous branches, derived from the first two lumbar nerves.

The *posterior primary rami* of the **fourth and fifth lumbar nerves** (like those of the last two cervical nerves) usually supply only muscular branches to the longitudinal muscles of the back. The fifth nerve in many cases sends a branch to form a loop of connexion with the posterior primary ramus of the first sacral nerve, contributing to the posterior sacral plexus.

SACRAL AND COCCYGEAL NERVES

The *posterior primary rami* of the sacral nerves issue from the posterior sacral foramina. As in the case of the thoracic and lumbar nerves, the upper sacral nerves differ from the lower in their distribution.

The *posterior primary rami* of the **first three sacral nerves** supply medial muscular branches for the multifidus and lateral cutaneous branches which pierce the fibres of the sacro-tuberous ligament and the gluteus maximus muscle, and supply the skin and fascia over the back of the sacrum and contiguous part of the gluteal region, giving rise to the posterior sacral plexus.

The **posterior sacral plexus** consists, like the posterior cervical plexus, of loops or plexiform communications over the back of the sacrum between the posterior primary rami

of the first three sacral nerves, to which are frequently joined branches of the last lumbar nerve and the fourth and even the fifth sacral nerve. From those loops branches proceed to supply the multifidus muscle; others pierce the sacro-tuberous ligament and form secondary loops deep to the gluteus maximus muscle. From the secondary loops two or more cutaneous branches arise, which, after traversing the muscle, supply the skin and fascia over the sacrum and medial part of the gluteal region.

The *posterior primary rami* of the **fourth and fifth sacral nerves** do not divide into medial and lateral branches. They unite together to form a loop which is joined by the minute *posterior primary ramus* of the **coccygeal nerve.** The union of the three constitutes a nerve which, after perforating the sacro-tuberous ligament, is distributed to the skin and fascia in the neighbourhood of the coccyx. It supplies no muscles. This nerve is the representative of the **superior caudal trunk** of tailed animals.

Morphology of Posterior Primary Rami

1. Muscular Distribution.—In their muscular distribution they are strictly limited to the longitudinal muscles of the back: namely, those associated with the axial skeleton alone.

2. Cutaneous Distribution.—Their cutaneous distribution presents two points of interest.

A. In the first place, while the skin of the back is supplied in a fairly regular segmental manner by the several nerves, certain of them fail to reach the surface at all. The absence of a cutaneous branch from the first cervical nerve may be due either to the absence of a perfect posterior root, or to its communication with the second nerve. The other nerves which do not usually supply the skin are the last two, three, or four cervical, and the fourth and fifth lumbar nerves. Those nerves are placed in the centre of regions in which the upper and lower limbs are developed. They are minute nerves, while the corresponding anterior primary rami are among the largest of the spinal nerves. Thus opposite the centre of each limb posteriorly there is a hiatus in the segmental distribution of the posterior primary rami of the spinal nerves to the skin of the shoulder and gluteal region, attributable to the formation of the limbs and the extension into them of the greater part of the nerves of the region. The gap, in the case of the upper limb, begins at the level of the vertebra prominens; in the case of the lower limb it commences at the level of the posterior superior iliac spine. It can be continued on to each limb as a hypothetical area (the **dorsal axial line**) which indicates the area of contact (and overlapping) of cutaneous nerves not in strictly numerical sequence. Thus, in the region of the shoulder, the sixth (or fifth) cervical nerve innervates an area of skin adjoining that supplied by the eighth cervical or first thoracic nerve; in the gluteal region the third lumbar nerve supplies an area contiguous with that supplied by the fifth lumbar or first sacral nerve (Fig. 916).

B. The cutaneous branches of the posterior primary rami of the spinal nerves differ from the muscular branches in respect of their penetration into regions beyond those supplied by their motor roots. The cutaneous branches, in regions where outgrowths or extensions from the trunk have occurred, follow those extensions; and, in consequence, supply skin covering parts which do not belong to segments represented by the nerves in question. Thus the second and third cervical nerves (greater and third occipital) are drawn upwards so as to supply the posterior part of the *scalp*; the upper thoracic nerves are drawn laterally over the *scapular region*; the upper lumbar and sacral nerves supply the skin of the *gluteal region*; and the lower lumbar and coccygeal nerves form a rudimentary *caudal nerve.*

3. Plexuses.—The plexuses formed by the posterior primary rami of the upper cervical and upper sacral nerves are the simplest met with in the human body. The posterior cervical plexus is one from which muscular branches are supplied; the posterior sacral plexus is mainly concerned with cutaneous offsets.

ANTERIOR PRIMARY RAMI OF SPINAL NERVES

The **anterior primary rami** of the spinal nerves are, with the exception of the first two cervical nerves, much larger than the posterior primary rami. Composed of elements of both posterior and anterior roots, each nerve separates from the posterior primary ramus on emerging from the intervertebral foramen, and, proceeding laterally, is distributed to structures on the lateral and anterior aspects of the body—including the limbs.

Each nerve is joined near its origin by a **grey ramus communicans** from the corresponding sympathetic trunk; and in the case of the thoracic and certain lumbar nerves the anterior primary ramus gives off a delicate bundle of fibres which forms the **white ramus communicans** to the sympathetic trunk. From two of the sacral nerves white rami (belonging to the parasympathetic) pass to the pelvic plexuses of the autonomic nervous system; those rami form the *pelvic splanchnic*

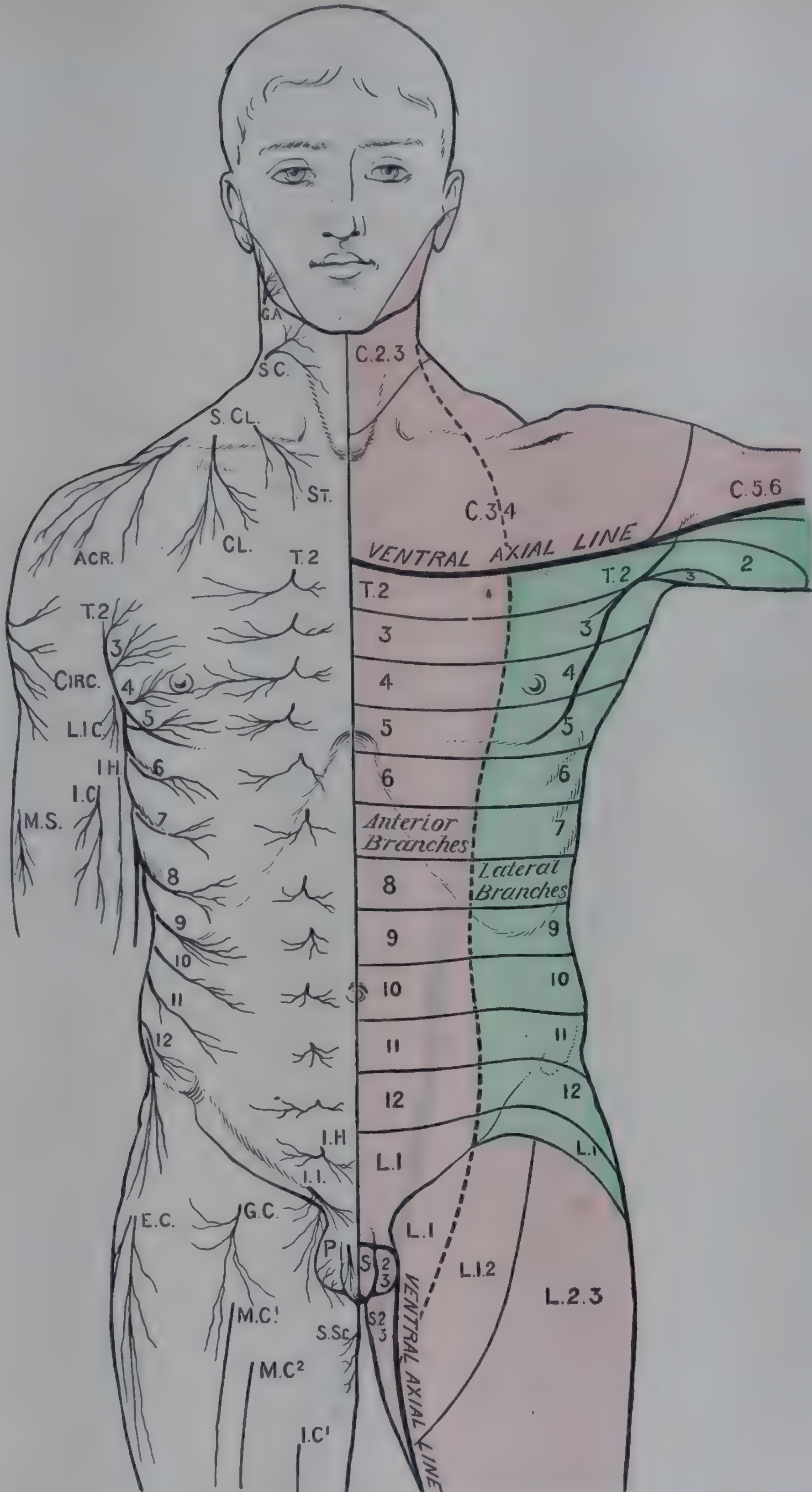

Fig. 918.—Distribution of Cutaneous Nerves on the Front of the Trunk.

On the left side of the figure the distribution of the several named nerves is represented.

G.A., Great auricular nerve; S.C., anterior cutaneous nerve of the neck; S.Cl., Supraclavicular nerves:—Acr., Lateral; Cl., Intermediate; St., Medial. T.2-12, Lateral and anterior branches of thoracic nerves; I.H. (below) Ilio-hypogastric nerve; I.I., Ilio-inguinal nerve; Circ., Cutaneous branch of circumflex nerve; L.I.C., Medial cutaneous nerve of the arm; I.H. (above) Intercosto-brachial; I.C., Medial cutaneous nerve of the forearm; M.S., Cutaneous branch of radial nerve; E.C., Lateral cutaneous nerve of thigh; G.C., Femoral branch of genito-femoral nerve; M.C.[1], [2], Branches of intermediate cutaneous nerve of thigh; I.C.[1], Branch of medial cutaneous nerve of thigh; P., Branches of pudendal nerve; S.Sc., Branches of posterior cutaneous nerve of the thigh.

On the right side a schematic representation is given of the segmental areas (dermatomes) supplied by the above nerves, the numerals indicating the spinal origin of the branches of distribution to each area. For the lower part of the trunk and upper part of the thigh, cf. Fig. 942, based on more recent clinical data.

nerve on each side as they extend towards the plexuses. That part of a spinal nerve which is distributed to the skeletal musculature and skin of the body-wall and limbs may be termed **somatic** ; the small white ramus communicans, innervating structures in the splanchnic area as well as blood-vessels and sweat-glands in the body-wall and limbs, may be termed the **visceral** or **splanchnic** part of a spinal nerve.

The anterior primary rami of the spinal nerves are distributed in a regular segmental manner only in certain cases. Except in the case of the thoracic nerves, the anterior primary rami combine to form **plexuses**—cervical, brachial, and lumbar, sacral and coccygeal—and their arrangement and distribution is exceedingly complex.

An **intercostal nerve,** such as the fifth or sixth, may be regarded as a type to illustrate the mode of distribution of the anterior primary rami of the spinal nerves (Fig. 913, p. 1050). It occupies an intercostal space; near its origin it possesses *grey* and *white rami communicantes*; it courses through the interval between the innermost and internal intercostal muscles and occupies the subcostal groove of the upper rib bounding the space; it supplies branches to those muscles and gives off, when it reaches the side of the chest, a large *lateral cutaneous branch*, which, after supplying small muscular branches, pierces the overlying intercostal muscles and is distributed to an area of skin and fascia over the lateral part of the trunk contiguous dorsally with a similar area innervated by the cutaneous branches of the posterior primary ramus of the same nerve. The lateral branch generally divides into a smaller *posterior* and a larger *anterior branch* as it pierces the muscles clothing the wall of the chest. The main trunk of the nerve, having given off its lateral branch, then pursues its course obliquely forwards to the side of the sternum, where, after piercing the pectoral muscles, it terminates superficially as the anterior cutaneous branch. A *collateral branch* of the main nerve is commonly present and runs close to the lower rib of the space concerned (Davies, Gladstone & Stibbe, 1932). It may arise quite far back in the space and continue as a separate trunk to the anterior end of the space and there become cutaneous, or it may rejoin the main nerve in its course round the chest-wall. The *anterior cutaneous branch* supplies an area of skin and fascia continuous with that

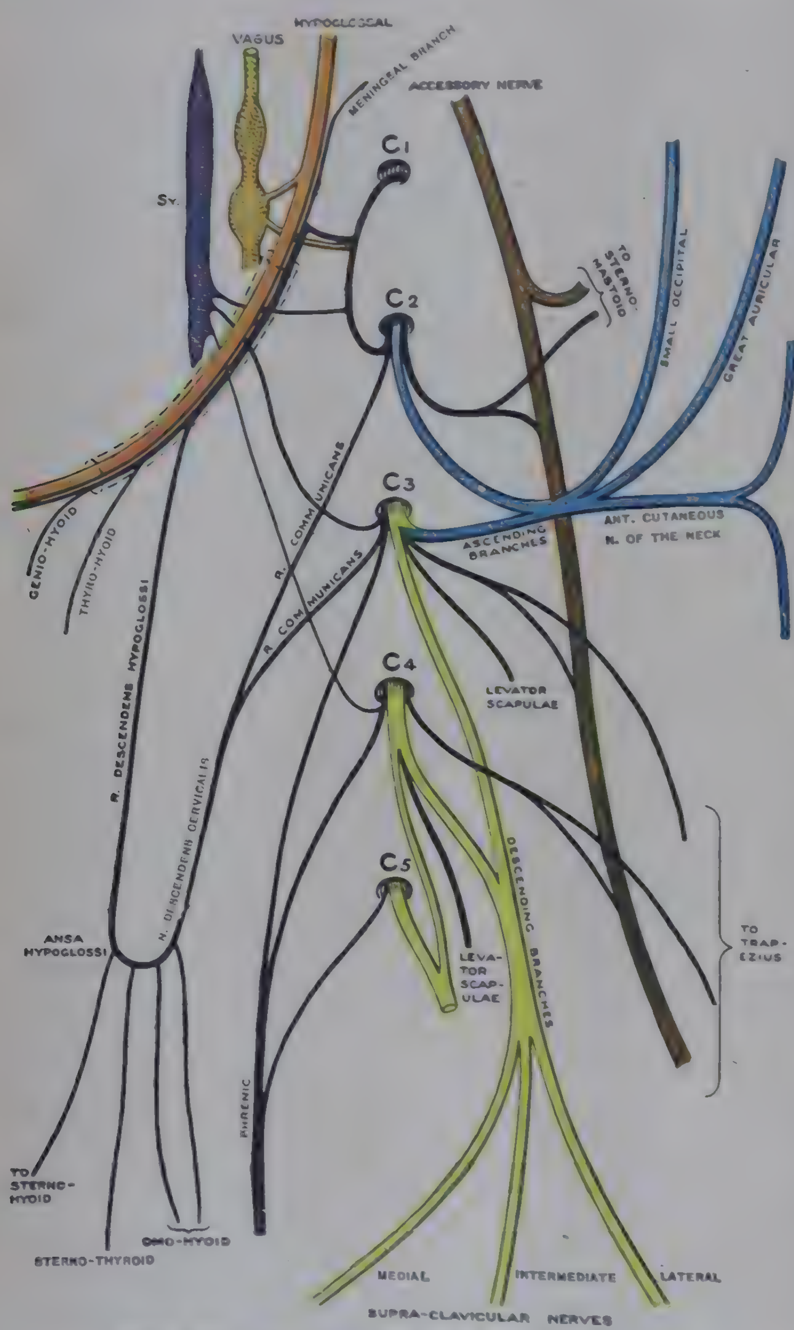

FIG. 919.—DIAGRAM OF LEFT CERVICAL PLEXUS.

supplied by the anterior part of the lateral branch of the same nerve. Such a nerve thus supplies, by means of its lateral and anterior branches, an area of skin which (with the area supplied by the cutaneous branch of its posterior primary ramus) forms a continuous and uninterrupted belt (*i.e.*, a dermatome), extending from the median plane behind to the median plane in front. The lateral and anterior branches of the nerve innervate in their course the intercostal and other muscles, to be mentioned in detail later.

CERVICAL NERVES

The *anterior primary rami* of the cervical nerves, together with parts of the first and second thoracic nerves, are distributed to the head, neck, and upper limb. The first four cervical nerves, by means of the **cervical plexus**, innervate the neck; the last four cervical nerves, together with a large part of the first thoracic nerve, through the **brachial plexus**, supply the upper limb. The second thoracic nerve may contribute to this plexus, and always assists in the innervation of the arm.

The *anterior primary ramus* of the **first cervical nerve** emerges from the vertebral canal by passing over the posterior arch of the atlas deep to the vertebral artery; it curves forwards round the lateral side of the upper articular process of that vertebra, lying medial to the vertebral artery, and, after passing between the rectus capitis lateralis and rectus capitis anterior, it descends in front of the transverse process of the atlas to form a loop with the ascending branch of the second cervical nerve. A large part of its fibres joins the hypoglossal nerve (*vide infra*).

The *anterior primary ramus* of the **second cervical nerve** passes between the vertebral arches of the first two vertebræ, behind the upper articular process of the axis. It curves forwards on the lateral side of the vertebral artery and divides into an ascending portion, which unites with the first cervical nerve and also contributes fibres to the hypoglossal nerve, and a descending part, which joins the third cervical nerve and takes part in the cervical plexus.

CERVICAL PLEXUS

The *anterior primary rami* of the first four cervical nerves are concerned in forming the **cervical plexus.** Each nerve emerges from the vertebral canal posterior to the vertebral artery. Each is joined on its emergence from the intervertebral foramen at the side of the vertebral column by one or more **grey rami communicantes** from the superior cervical ganglion of the sympathetic trunk. In the neck the cervical nerves are concealed at their origins by the sterno-mastoid muscle; in front lies the longus capitis muscle, and behind are the scalenus medius, and (behind the first nerve) the rectus capitis lateralis. The cervical plexus is constituted by the combination of the four nerves in an irregular series of loops under cover of the sterno-mastoid muscle and overlapped by the internal jugular vein.

From the loops of the plexus the branches of distribution arise, as (*a*) **cutaneous branches** to the head, neck, and shoulder; (*b*) **muscular branches** to muscles of the neck and to the diaphragm; and (*c*) **communicating branches** to the vagus, accessory, hypoglossal, and sympathetic nerves (Figs. 919, 922).

For convenience of description, the nerves derived from the plexus may be classified as follows:—

I. Superficial (Cutaneous) Branches—

A. **Ascending Branches** (C. 2, 3).
Lesser occipital,
Great auricular,
Anterior cutaneous of the neck.

B. **Descending (supraclavicular) Branches** (C. 3, 4).
Medial supraclavicular,
Intermediate supraclavicular,
Lateral supraclavicular.

II. Deep (Muscular and Communicating) Branches—

A. Lateral Branches.

1. Muscular branches to
   Sterno-mastoid (C. 2),
   Trapezius (C. 3, 4),
   Levator scapulæ (C. 3, 4),
   Scaleni (medius and posterior) (C. 3, 4).
2. Communicating branches to
   Accessory nerve (C. 2, 3, 4).

B. Medial Branches.

1. Muscular to
   Prevertebral muscles (C. 1, 2, 3, 4),
   Infrahyoid muscles (C. 1, 2, 3) (ansa hypoglossi),
   Diaphragm (C. 3, 4, 5) (phrenic nerve).
2. Communicating branches to
   Vagus nerve (C. 1, 2),
   Hypoglossal nerve (C. 1, 2),
   Ansa hypoglossi (C. 2, 3),
   Sympathetic (C. 1, 2, 3, 4).

The second, third, and fourth cervical nerves are the chief nerves engaged in forming the plexus.

Superficial Cutaneous Branches.—These nerves, six in number, are entirely cutaneous. They radiate from the plexus, and appear in the posterior triangle of the neck a little above the mid-point of the posterior border of the sterno-mastoid muscle. They are divisible into two series—(1) the **ascending**: lesser occipital, great auricular, and the anterior cutaneous nerve of the neck; (2) **descending** (supraclavicular): lateral, intermediate and medial.

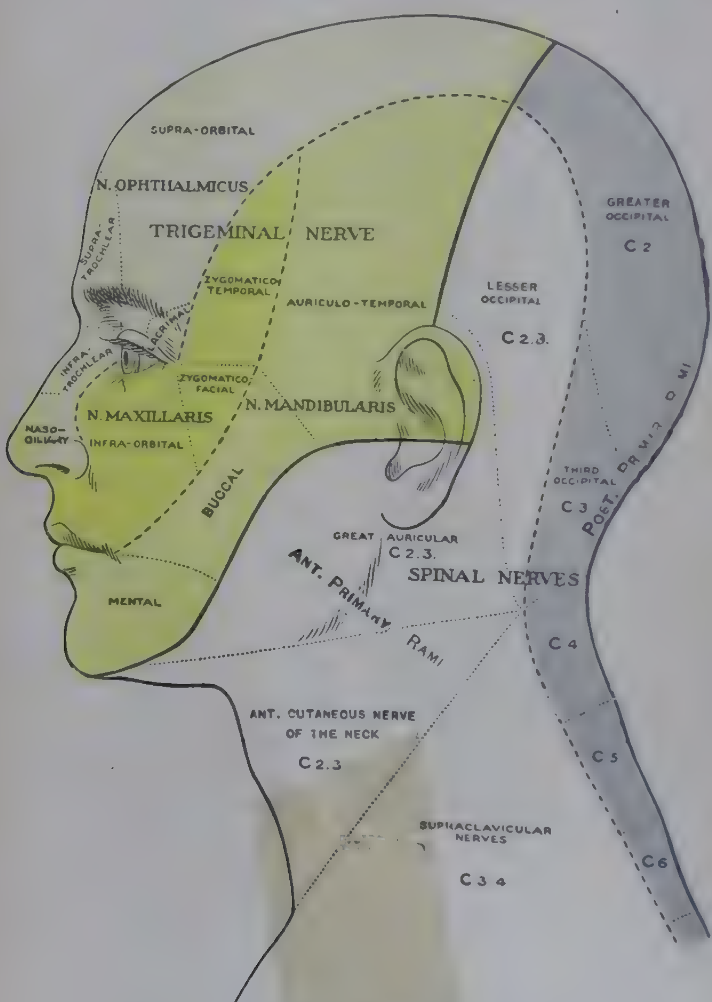

FIG. 920.—DISTRIBUTION OF CUTANEOUS NERVES TO HEAD AND NECK.

Ascending Branches.—The **lesser occipital nerve** is variable in size and is sometimes double. Its origin is from the second and third cervical nerves (more rarely from the second only). It extends backwards under cover of the sterno-mastoid, and then upwards along its posterior border. Piercing the deep fascia near the apex of the posterior triangle, it divides into branches for the supply of the skin and fascia of the upper part of the neck, the cranial surface of the auricle and part of the scalp adjoining. The nerve communicates on the scalp with the greater occipital and great auricular nerves, and with the posterior auricular branch of the facial nerve.

The **great auricular nerve** is the largest of the cutaneous branches. It arises from the second and third cervical nerves (or, more rarely, from the third alone). Winding round the posterior border of the sterno-mastoid muscle, it proceeds upwards and forwards towards the front of the auricle. In its course it crosses the sterno-mastoid muscle obliquely and is covered by the platysma muscle. Before arriving at the auricle it subdivides into three groups of branches. The posterior ascend over the mastoid process and supply the skin and fascia of the scalp immediately behind the auricle, communicating with the lesser occipital

and posterior auricular nerves. The middle ones ascend to the auricle and supply its lower part on both surfaces; their communications are similar to those of the posterior branches. The anterior pass over the angle of the mandible and through the substance of the parotid gland to supply the skin and fascia of the face over the inferior part of the masseter muscle and the parotid gland. They communicate with branches of the facial nerve in the parotid gland.

The **anterior cutaneous nerve of the neck** arises from the second and third cervical

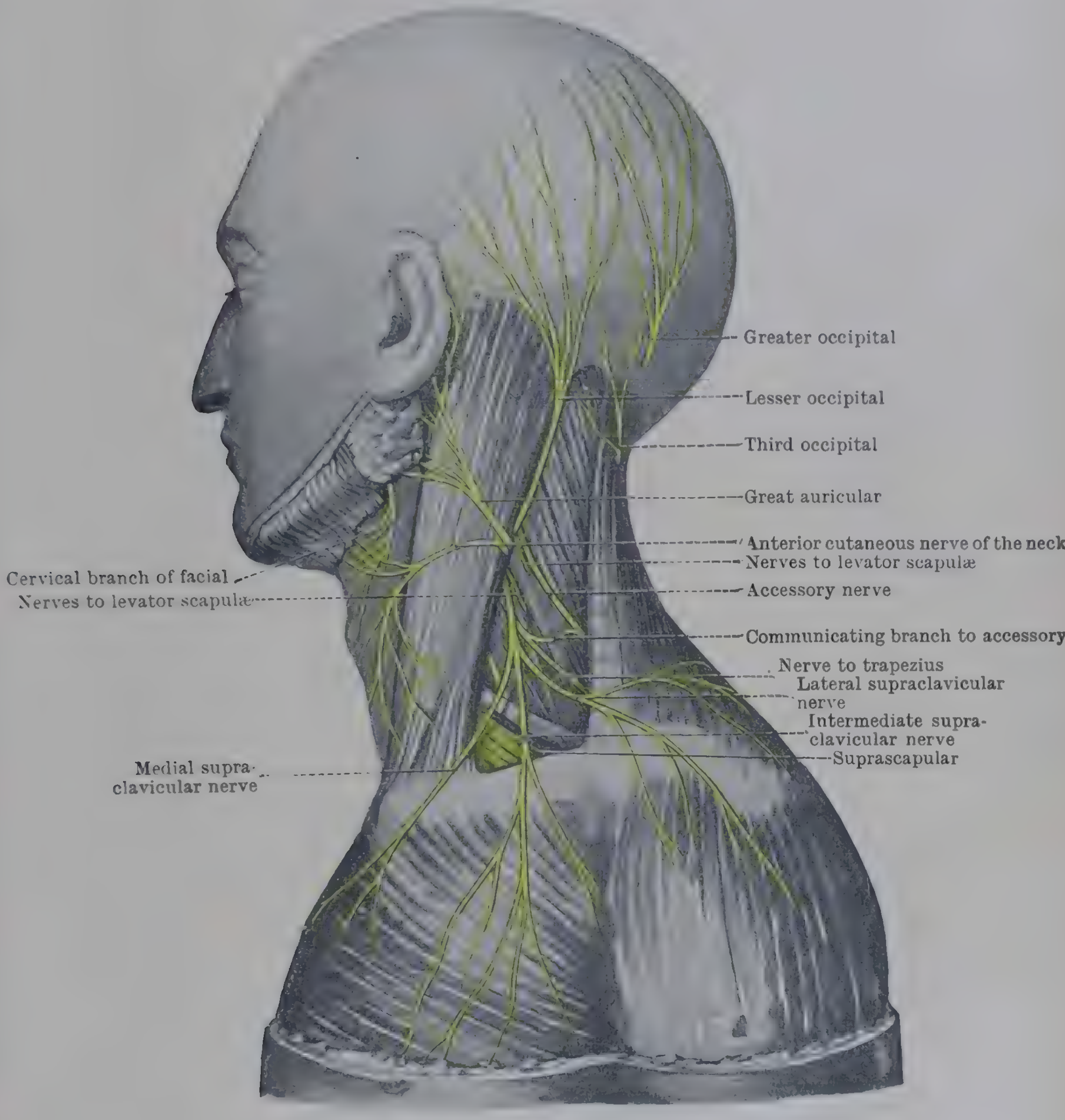

FIG. 921.—NERVES OF SIDE OF NECK.

nerves. It winds round the posterior border of the sterno-mastoid muscle, and crosses the muscle to reach the anterior triangle, under cover of the platysma muscle and the external jugular vein. It divides near the anterior edge of the sterno-mastoid muscle into superior and inferior branches which are distributed through the platysma to the skin and fascia covering the anterior triangle of the neck. The upper branches communicate freely, under cover of the platysma, with the cervical branch of the facial nerve.

Descending (Supraclavicular) Branches.—By the union of two roots derived from the third and fourth cervical nerves a considerable trunk is formed which emerges from under cover of the sterno-mastoid muscle and extends obliquely downwards through the inferior part of the posterior triangle of the neck. It subdivides into radiating branches—**medial, intermediate,** and **lateral**—which pierce the deep fascia of the neck above the clavicle, and are distributed to the skin and fascia

of the inferior part of the side of the neck, to the front of the chest, and the shoulder. The **medial branches** are the smallest. They pass over the medial part of the clavicle, and supply the skin and fascia of the neck and chest as far down as the angle of the sternum. Twigs of supply are given also to the sterno-clavicular joint. The **intermediate branches** pass over the intermediate third of the clavicle, deep to the platysma, and can be traced as low as the third rib. These branches may groove the clavicle, and one of them may even pierce it. The **lateral branches** pass over or through the insertion of the trapezius muscle and over the lateral third of the clavicle to the shoulder, where they supply the skin and fascia as far down as the distal third of the deltoid muscle. Occasionally one of these branches pierces the clavicle. Small twigs assist in the supply of the acromio-clavicular joint.

Deep Branches.—The deep branches of the cervical plexus are separated into a **lateral** and a **medial set**. Deep to the sterno-mastoid muscle, the lateral branches are directed laterally towards the posterior triangle; the medial branches pass medially towards the anterior triangle.

The **lateral branches** consist of muscular and communicating nerves, which for the most part lie in the posterior triangle.

The **muscular branches** are the following: (1) To the *sterno-mastoid*, from the second cervical nerve; it enters the muscle on its deep surface and communicates with the accessory nerve. (2) To the *trapezius*, from the third and fourth cervical nerves; these branches cross the posterior triangle and end in the trapezius, after communicating with the accessory nerve, both in the posterior triangle, and under cover of the muscle. (3) To the *levator scapulæ*, from the third and fourth cervical nerves; two independent branches enter the lateral surface of the muscle in the posterior triangle. (4) To the *scaleni* (medius and posterior), from the third and fourth cervical nerves.

The **communicating branches** are three in number. They join the accessory nerve in three situations: (*a*) A branch from the second cervical nerve to the sterno-mastoid joins the accessory nerve *under cover of that muscle.* (*b*) Branches to the trapezius from the third and fourth nerves are connected with the accessory nerve *in the posterior triangle.* (*c*) Branches from the same nerves join the accessory *under cover of the trapezius muscle.*

The **medial branches** of the plexus also comprise muscular and communicating branches. The anterior ramus of the first cervical nerve assists in the formation of this series of nerves, forming a slender loop with part of the second nerve in front of the transverse process of the atlas.

Communicating Branches.—(*a*) *With the sympathetic.*—A grey ramus communicans passes to each of the first four cervical nerves, near its origin, from the superior cervical ganglion or from the trunk below the ganglion. (*b*) *With the vagus nerve.*—The inferior ganglion of the vagus may be connected by a slender nerve with the loop between the first two cervical nerves. That communication is not constant. (*c*) *With the hypoglossal.*—An important communication occurs between the hypoglossal nerve and the loop between the first and second cervical nerves (Figs. 909, 919). A branch from the loop joins the hypoglossal just beyond its exit from the skull; some cervical fibres are then carried upwards along the hypoglossal to the cranium (*meningeal branch*), but the main group of cervical fibres descends with the hypoglossal and subsequently leaves it as three branches—the **descending branch** (ramus descendens), and the **branches to the thyro-hyoid** and **genio-hyoid muscles**. It is probable that no part of the hypoglossal nerve itself is concerned in the formation of those three branches. The descending branch of the hypoglossal descends in front of the internal and common carotid arteries, and is joined under cover of the sterno-thyroid muscle by the **nervus descendens cervicalis** which winds obliquely round the internal jugular vein to form the **ansa hypoglossi**, from which the infrahyoid muscles, except the thyro-hyoid, are innervated. (The "descending branch of the hypoglossal", in some cases, arises from the vagus nerve.)

Muscular Branches.—The muscles supplied by the medial branches of the plexus are the prevertebral muscles, the genio-hyoid and the infrahyoid muscles, and the diaphragm.

(*a*) **Prevertebral Muscles.**—(1) From the loop between the first and second cervical nerves a small branch arises for the supply of the rectus capitis lateralis, longus capitis, and the rectus capitis anterior. (2) From the second, third, and fourth nerves small branches supply the intertransverse, longus cervicis, and longus capitis muscles. (3) From the third and fourth nerves a branch arises for the supply of the scaleni (medius and posterior).

(*b*) **Genio-Hyoid and Infrahyoid Muscles.**—The **nervus descendens cervicalis** is formed in front of the internal jugular vein by the union of two slender trunks from the second and third cervical nerves. It forms a loop of communication in front of the carotid sheath with the descending branch of the hypoglossal nerve (derived ultimately from the first two cervical nerves). The loop of communication is called the **ansa hypoglossi.** It is often plexiform; and from it branches are given to the sterno-hyoid and sterno-thyroid muscles and both bellies of the omo-hyoid muscle. The nerve to the sterno-hyoid muscle is often continued behind the sternum, to join, in the thorax, with the phrenic nerve or the cardiac plexus.

The thyro-hyoid and genio-hyoid muscles are supplied by branches of the hypoglossal nerve, but the fibres concerned are derived from the loop between the first two cervical nerves.

The anterior muscles in immediate relation to the median plane of the neck, between the chin and the sternum, are thus continuously supplied by the first three cervical nerves. The hypoglossal is the source of supply to the intrinsic muscles of the tongue, and it is improbable that it contributes any fibres to the above-named muscles.

(*c*) **Diaphragm.**—The phrenic nerve supplies the diaphragm.

Phrenic Nerve

The **phrenic nerve** is derived mainly from the **fourth cervical nerve**, reinforced by roots from the third (either directly or through the nerve to the sterno-hyoid) and fifth (either directly or through the nerve to the subclavius muscle). It runs downwards in the neck upon the scalenus anterior muscle postero-lateral to the internal jugular vein; at the root of the neck it passes between the subclavian artery and vein, enters the thorax and traverses the mediastinum to reach the diaphragm, lying in the middle mediastinum between the pericardium and pleura and anterior to the root of the lung. In its course it presents certain differences on the two sides. In the neck, on the left side, it crosses the first part of the subclavian artery; on the right side it crosses the second part. On both sides after crossing the subclavian artery the nerve deviates medially and crosses in front of the internal mammary artery; occasionally on the left side the nerve may run behind that artery. In the superior mediastinum, on the left side, it lies between the left subclavian and carotid arteries, and crosses lateral to the vagus nerve and the aortic arch. On the right side it accompanies the innominate vein and superior vena cava, and has no direct relationship with the vagus nerve. The right nerve sends fibres along the inferior vena cava through the hiatus venæ cavæ. Reaching the diaphragm the nerve separates into numerous branches for the supply of the muscle; some enter its thoracic surface (subpleural branches), but most of the fibres supply it after piercing the muscle (subperitoneal branches). It is apparent, from clinical observations, that the nerve contains some afferent fibres as well as motor.

The **branches of the phrenic nerve** are:—(1) Muscular (to the diaphragm); (2) pleural (to mediastinal and diaphragmatic pleura); (3) pericardial; (4) abdominal (to diaphragmatic peritoneum and probably, through the phrenic and hepatic plexuses, to the inferior vena cava and the liver).

Of interest to the surgeon, particularly with reference to the operation of avulsion of the phrenic, is the occasional presence of an *accessory phrenic nerve.* It arises from the fifth or fifth and sixth cervical nerves and, after descending for a variable distance, joins the main nerve in the lower part of the neck or in the thorax. The accessory phrenic nerve not uncommonly arises from the nerve to the subclavius muscle.

Communications of Phrenic Nerve.—(1) As stated in the previous paragraph, the phrenic nerve may communicate with the nerve to the subclavius muscle, and with the fifth and sixth cervical nerves. (2) It may communicate with the *ansa hypoglossi*, or a branch from it (the nerve to the sterno-hyoid). (3) It frequently communicates with the cervical part of the sympathetic. (4) It communicates with the cœliac plexus by a junction on the abdominal surface of the diaphragm with the *phrenic plexus* on the phrenic artery, in which a small *phrenic ganglion* is found on the right side. From the junction branches are given off to the inferior vena cava and hepatic plexus.

Morphology of Cervical Plexus

The characteristic feature of the cervical plexus is the combination of parts of adjacent nerves into compound nerve-trunks by the formation of series of loops. The result of the formation of

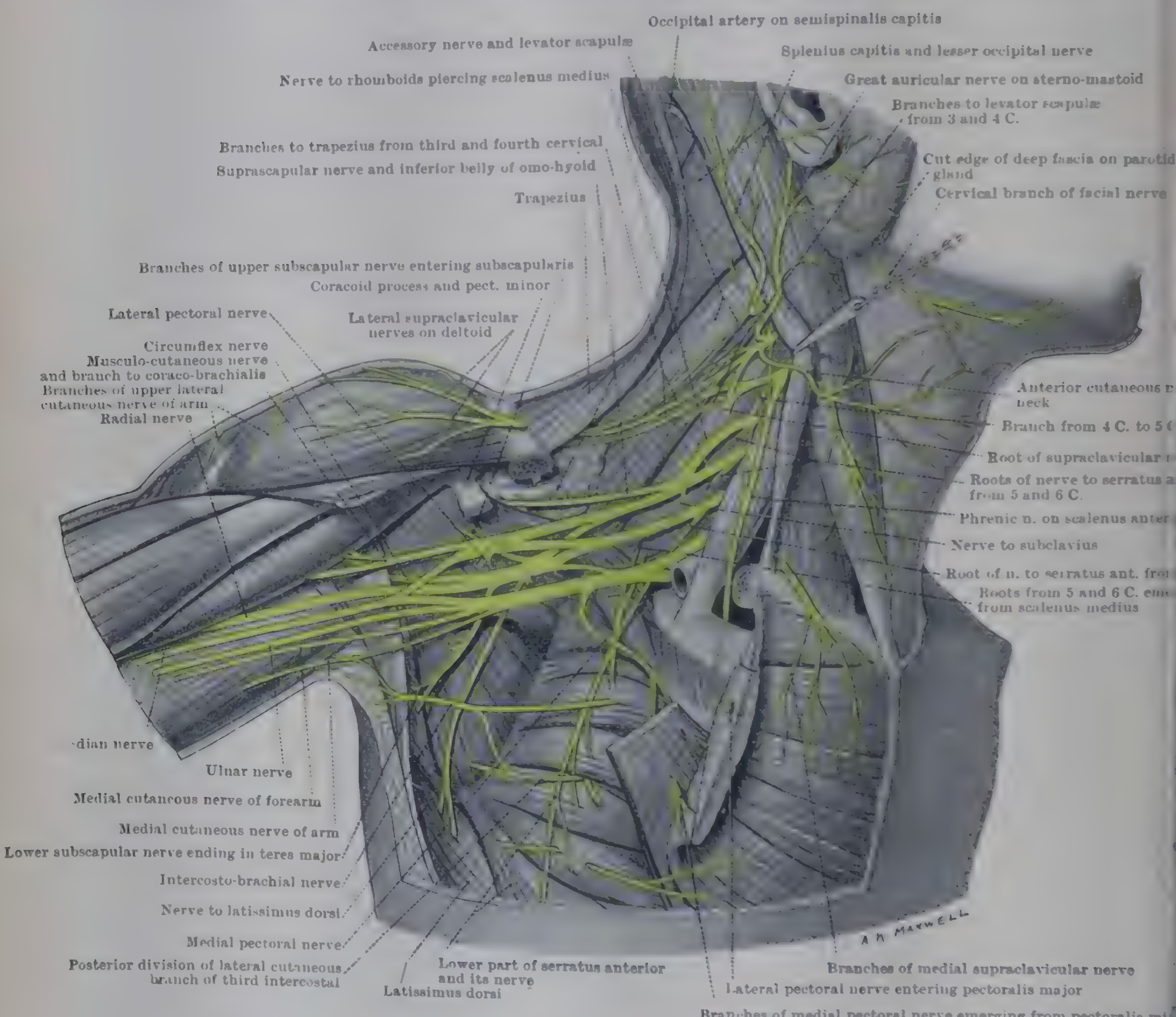

Fig. 922.—Posterior Triangle and Axilla, showing Cervical and Brachial Plexuses and Origin of their Principal Branches.

these loops is that parts (particularly cutaneous areas) are supplied by branches of more than one spinal nerve.

A. **Cutaneous Distribution.**—By the combinations of the nerves into loops the discrimination of the elements in the upper cervical nerves, corresponding to the lateral and anterior branches of a typical intercostal nerve, is made a matter of some difficulty. The second, third, and fourth nerves, through the cervical plexus, supply an area of skin extending laterally from the side of the head to the shoulder; anteriorly from the face to the level of the third rib. The higher nerves supply the upper region (second and third); the lower nerves supply the lower region (third and fourth). It is not possible to compare the individual nerves strictly with the lateral and anterior branches of an intercostal nerve. A line drawn from the auricle to the middle of the clavicle separates, however, a lateral from an anterior cutaneous area; and certain of the cutaneous nerves fall naturally into one of these two categories. The nerves homologous with the anterior continuations of the anterior branches of intercostal nerves are the anterior

cutaneous nerve of the neck and the medial branches of the supraclavicular series; those homologous with lateral branches are the lesser occipital and lateral supraclavicular branches. The great auricular and intermediate supraclavicular branches are mixed nerves, comprising elements belonging to both sets.

B. **Muscular Distribution.**—The nerves from the cervical plexus that supply muscles are simpler in their arrangement. They are not generally in the form of loops, and they are easily separated into lateral and medial series. The lateral nerves comprise the branches to the rectus capitis lateralis, sterno-mastoid, trapezius, levator scapulæ. The nerves in the medial series are those to the longus capitis, rectus capitis anterior, the hyoid muscles, and the diaphragm.

It is noteworthy that the last-named muscles—genio-hyoid, thyro-hyoid, sterno-hyoid, omohyoid, sterno-thyroid, and diaphragm—are continuously supplied by branches from the first five cervical nerves: the higher muscles by the higher nerves; the lower muscles by the lower nerves.

BRACHIAL PLEXUS

The **brachial plexus** is formed by the anterior primary rami of the fifth, sixth, seventh and eighth cervical nerves, along with the greater part of that of the first thoracic nerve. More often than not a slender branch of the fourth cervical nerve

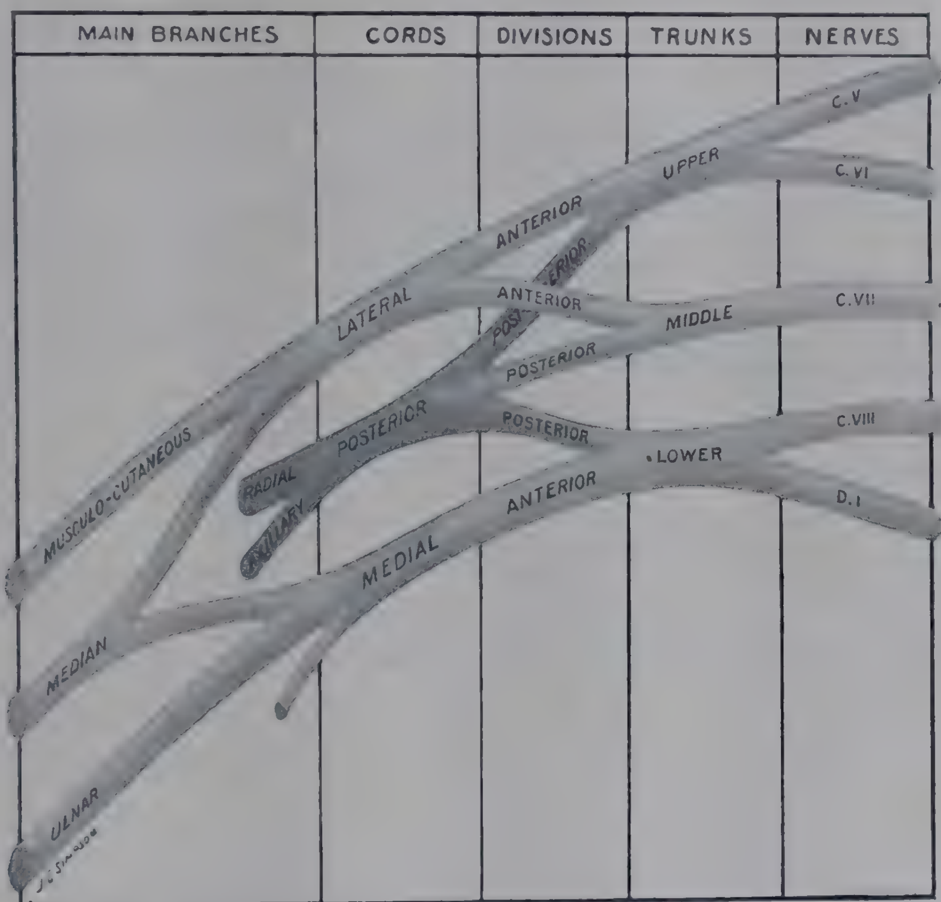

FIG. 923.—SCHEME TO SHOW STAGES OF FORMATION OF BRACHIAL PLEXUS.

is also engaged; and the second thoracic nerve always contributes to the innervation of the arm through the intercosto-brachial nerve. Frequently it contributes also directly to the plexus by an intrathoracic communication with the first thoracic nerve.

Position of the Plexus.—The nerves that contribute to the brachial plexus appear in the posterior triangle of the neck between the scalenus anterior and scalenus medius muscles in series with the nerves that form the cervical plexus (Fig. 922). In the triangle the plexus is covered by the skin, platysma, supraclavicular nerves, and the deep fascia, and is crossed by the nerve to the subclavius muscle, external jugular vein, inferior belly of the omo-hyoid muscle, and the transverse cervical artery, which vessel sometimes passes between its branches. At the root of the neck the plexus passes behind the clavicle, subclavius muscle, and suprascapular vessels, and it lies above and behind the third part of the subclavian artery. In the axilla its cords and branches surround the axillary artery.

Constitution of Brachial Plexus.—Whilst liable to some variation in the sequence of separation and junction of its individual parts, in a typical plexus four stages may always be identified:—

(1) The undivided anterior primary rami of the nerves.
(2) The formation of three trunks.
(3) The separation of each trunk into an anterior and a posterior division.
(4) The union of the divisions to form three cords from which the principal nerves of distribution originate.

(1) The undivided **nerves** or **roots of the plexus** have only a very short independent course at the side of the neck whilst passing between the scalene muscles.

(2) Immediately after entering the posterior triangle, there are formed three **trunks** in order from above downwards: the *upper trunk* is formed by the union of the fifth and sixth nerves; the *middle trunk* is always formed by the seventh

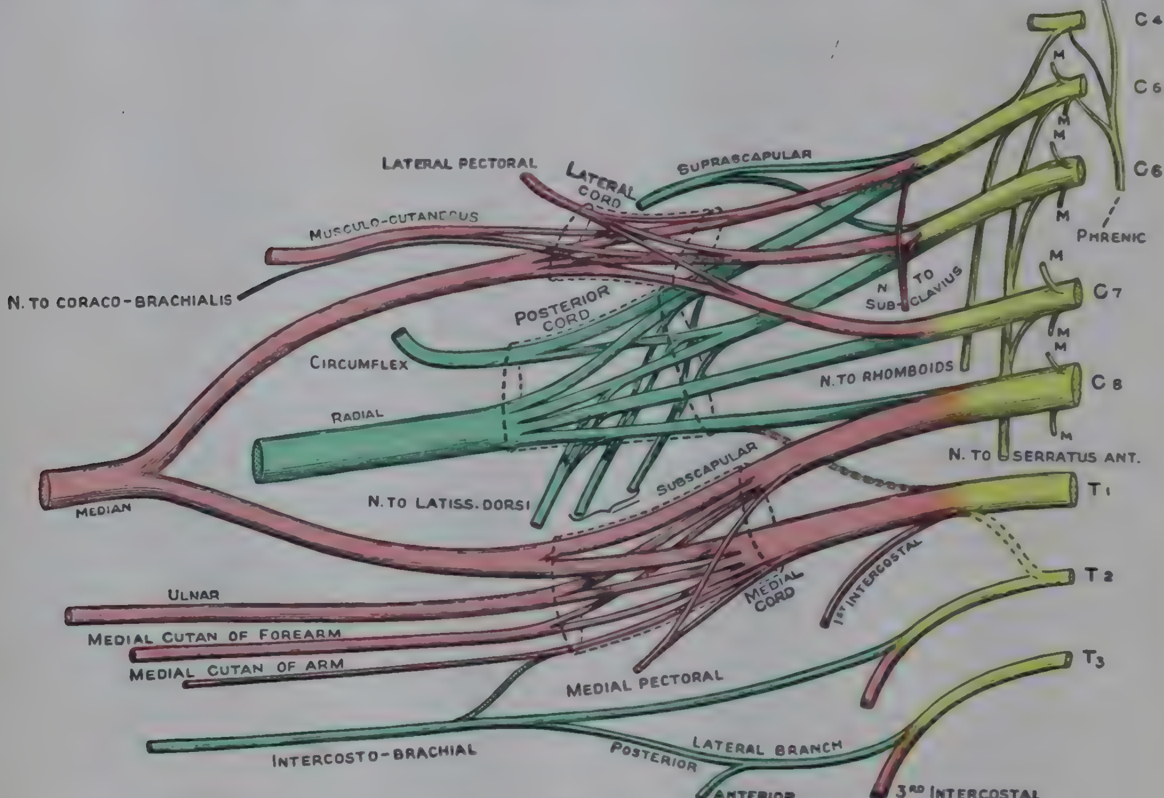

FIG. 924.—DIAGRAM OF BRACHIAL PLEXUS, SHOWING THE ORIGINS OF ITS BRANCHES.

nerve alone; and the *lower trunk*, by the union of the eighth cervical and first thoracic nerves. The lower trunk often grooves the upper surface of the first rib behind the groove for the subclavian artery.

(3) Each trunk divides into anterior and posterior **divisions**, which represent corresponding separation of the nerves; sometimes the nerves themselves divide before or during the formation of the trunks, making identification of those two stages difficult. The anterior and posterior divisions of the fifth, sixth, and seventh nerves are nearly equal in size; the posterior division of the eighth cervical nerve is much smaller; and that of the first thoracic nerve is minute and may not be present at all. The division is of morphological significance, since it indicates the separation of the nerve-fibres destined for the supply of the originally ventral parts of the limb from those which supply the dorsal parts.

(4) The **cords** of the plexus are formed by combinations of the anterior and posterior divisions. They are three in number, and lie in relation to the axillary artery. The *lateral cord* is formed by union of the anterior divisions of the upper and middle trunks, or of the fifth, sixth, and seventh nerves, and lies on the lateral side of the axillary artery. The *medial cord* is formed by the anterior division of the lower trunk, containing the corresponding division of the eighth nerve with the part of the first thoracic nerve; it lies on

the medial side of the axillary artery. The *posterior cord* is made up of the posterior divisions of all three trunks, that is, of the fifth, sixth, seventh, and eighth cervical and first thoracic nerves; it lies behind the axillary artery. The first thoracic nerve generally contributes a small branch to the posterior cord (Harris, 1939).

The **nerves of distribution** for the shoulder and arm are derived from the cords, and receive in that way various contributions from the constituent spinal nerves. *From the lateral cord* arise the lateral pectoral and musculo-cutaneous nerves, and the lateral root of the median nerve. *From the medial cord* arise the medial pectoral nerve, the medial cutaneous nerves of the arm and forearm, the ulnar nerve, and the medial root of the median nerve. *From the posterior cord* arise the two subscapular nerves, the nerve to the latissimus dorsi, the circumflex nerve, and the radial nerve.

It is to be remembered that, although derived from a cord formed by a certain set of spinal nerves, any given nerve does not necessarily contain fibres from all the constituent nerves; *e.g.*, the musculo-cutaneous and the circumflex nerves, from the lateral and posterior cords respectively, are ultimately derived only from the fifth and sixth cervical nerves. In other words, the cords are merely collections of nerves of distribution bound together in a common sheath in their passage through the axilla. It may be pointed out also that it is impossible in nearly all cases to dissect out and trace the fibres of a given spinal nerve through the plexus to their ultimate distribution, owing to the complex manner in which the nerve bundles interlace with one another.

Communications with Sympathetic.—The lower four cervical nerves communicate with the cervical portion of the sympathetic by means of **grey rami communicantes.** Commonly two branches arise from the middle cervical ganglion; they join the anterior primary rami of the fifth and sixth nerves. Two or more from the inferior cervical ganglion join the seventh and eighth nerves. They reach the nerves either by piercing the prevertebral muscles or by passing beneath the medial border of the scalenus anterior muscle. The sympathetic plexus associated with the vertebral artery gives branches (post-ganglionic fibres) to the fourth, fifth, and sixth cervical nerves.

Variations are found (1) in the number of nerves that take part in the formation of the plexus; and (2) in the pattern formed by the union and division of its constituent parts. (1) As regards the former, Kerr (1918), on an examination of 175 plexuses, forms three groups: (*a*) a part of the fourth nerve joins the plexus in nearly two-thirds; (*b*) no contribution is received from the fourth nerve. but all the fifth joins the plexus in one-third; (*c*) a part only of the fifth enters the plexus in about 7 per cent. At the lower end of the plexus there is an intrathoracic communication between the second and first thoracic nerves in one-third or more. These figures indicate a possible higher or lower position (prefixation or postfixation) of the plexus relative to the vertebral column, though it is evidently subject to very slight variation. The presence of a cervical rib may coincide with little or no change in the relation of the nerves. (2) Variations in the pattern of the plexuses are due to (*a*) the stage of either trunk-, divisional or even cord-formation being absent in one or other part of the plexus, prior to a succeeding stage; in all such cases, however, there is no alteration in the typical nerve-source of the ultimate terminal branches; (*b*) in very few cases the lateral or the medial cord may receive fibres from nerves below the seventh or above the eighth respectively—that is, a new element is introduced into their composition. (For further details concerning the brachial plexus see Herringham (1886), Harris (1904, 1939) and Wood Jones (1910).)

Branches of Brachial Plexus

It is customary to separate artificially the nerves of distribution of the brachial plexus into two sets: (1) supraclavicular and (2) infraclavicular, a topographical division which is, to some extent, affected by the alteration in position of the bone in raising or lowering the shoulder.

The point of junction of the three posterior divisions of the trunks to form the posterior cord has been found fairly constantly situated 6·75 cm., or $2\frac{3}{4}$ inches, horizontally lateralwards, from the lateral border of the common carotid artery at the root of the neck, the arm being fully abducted; a vertical line passing through this point separates the trunks from the cords (Linell, 1921).

Clinically it is important to realize the position of origin of the nerves relative to the different stages of formation of the plexus. (*a*) The nerves to the prevertebral muscles, the communication with the phrenic, the nerves to the rhomboids and serratus anterior arise from the *anterior primary rami* of the nerves involved in the plexus. (*b*) The suprascapular and the nerve to the subclavius

arise at the level of formation of the *trunks*. (*c*) The pectoral and subscapular nerves, the nerve to the latissimus dorsi, and the medial cutaneous nerves of the arm and forearm arise from the *cords*, prior to their ultimate division into the nerves of distribution for the upper limb. (*d*) All the rest are terminal branches.

Supraclavicular Branches.—The nerves derived from the plexus above the level of the clavicle are, like the main trunks, divisible into two series: **anterior branches**, arising from the front of the plexus; **posterior branches**, arising from the back of the plexus (Fig. 924).

(a) Arising from the Primary Rami.

Anterior Branches

1. Nerves to scalenus anterior and longus cervicis.
2. Communicating nerve to join the phrenic nerve.

Posterior Branches

1. Nerves to scalenus medius and scalenus posterior.
2. Nerve to the rhomboids.
3. Nerve to serratus anterior.

(b) Arising from the Trunks.

3. Nerve to the subclavius muscle.
4. Suprascapular nerve.

The **muscular twigs** to the anterior scalene and longus cervicis muscles arise from the lower four cervical nerves as they emerge from the intervertebral foramina.

The **communicating branch to the phrenic nerve** arises usually from the fifth cervical nerve at the lateral border of the anterior scalene muscle. It is sometimes absent, and occasionally an additional root is present from the sixth cervical nerve. In some instances the nerve is replaced by a branch which springs from the nerve to the subclavius, and passes medially behind the sterno-mastoid muscle to join the phrenic at the inlet of the thorax.

The **nerve to the subclavius** is a slender nerve which arises from the front of the upper trunk of the plexus, and usually receives fibres from the fourth, fifth, and sixth cervical nerves. It descends in the posterior triangle of the neck anterior to the third part of the subclavian artery. It often communicates with the phrenic nerve (see *accessory phrenic nerve*, p. 1065).

The **branches to the scalenus medius and scalenus posterior** are small, and arise from the lower four cervical nerves as they emerge from the intervertebral foramina.

The **nerve to the rhomboids** arises from the back of the fifth cervical nerve as it emerges from the intervertebral foramen. It appears in the posterior triangle of the neck, after piercing the scalenus medius muscle, and it passes downwards, under cover of the levator scapulæ and rhomboid muscles, and along the medial border of the scapula, to be distributed to the levator scapulæ, rhomboideus minor, and rhomboideus major muscles. It occasionally pierces the levator scapulæ.

The **nerve to the serratus anterior** arises by three roots, of which the middle one is usually the largest, from the back of the fifth, sixth, and seventh nerves as they emerge from the intervertebral foramina. The upper two roots pierce the scalenus medius and unite into one stem which is joined by the contribution from the seventh cervical nerve which passes in front of that muscle. The nerve descends in the neck behind the cords of the brachial plexus and enters the axilla between the superior edge of the serratus anterior muscle and the axillary artery. It continues downwards on the axillary surface of the serratus, to the slips of which it is distributed.

There is a more or less definite relation between the roots of the nerve and the parts of the serratus muscle. The upper part of the muscle is innervated by the fifth nerve alone; the middle part by the fifth and sixth, or the sixth alone; the lower part by the sixth and seventh, or the seventh nerve alone.

The **suprascapular nerve** arises from the back of the upper trunk of the plexus, receiving fibres from the fourth, fifth, and sixth cervical nerves. It occupies a position above the cords of the brachial plexus, and courses downwards and

laterally parallel to them towards the superior border of the scapula, where it passes through the suprascapular notch to the dorsum of the scapula. After supplying the supraspinatus muscle it passes through the spino-glenoid notch in company with the suprascapular artery and terminates in the infraspinatus muscle. It also supplies articular branches to the shoulder joint.

Infraclavicular Branches.—The so-called infraclavicular branches of the brachial plexus all arise from the *cords* of the plexus and are distributed to the chest, shoulder, upper arm, and forearm. According to their origin they are divisible into two sets—an **anterior set,** derived from the lateral and medial cords, and a **posterior set,** derived from the posterior cord. In their distribution the same arrangement is maintained. The anterior nerves of distribution, springing from the lateral and medial cords, supply the chest and the front of the limb; the posterior nerves, springing from the posterior cord, supply the shoulder and the back of the limb.

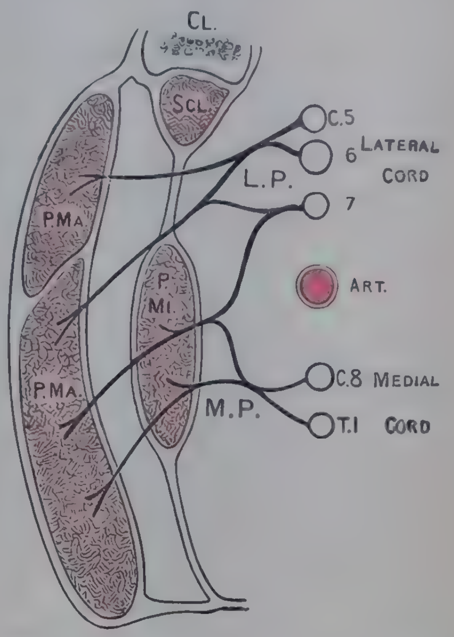

FIG. 925.—DIAGRAM OF THE ORIGIN AND DISTRIBUTION OF THE NERVES TO THE PECTORAL MUSCLES.

L.P., Lateral pectoral nerve; M.P., Medial pectoral nerve; C. 5, 6, 7, C. 8, T. 1, Nerves of the brachial plexus; ART., Axillary artery; CL., Clavicle; SCL., Subclavius muscle; P.MI., Pectoralis minor, joined to subclavius by clavi-pectoral fascia; P.MA., Pectoralis major.

(c) and (d) Arising from the Cords.

Anterior Branches

From the Lateral Cord

Lateral pectoral,
Median (lateral root).
Musculo-cutaneous.

From the Medial Cord

Medial pectoral.
Median (medial root).
Ulnar.
Medial cutaneous nerve of arm.
Medial cutaneous nerve of forearm.

Posterior Branches

Circumflex nerve.
Radial nerve.
Two subscapular nerves.
Nerve to latissimus dorsi.

PECTORAL NERVES

The **pectoral nerves** are two in number, lateral and medial. The **lateral pectoral nerve** arises from the anterior divisions of the fifth, sixth, and seventh cervical nerves just before they form the lateral cord of the plexus. The **medial pectoral nerve** arises from the medial cord of the plexus immediately after its formation, receiving fibres from the eighth cervical and first thoracic nerves. Both course downwards and forwards, one on each side of the axillary artery, and a loop of communication is formed between them in front of the artery. They are distributed to the pectoralis major and minor muscles (Fig. 925).

The nerves are distributed to the pectoral muscles in the following way. Two sets of branches from the lateral pectoral nerve pierce the clavi-pectoral fascia. The superior branches supply the *clavicular part* of the pectoralis major; the inferior branches are distributed to the superior fibres of the *sterno-costal portion* of the muscle. The superior branches come from the fifth and sixth cervical nerves; the inferior branches, from the fifth, sixth, and seventh nerves. The *pectoralis minor* is pierced by two sets of nerves—the superior set is derived from the loop of communication between the two pectoral nerves over the axillary artery; the inferior set is derived from the medial pectoral nerve alone. The two sets supply the *pectoralis minor* muscle, and, after piercing it, supply the *sterno-costal part* of the pectoralis major. The inferior set, in many cases, sends its branches to the pectoralis major round the infero-lateral border of the pectoralis minor, and they may supply the *axillary arches*, if present. The two branches

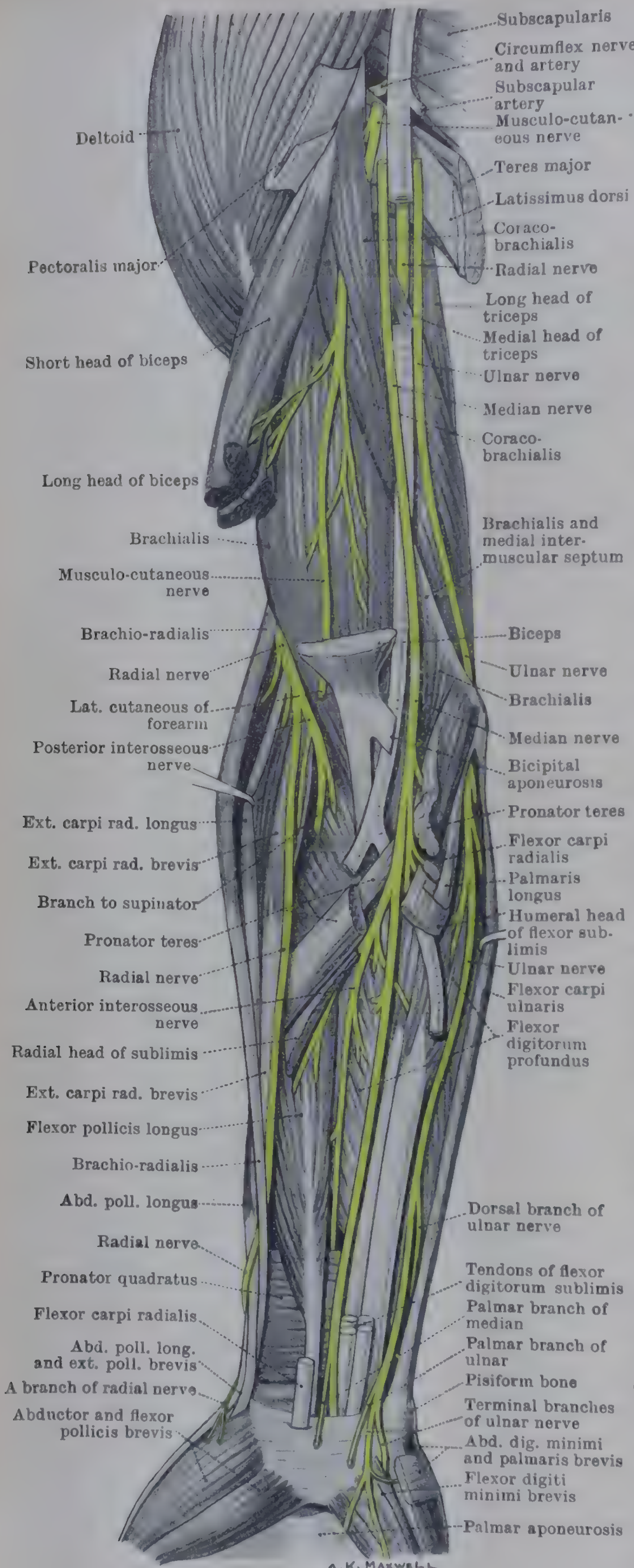

FIG. 926.—DEEPER NERVES OF FRONT OF UPPER ARM AND FOREARM.

of the superior set are derived from the seventh and eighth cervical and first thoracic nerves; those of the inferior set from the eighth cervical and first thoracic nerves. The pectoral muscles are thus both supplied by the two pectoral nerves. The clavicular fibres of the pectoralis major are innervated by the fifth and sixth nerves; the sterno-costal fibres, from above downwards, by the fifth, sixth, seventh, and eighth cervical and first thoracic nerves; and the pectoralis minor is supplied by the seventh and eighth cervical and first thoracic nerves.

MUSCULO-CUTANEOUS NERVE

The **musculo-cutaneous nerve** takes origin from the lateral cord of the plexus, from the fifth and sixth cervical nerves, and also from the fourth in over half the number of cases (Fig. 924). The **nerve to the coraco-brachialis muscle**, arising from the seventh or sixth and seventh nerves, is usually incorporated with it. After the musculo-cutaneous nerve separates from the lateral root of the median nerve, it lies at first between the coraco-brachialis muscle and the axillary artery. It then passes between the two parts of the coraco-brachialis, and runs between the biceps and brachialis muscles, to the bend of the elbow. It pierces the deep fascia over the front of the elbow, between the biceps and brachio-radialis (Fig. 926), and terminates as the *lateral cutaneous nerve of the forearm.* Whilst behind the biceps it may send a communicating branch to the median nerve.

The branches of the nerve are muscular and cutaneous. The **muscular branches** are supplied to the two heads of the biceps and the brachialis, as the nerve lies between the muscles, and to the coraco-

brachialis. The nerve to the coraco-brachialis (usually incorporated with the trunk of the musculo-cutaneous nerve) has an independent origin from the seventh or sixth and seventh nerves (possibly the fifth also). The **lateral cutaneous nerve of the forearm** divides into anterior and posterior branches. The **anterior branch** descends along the front of the lateral aspect of the forearm to the wrist, and supplies an area of skin and fascia extending medially to the middle line of the front of the forearm, and distally to the ball of the thumb. It usually communicates, proximal to the wrist, with the radial nerve, and supplies branches to the radial artery. The **posterior branch** passes backwards and downwards over the extensor muscles and supplies the skin and fascia over a variable extent on the lateral aspect of the forearm posteriorly. It communicates with the cutaneous branches of the radial nerve, and it sometimes extends on to the dorsum of the hand, supplying the skin and fascia over the first metacarpal bone.

In addition to the above branches, the musculo-cutaneous nerve supplies in many cases the following small twigs in the arm: (1) a medullary branch to the humerus; (2) a periosteal branch to the distal end of the humerus on its anterior surface; and (3) a branch to the brachial artery.

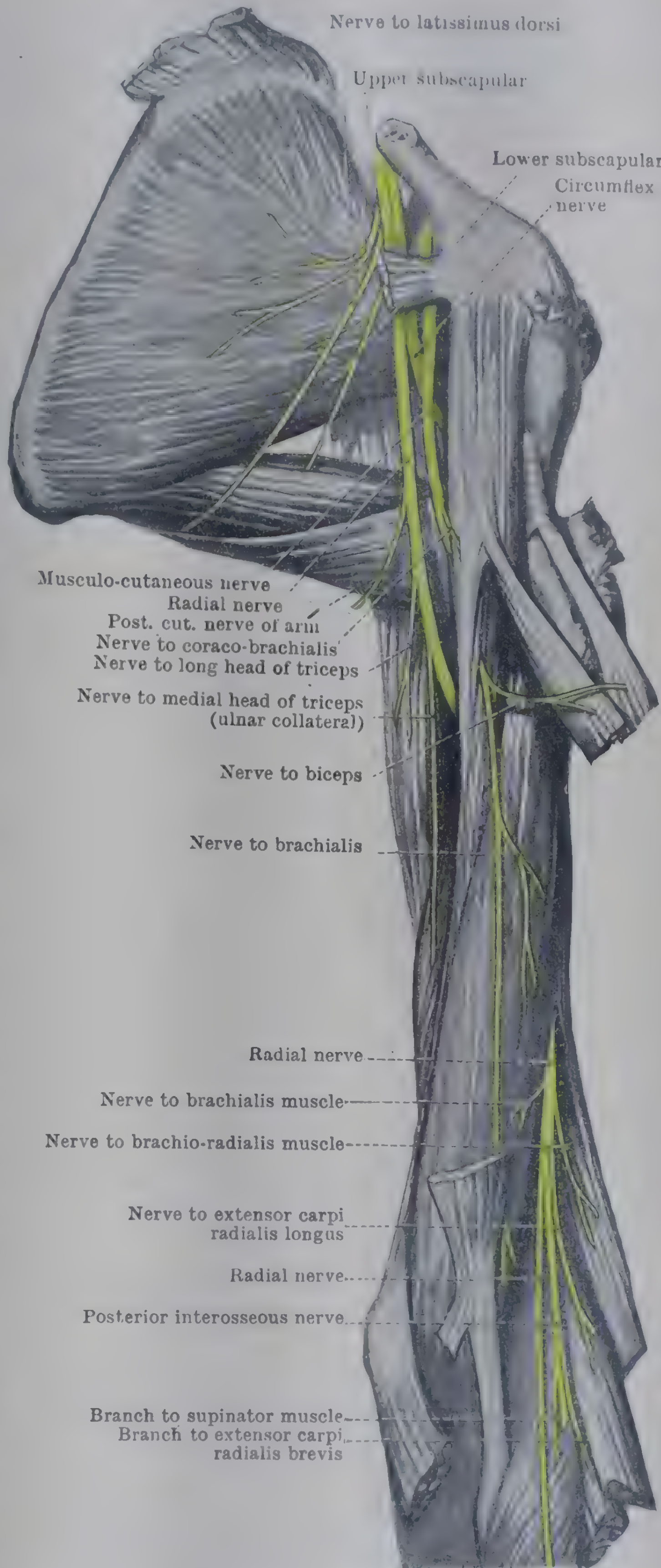

Fig. 927.—Deeper Nerves of Upper Arm.

The nerve to the brachialis usually enters the medial side of the muscle as in Fig. 926.

Median Nerve

The **median nerve** arises by two roots—one from the lateral cord of the brachial plexus, the other from the medial cord. The lateral root, from the (fifth), sixth, and seventh nerves, descends along the lateral side of the axillary artery; the medial root, from the eighth cervical and first thoracic nerves, crosses in front of the terminal part of the axillary artery or the beginning of the brachial artery, to join the lateral root in the proximal part of the upper arm. The trunk therefore receives fibres from all the main nerves that form the plexus. It descends along the lateral side of the brachial artery to the

level of the insertion of the coraco-brachialis, where it crosses the artery (usually in front). Thereafter it lies on the medial side of the artery (Figs. 926, 930) and in the hollow of the elbow it is behind the bicipital aponeurosis and the median cubital vein. It passes into the forearm between the two heads of the pronator teres muscle, separated from the ulnar artery by the ulnar head of that muscle, and extends downwards, along the middle of the forearm between the superficial and

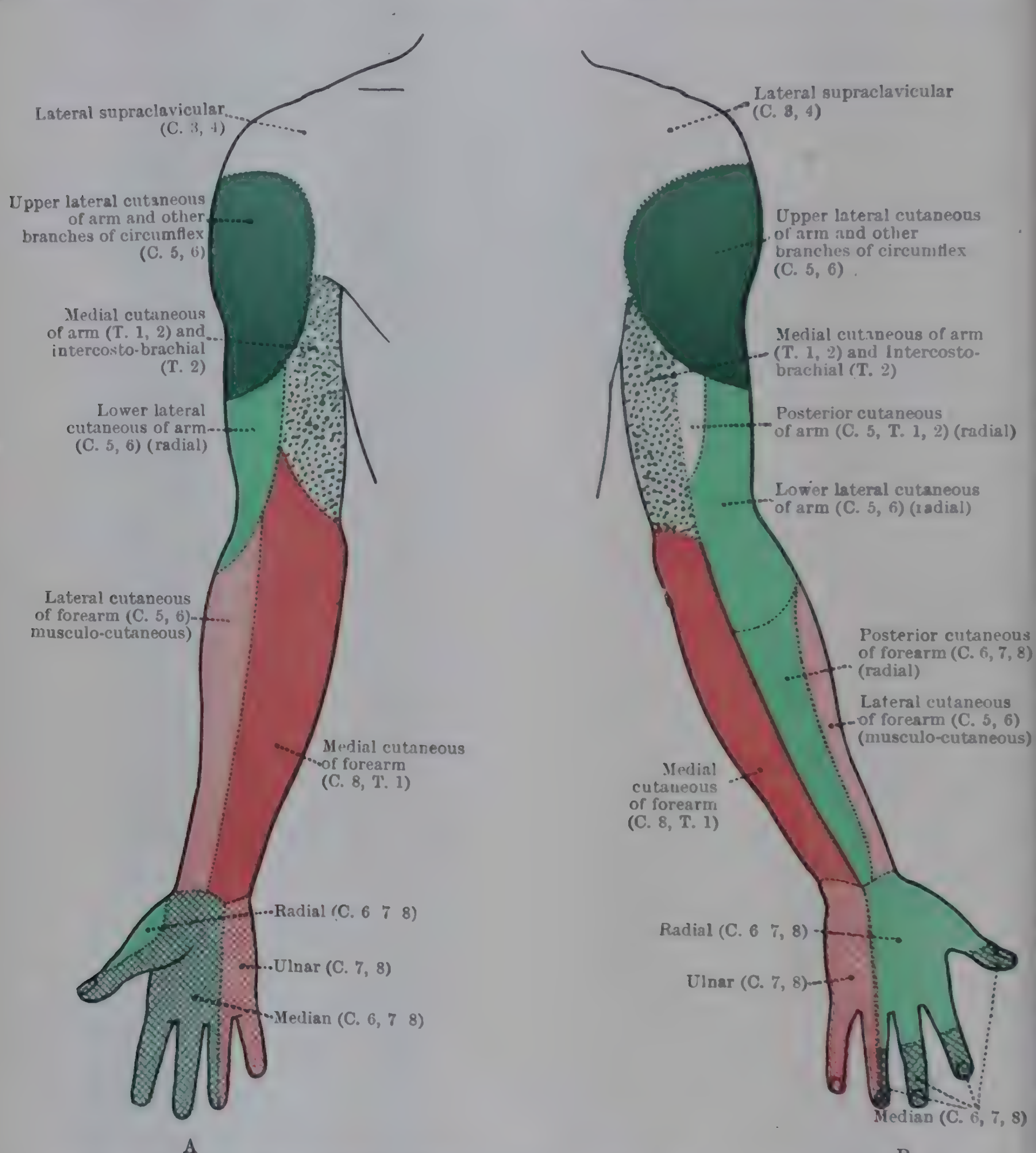

Fig. 928.—Distribution of Cutaneous Nerves: A, on the Front; B, on the Back of Upper Limb. The overlapping of nerve-areas, and of dermatomes in Fig. 929, is not shown (see p. 1053).

deep muscles. In its course in the forearm the nerve is closely bound to the deep surface of the flexor sublimis. As it approaches the wrist it becomes more superficial and enters the palm of the hand by passing deep to the flexor retinaculum in front of the tendons of the flexor digitorum sublimis. In the hand it spreads out at the distal border of the flexor retinaculum, under cover of the palmar aponeurosis and superficial palmar arch, and separates into its six terminal branches (Fig. 931). In the forearm a small artery accompanies it—the median branch of the anterior interosseous artery.

Branches.—The median nerve usually gives off no branches in the upper arm.

Branches in Forearm.—(1) **Articular Branches.**—Minute articular filaments

arise from the muscular branches and are distributed to the front of the elbow joint.

(2) **Muscular Branches.**—In the hollow of the elbow a bundle of nerves arises to be distributed to the following muscles: pronator teres, flexor carpi radialis, palmaris longus, flexor digitorum sublimis. Nerves are also generally traceable from that bundle to the upper fibres of the flexor pollicis longus and flexor digi-

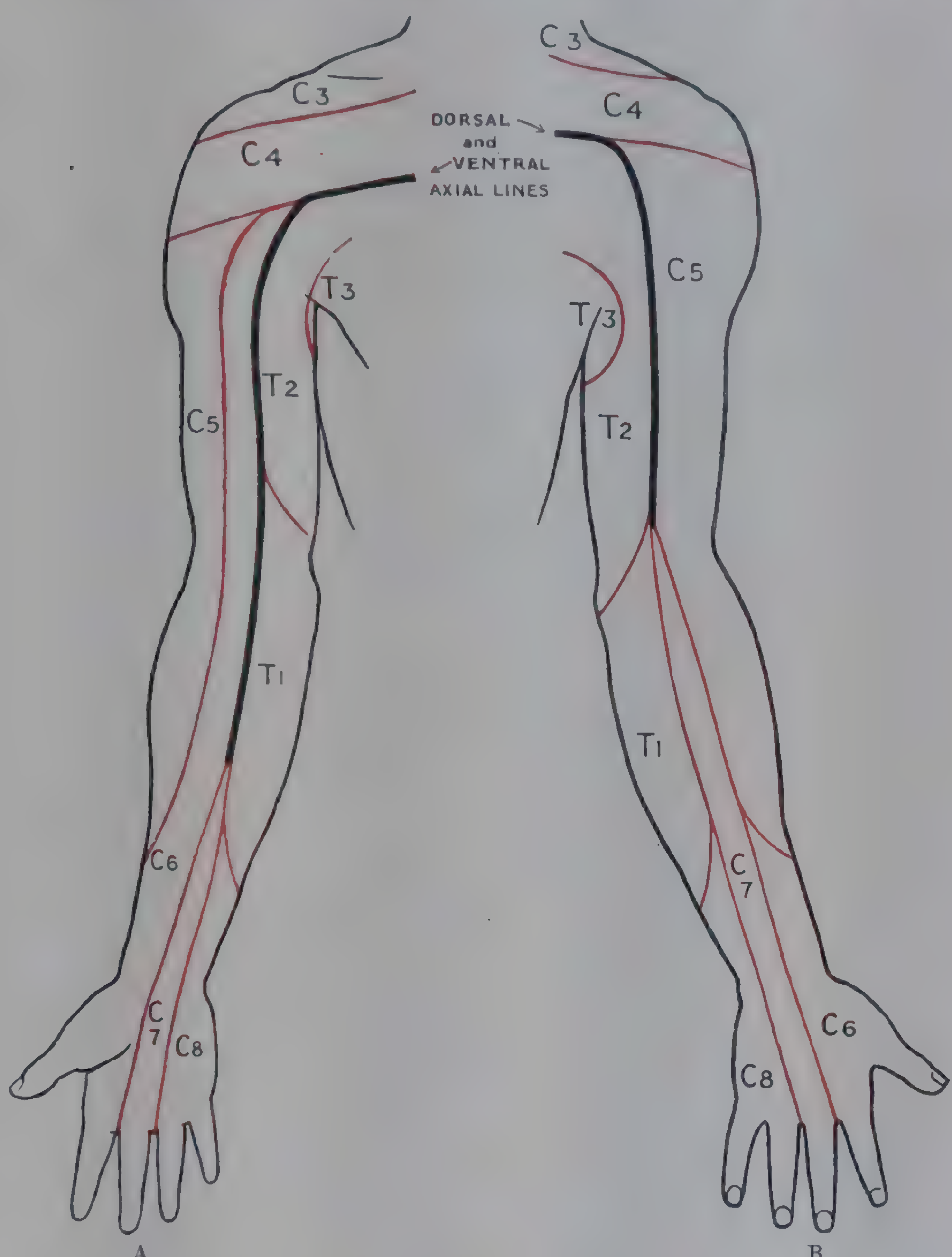

Fig. 929.—Dermatomes of Upper Limb, showing the Segmental Cutaneous Distribution of Spinal Nerves (C—T) on A, the Front, and B, the Back of the Limb (after Head, 1893 and Foerster, 1933). See p. 1053 for definition of "dermatome" and p. 1114 for more particular reference to the segmental innervation of the upper limb.

torum profundus. A separate branch to the index belly of the sublimis often leaves the nerve in the lower half of the forearm. The nerve to the pronator teres, which is the first given off, often arises independently in the hollow of the elbow but seldom proximal to the joint.

(3) The **anterior interosseous nerve** arises from the posterior surface of the median nerve in the cubital fossa. It extends downwards on the front of the interosseous membrane along with the anterior interosseous artery, passes behind the pronator quadratus muscle, and terminates by supplying articular filaments to the radio-carpal and intercarpal joints. In its course the nerve supplies muscular branches to the flexor pollicis longus, the lateral half of the flexor digitorum pro-

fundus, and the pronator quadratus, minute medullary branches to the radius and ulna, and twigs to the periosteum and interosseous membrane.

(4) **Palmar Cutaneous Branch.**—In the distal third of the forearm a small cutaneous branch arises which pierces the deep fascia and crosses the flexor retinaculum to reach the palm of the hand. It supplies a small piece of the skin and fascia of the palm and communicates with a similar branch of the ulnar nerve. It is not always present.

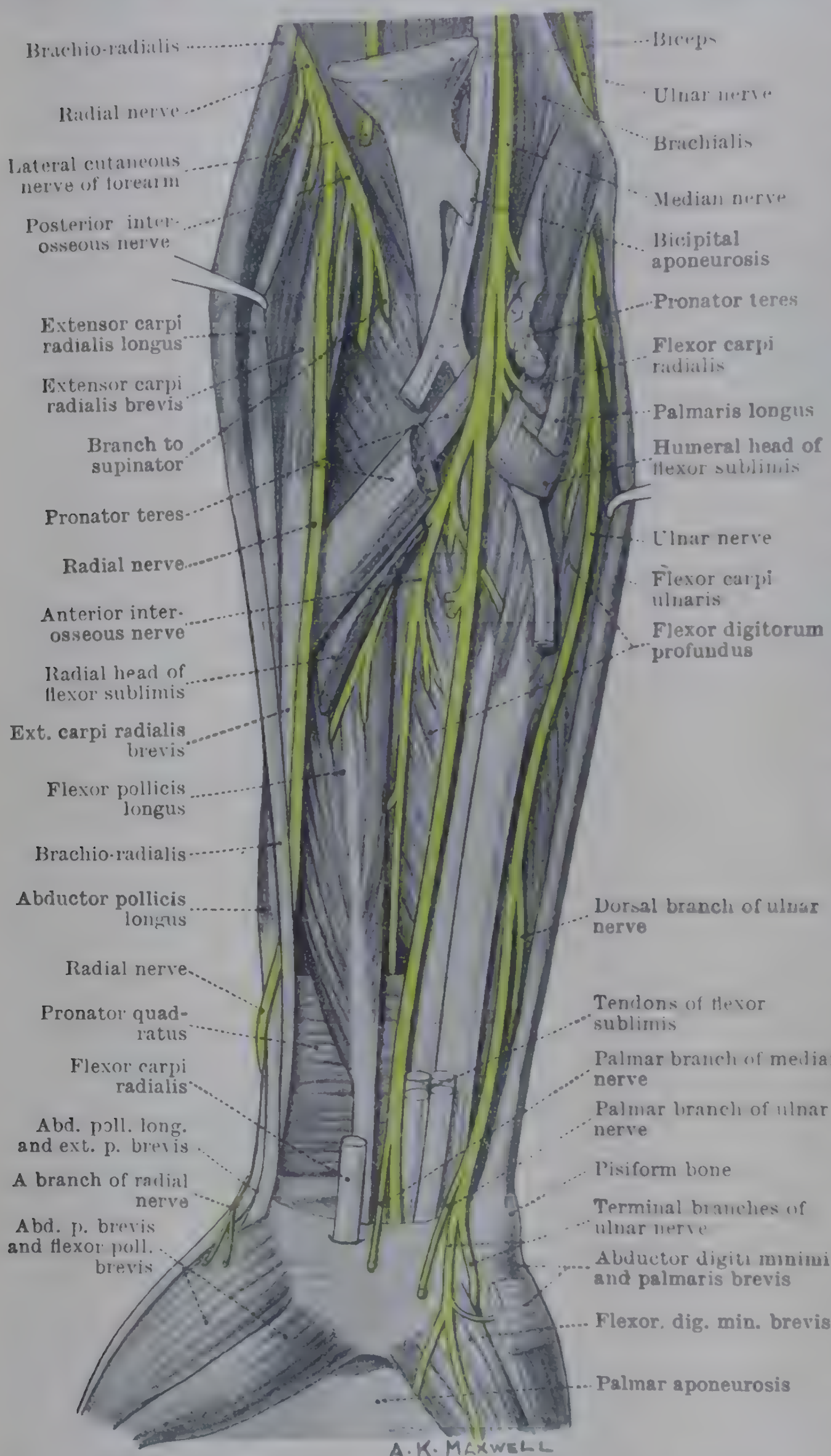

FIG. 930.—MEDIAN, ULNAR, AND RADIAL NERVES IN FOREARM.

Branches in Hand.—In the hand the median nerve gives off its terminal branches (Fig. 931). They are muscular, cutaneous, articular, and vascular.

The main **muscular branch** arises just distal to the flexor retinaculum and passes to the base of the thenar eminence; entering the ball of the thumb superficially on the medial side, it supplies branches to the abductor pollicis brevis, opponens pollicis, and the flexor pollicis brevis.

The **cutaneous branches** (*palmar digital nerves*) are five in number. Three separate branches supply the two sides of the thumb and the lateral side of the index finger. The two remaining branches divide, at the clefts between the second and third and the third and fourth fingers, into branches which supply the adjacent sides of the second and third and the third and fourth fingers. From the nerves which supply the lateral side of the index finger and the contiguous sides of the index and middle fingers, fine muscular branches arise for the lateral two lumbrical muscles. The cutaneous branches of the median nerve are placed in the palm between the superficial palmar arch and the flexor tendons. They become superficial at the roots of the fingers between the slips of the palmar aponeurosis, or, in the case of the nerves to the thumb and lateral side of the index finger, at the lateral edge of the palmar aponeurosis. In the fingers they are placed in front of the digital arteries, and are distributed to the sides and palmar surfaces of the fingers. These palmar branches, as in the case of the ulnar nerve, are beset with numerous lamellated corpuscles. Each nerve supplies one or more *dorsal branches*, distributed to the skin and fascia on the

back of the distal phalanx of the thumb and the distal two phalanges of the first two and a half fingers.

Articular branches can be traced to the interphalangeal joints, and usually also to the metacarpo-phalangeal joints of the thumb and index and middle fingers. Numerous **vascular** branches are distributed to the neighbouring arteries by the palmar cutaneous nerve and its branches.

Communications.—(1) The median nerve sometimes receives a communicating branch from the musculo-cutaneous nerve in the upper arm. (2) It communicates in some cases, in the proximal part of the forearm, with the ulnar nerve behind the flexor muscles. (3) It communicates by means of its cutaneous branches with the ulnar nerve in the palm of the hand.

Ulnar Nerve

The **ulnar nerve** arises from the medial cord of the brachial plexus, and contains fibres from the eighth cervical and first thoracic nerves (Fig. 924). In over half the number of cases it has also a root from the lateral cord of the plexus or from the lateral root of the median nerve (seventh cervical nerve). This additional root is subject to great variation in size. In the axilla the ulnar nerve lies between the axillary artery and vein, and behind the medial cutaneous nerve of the forearm; in the proximal half of the upper arm it lies on the medial side of the brachial artery anterior to the triceps muscle. In the distal half of the upper arm it separates from the brachial artery, pierces the medial intermuscular septum and descends in front of the medial head of the triceps in company with the ulnar collateral artery to reach the interval between the medial epicondyle of the humerus and the olecranon. It is there protected by an aponeurotic arch between the epicondyle and the olecranon. It enters the forearm between the humeral and ulnar origins of the flexor carpi ulnaris lying deeply on the coronoid process, and then descends between the flexor carpi ulnaris and flexor digitorum profundus. In the distal half of the forearm it becomes comparatively superficial, lying on the medial side of the ulnar artery (to which it furnishes branches) overlapped by the tendon of the flexor carpi ulnaris (Fig. 930). Just proximal to the flexor retinaculum it pierces the deep fascia in company with the artery, and passes on to the front of the retinaculum at the lateral side of the pisiform bone, where it divides, under cover of the palmaris brevis muscle, into its two terminal branches—superficial and deep.

Branches.—The ulnar nerve usually gives off no branches until it reaches the forearm.

In **the forearm** it gives off articular, muscular, and cutaneous branches.

The **articular branch** is distributed to the elbow joint and arises as the nerve passes behind the medial epicondyle of the humerus.

The **muscular branches** arise as soon as the nerve enters the forearm. They are distributed to the muscles between which the nerve lies—the flexor carpi ulnaris and the medial half of the flexor digitorum profundus. The flexor carpi ulnaris usually receives, just below the elbow joint, two branches, one each to its olecranon and condylar heads; the latter head may receive a secondary supply at a lower level, and a fourth branch to the muscle may be found. Only in exceptional cases does one of the branches arise proximal to the elbow joint (Linell, 1921).

The **cutaneous branches** are two in number—palmar and dorsal.

The **palmar cutaneous branch** is variable in size and position. It pierces the deep fascia in the distal third of the forearm and passes to the medial part of the palm of the hand, to the skin and fascia over which it is distributed. It gives branches to the ulnar artery, and often communicates with the medial cutaneous nerve of the forearm and the palmar cutaneous branch of the median nerve.

The **dorsal branch of the ulnar** is much larger. It arises from the ulnar nerve at a variable point in the middle third of the forearm; and, directed obliquely downwards and backwards, under cover of the tendon of the flexor carpi ulnaris and in contact with the ulna, it becomes cutaneous on the medial side of the forearm in its distal fourth. At the medial side of the wrist it lies on the triquetrum where it may be rolled against that bone in palpation. It then passes on to the back of the hand, and, after giving off branches to the skin and fascia of the

usually innervation.

dorsum of the wrist and hand which communicate with the radial nerve, it terminates in ~~three~~ 2 *dorsal digital nerves* to supply the little finger, ~~the ring finger~~, ~~and~~ half of the ~~middle finger in~~ ring the following way: one branch courses along the ulnar side of the dorsum of the hand and supplies the little finger as far as the root of the nail; another branch divides at the cleft between the little and ring fingers to supply their adjacent sides to the same extent; a third branch bifurcates at the cleft between the ring and middle fingers, and supplies their adjacent sides, but only as far as the

Rarely 2½ fingers common 1½ f.

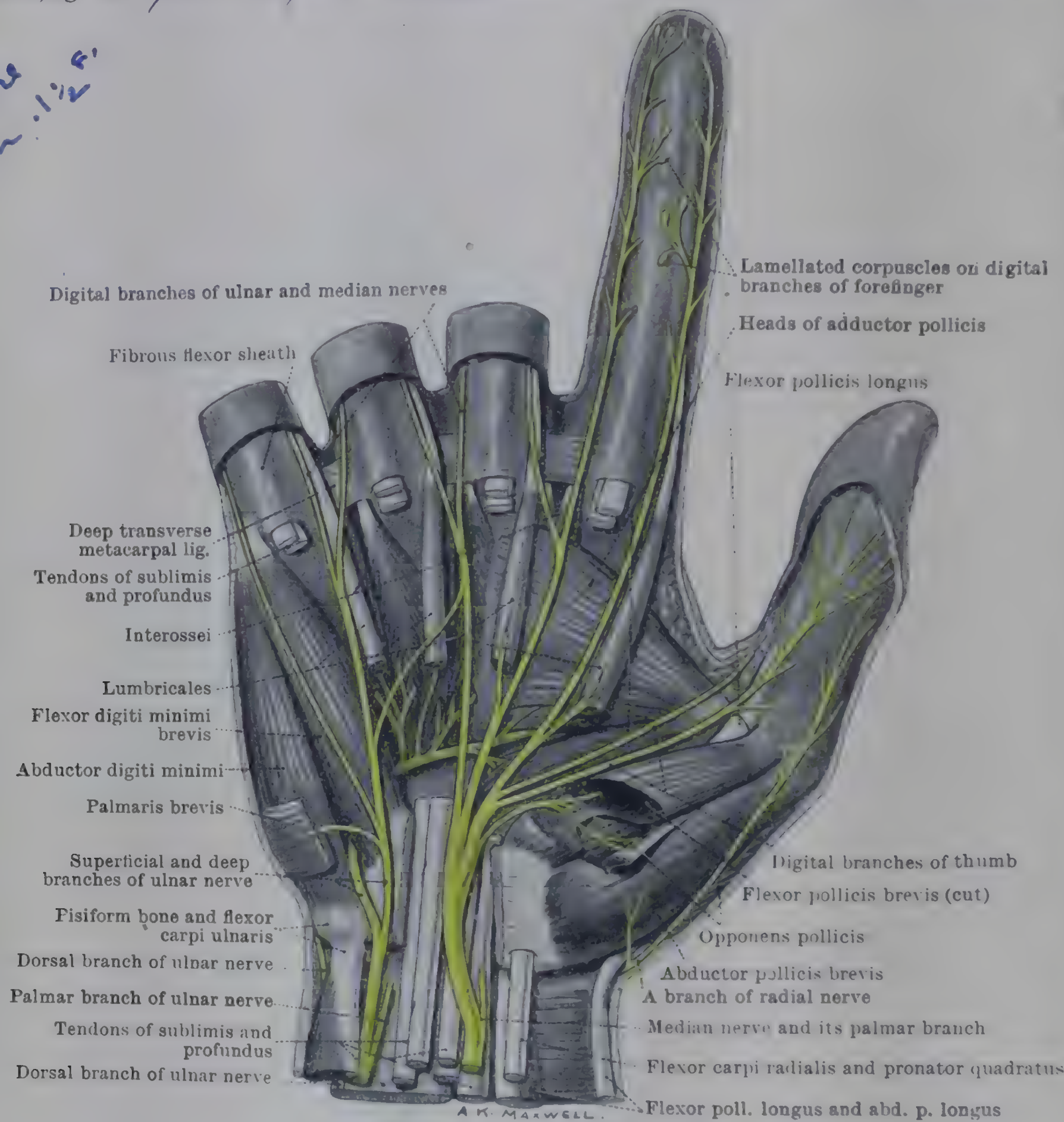

Fig. 931.—Median and Ulnar Nerves in Hand.

level of the proximal interphalangeal joints, the distal part of the surfaces being supplied by branches of the median overlapping from the palmar aspect. The last branch communicates with the radial nerve. The ulnar nerve sometimes supplies only the little finger and half of the ring finger on their dorsal surfaces.

In the palm the ulnar nerve supplies a small muscular branch to the palmaris brevis, and then divides into its terminal branches.

Terminal Branches.—The **superficial terminal branch** passes downwards deep to the palmar aponeurosis, and divides into a medial and a lateral branch. The medial branch proceeds along the medial border of the little finger, which it supplies on its palmar surface. The lateral branch becomes superficial at the cleft between the fourth and fifth digits, between the slips of the palmar aponeurosis, where it lies with the fourth lumbrical and the corresponding digital vessels in front of the deep transverse ligament of the palm. Here it divides into two branches (*palmar digital nerves*) which supply the adjacent sides of those fingers on their palmar surface. It communicates with the adjacent digital branch

of the median nerve, and it usually supplies the metacarpo-phalangeal and interphalangeal joints of the ring and little fingers. The digital nerves supply the neighbouring arteries also.

The ulnar nerve, therefore, usually supplies one and a half fingers on their palmar surfaces and two and a half fingers on their dorsal surfaces, the remaining digits being supplied by the median nerve on the palmar surface, and the radial nerve on the dorsal surface. The median nerve further extends on to the dorsal surface of the distal phalanx of the thumb and the distal two phalanges of the first two and a half fingers, so making up for the deficiency of the radial nerve in those regions. Clinical observations show this to be a much more common arrangement than the classical description of the distribution of the ulnar nerve to one and a half fingers on both their surfaces (Stopford, 1918).

The **deep terminal branch** is distributed mainly to muscles, but receives some fibres from afferent end-organs in the deep structures of the palm. It separates from the superficial branch and passes deeply (Fig. 931) between the flexor and abductor digiti minimi muscles; it supplies those muscles and the opponens digiti minimi, and, turning laterally round the hook of the hamate bone along the line of the deep palmar arch and under cover of the deep flexor tendons, it supplies branches to the following muscles: interossei, third and fourth lumbricals (on their deep surfaces), and the adductor pollicis (oblique and transverse heads). Vascular branches are given to the deeper vessels of the palm. The ulnar supply to the first dorsal interosseous muscle may be replaced in part, or even completely, by the median nerve (Brooks, 1888; Sunderland, 1946). (See also p. 508.)

Communications.—The ulnar nerve communicates (1), in some cases, with the median nerve in the forearm; (2) with the medial cutaneous nerve of the forearm, and sometimes with the median nerve, by its palmar branch; (3) with the cutaneous part of the median nerve in the palm, by means of its terminal cutaneous branches; (4) with the radial nerve on the dorsum of the hand by means of its dorsal branch.

Medial Cutaneous Nerve of Forearm

The **medial cutaneous nerve of the forearm** arises from the medial cord of the brachial plexus, and contains fibres of the eighth cervical and first thoracic nerves (Figs. 924 and 928). In the axilla and proximal half of the upper arm it lies superficial to the main artery. It becomes cutaneous by piercing the deep fascia about the middle of the upper arm on its medial side, and, accompanying the basilic vein through the distal half, it divides at the front of the elbow into its two terminal branches.

Branches.—In the upper arm, as soon as it becomes superficial, the nerve gives off a branch which supplies the skin and fascia of the distal half of the anterior surface of the upper arm on its medial side. At the elbow its two terminal branches—anterior and posterior—cross superficial or deep to the median cubital vein, and are distributed to the medial side of the forearm.

The **anterior branch** can be followed to the wrist and supplies the whole of the front of the forearm in the medial half. The **posterior branch** is not so large; it passes obliquely backwards and downwards over the origins of the pronator and flexor muscles, and it is distributed to the proximal two-thirds or three-fourths of the back of the forearm on the medial side.

Communication.—The medial cutaneous nerve of the forearm communicates with the ulnar nerve in the distal part of the forearm.

Medial Cutaneous Nerve of Arm

The **medial cutaneous nerve of the arm** arises from the medial cord of the brachial plexus, and ultimately from the first thoracic nerve (Fig. 924, p. 1068). It lies at first between the axillary artery and vein; and, after descending over, under, or even, in some cases, through the axillary vein, it perforates the deep fascia and is distributed to the skin and fascia of the upper arm for the proximal half or more on its medial side.

The nerve varies considerably in size. It may be absent, its place being taken by branches of the intercosto-brachial or by branches from the posterior cutaneous branch of the radial nerve. It generally bears a distinct relation in size to the intercosto-brachial, due to the fact that the size of the latter depends upon the size of the part of the second thoracic nerve connected

with the first in the thorax. If an intrathoracic connexion occurs between the first and second thoracic nerves, the intercosto-brachial may be deprived of a certain number of its fibres, which in that case reach the upper limb through the medial cutaneous nerve of the arm. When traced up to the plexus the medial cutaneous nerve of the arm is found to have an origin from the posterior part of the cord formed by the eighth cervical and first thoracic nerves, and usually receives fibres from the first thoracic nerve only. In cases where "*axillary arches*" are present they may be supplied by this nerve.

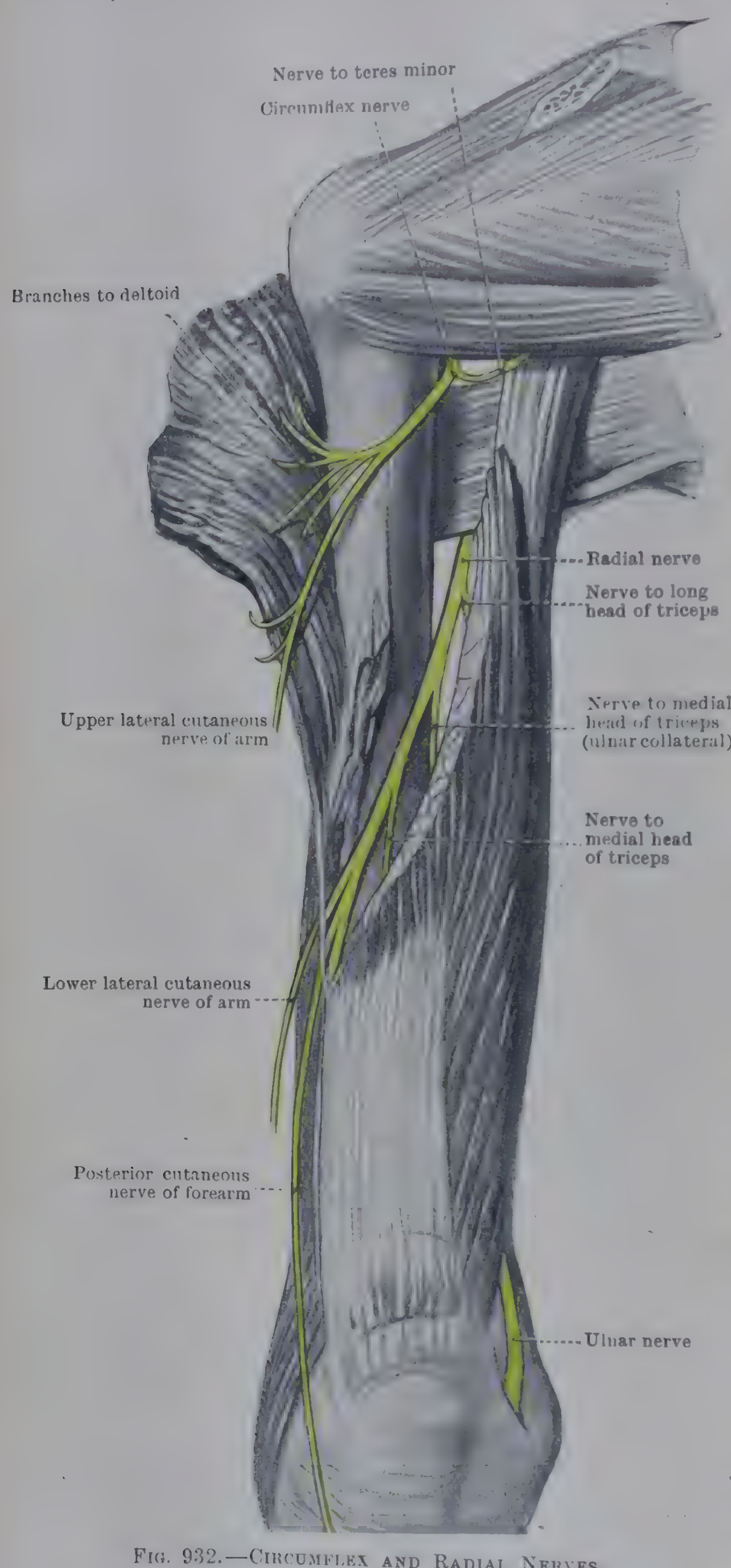

FIG. 932.—CIRCUMFLEX AND RADIAL NERVES.

CIRCUMFLEX NERVE

The **circumflex nerve** is a terminal branch of the posterior cord, and contains fibres of the fifth and sixth cervical nerves. At first it lies behind the axillary artery, but, at the lower border of the subscapularis, it leaves the axilla by passing backwards, in company with the posterior circumflex humeral artery, through a quadrilateral space bounded by the humerus, subscapularis, triceps (long head), and teres major and then divides into anterior and posterior branches. The anterior branch winds round the back of the surgical neck of the humerus from medial to lateral side in company with the artery and is distributed to the deltoid through its deep surface; a few filaments pierce the muscle and become cutaneous. The posterior branch supplies the teres minor, and, after giving a few twigs to the posterior part of the deltoid, curves round the posterior border of that muscle to become the *upper lateral cutaneous nerve of the arm* (Fig. 932).

Branches. — **Muscular branches** are supplied to the teres minor and deltoid muscles. It may give off the lower subscapular nerve. The nerve to the teres minor enters the lateral margin of the muscle; it has a pseudo-ganglionic thickening of fibrous tissue on its trunk.

Articular branches enter the lower part of the capsule of the shoulder joint.

A **cutaneous branch** of considerable size—*the upper lateral cutaneous nerve of*

the arm—becomes superficial at the posterior border of the deltoid muscle, and, passing obliquely downwards and forwards, supplies the skin and fascia over its lower half (Figs. 928, p. 1074, and 932).

Radial Nerve

The **radial nerve** appears to be the continuation into the upper limb of the posterior cord of the brachial plexus. It usually takes origin from all the nerves which form the posterior cord—the fifth, sixth, seventh, and eighth cervical and first thoracic nerves (Fig. 924, p. 1068). In some cases the first thoracic contributes no fibres, and often the fifth cervical nerve is excluded from it. It extends from the axilla, round the back of the humerus, to the bend of the elbow, where it passes into the forearm under cover of the brachio-radialis. After accompanying the radial artery in the middle third of the forearm, it passes backwards under the tendon of the brachio-radialis and becomes cutaneous by piercing the deep fascia on the lateral surface of the distal third of the forearm.

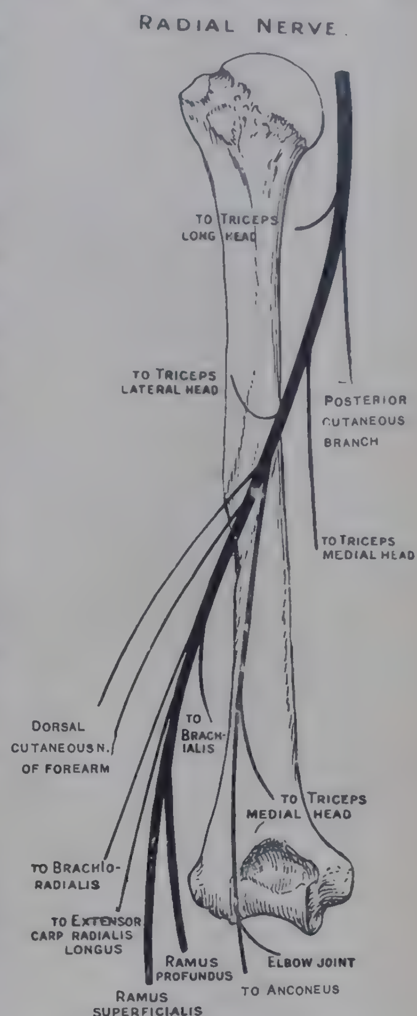

Fig. 933.—Diagram of Branches of Radial Nerve. *Ramus superficialis* = continuation of radial nerve ; *Ramus profundus* = posterior interosseous nerve.

In the axilla it lies behind the axillary artery, and in front of the subscapularis, teres major, and latissimus dorsi muscles.

In the upper arm it first lies to the medial side of the humerus, behind the brachial artery, and in front of the long head of the triceps. Leaving the front of the limb with the profunda brachii artery, it passes between the long and medial heads of triceps to reach the spiral groove. It extends laterally and downwards in the groove, accompanied by the artery, round the back of the humerus and under cover of the lateral head of the triceps. Reaching the distal third of the upper arm, it pierces the proximal part of the intermuscular septum at the lateral border of the triceps, and passes to the front of the lateral epicondyle of the humerus, where it is deeply placed in the interval between the brachio-radialis and the brachialis muscles. Under cover of the former muscle it gives off the posterior interosseous nerve and then descends into the forearm.

In the forearm it descends at first under the brachio-radialis and accompanies and supplies the radial artery in the middle third of the forearm. After passing backwards under the tendon of the brachio-radialis it pierces the deep fascia on the lateral surface of the forearm in the distal third. It is then distributed to the skin and fascia of the dorsum of the wrist, the lateral side and dorsum of the hand, and the dorsum of the thumb and lateral two and a half fingers (Fig. 928, p. 1074).

The **collateral branches** are in four sets, arising (*a*) on the medial side, (*b*) on the back, and (*c*) on the lateral side of the humerus (Fig. 933); and (*d*) in the forearm and hand.

I. **Branches which arise medial to Humerus.**—1. The **posterior cutaneous nerve of the arm**, arising in common with one of the following, or independently, pierces the fascia on the medial side of the limb near the axilla. It supplies the skin and fascia of the posterior surface of the upper arm in the proximal third, above and behind the area supplied by the medial cutaneous nerve of the arm and intercosto-brachial (Fig. 928). It varies in size inversely with the thickness of these two nerves.

2. The **muscular branches** supply the triceps and the anconeus. The triceps receives four distinct branches in the following order: (i) to the long head, arising from the nerve in the axilla; (ii) to the distal part of the medial head, arising near the lower border of the teres major, and sometimes termed the *ulnar collateral nerve*

because it accompanies the ulnar nerve in the middle third of the arm; (iii) to the lateral head, arising just distal to the last-mentioned branch; and (iv) the main supply to the medial head, arising from the nerve just prior to its entry into the spiral groove of the humerus. The last branch, after supplying the medial head of the triceps, passes through the muscle and behind the lateral epicondyle of the humerus to terminate in the anconeus muscle. All these branches arise above the spiral groove or just as the nerve enters it; the only branches of any consequence that arise in the groove are the lower lateral cutaneous nerve of the arm and the posterior cutaneous nerve of the forearm.

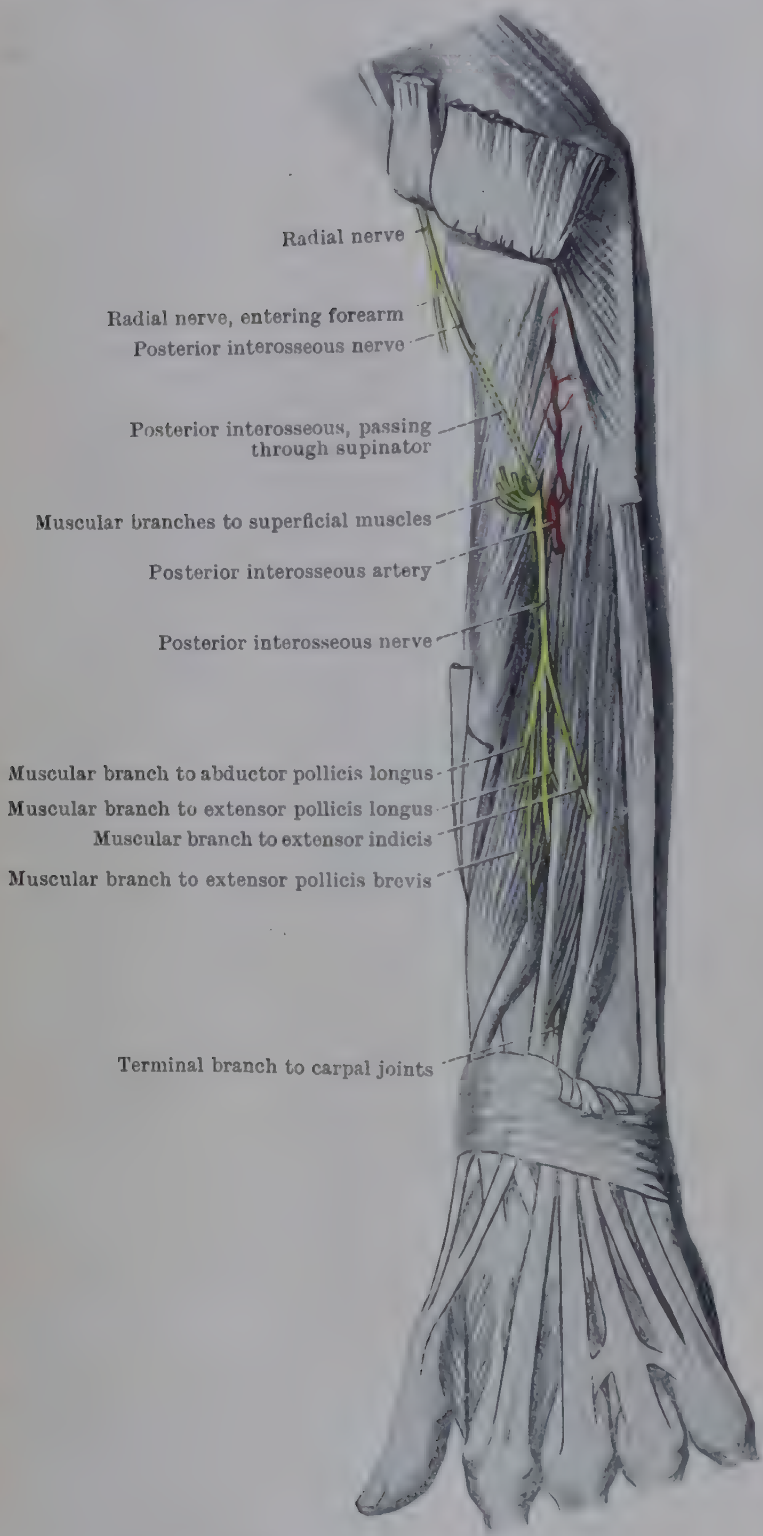

FIG. 934.—POSTERIOR INTEROSSEOUS NERVE.

II. **Branches which arise on Posterior Surface of Humerus.**—The **lower lateral cutaneous nerve of the arm** arises before the radial passes through the lateral intermuscular septum, and, piercing the deep fascia a little below the deltoid, it supplies the skin and fascia of the lateral surface and back of the distal third of the upper arm and a small portion of the back of the forearm. The **posterior cutaneous nerve of forearm** arises with the preceding or immediately below it, and pierces the deep fascia about an inch lower down; it descends into the back of the forearm, where it supplies the skin and fascia, medial to the area innervated by the musculo-cutaneous nerve (Fig. 928, p. 1074). The extent of this area is variable; sometimes it approaches or reaches the level of the wrist, whilst in others it extends on to the dorsum of the hand and supplements the supply from the terminal part of the radial nerve itself.

III. **Branches which arise at Lateral Side of Humerus.**—In the interval between the brachialis and brachio-radialis muscles, the radial nerve supplies **muscular branches** to the brachio-radialis (often double) and extensor carpi radialis longus. It may also provide the nerve to the extensor carpi radialis brevis. An inconstant branch is given to the brachialis, but it would appear from the negative results of electrical stimulation to be an afferent path.

IV. **Branches in Forearm and Hand.**—The only branches which arise from the radial nerve in this part of its course are: (1) some filaments

to the radial artery and (2) the terminal **dorsal digital nerves**. The terminal branches communicate on the ball of the thumb with the musculo-cutaneous nerve, and on the dorsum of the hand, with the dorsal branch of the ulnar nerve. The **dorsal digital nerves** are small, and are five in number. They supply a very variable extent of the dorsum of the hand and fingers. Two pass to the back of the thumb and reach the level of the interphalangeal joint, to which joint and the metacarpo-phalangeal they usually give filaments. One supplies the lateral side of the index finger as far as the second phalanx. The remaining two branches divide at the clefts between the second and third and third and fourth fingers and innervate the adjacent sides of these fingers as far as the middle phalanx. The rest of the skin and fascia of these digits is supplied by digital branches of the median nerve. The radial nerve may supply only the thumb and one and a half fingers, being replaced by branches from the ulnar nerve.

From clinical observations the last distribution would appear to be the more common, since in about 70 per cent of cases the radial has been found not to extend medially beyond the second metacarpal bone. The digital branches frequently give filaments to the metacarpo-phalangeal joints of the index, and more rarely to the same joint of the middle finger (Stopford, 1930).

Posterior Interosseous Nerve

The **posterior interosseous nerve** is entirely muscular and articular in its distribution. It arises under cover of the brachio-radialis muscle. Directed obliquely downwards and backwards, it reaches the back of the forearm after passing round the lateral side of the radius by piercing the fibres of the supinator muscle (Fig. 934). On the dorsal surface of the forearm it is placed in the proximal part of its course deep to the superficial extensor muscles, and superficial to the supinator and abductor pollicis longus, along with the posterior interosseous artery, to which it furnishes twigs. In the distal half of the forearm it passes deep to the extensor pollicis longus, and lies on the interosseous membrane. At the wrist it passes deep to the extensor tendons on to the back of the carpus, where it terminates in a gangliform enlargement of small size from which branches pass to the intercarpal joints. The nerve gives off the following branches:—

(1) Terminal **articular branches** to the intercarpal joints.

(2) **Muscular branches**, in its course through the forearm. On the lateral side of the radius, it supplies the extensor carpi radialis brevis and the supinator muscles before it enters the supinator. After emerging from that muscle, it gives branches to the extensor digitorum, extensor digiti minimi, and extensor carpi ulnaris, near their origins. At a more distal level it gives branches to the abductor pollicis longus, extensor pollicis longus and extensor pollicis brevis, and extensor indicis.

Subscapular Nerves

There are two subscapular nerves (Figs. 924 and 927)—upper and lower.

The **upper subscapular nerve** is often represented by two or three branches. It arises from the posterior cord of the plexus behind the axillary artery and contains fibres from the fifth and sixth cervical nerves (often from the fourth and seventh in addition). It passes downwards to supply the subscapularis muscle.

The **lower subscapular nerve** also arises behind the axillary artery from the posterior cord of the plexus (from the fifth and sixth cervical nerves) and it often arises in common with the circumflex nerve. It courses downwards behind the subscapular vessels to the teres major muscle, in which it ends. It supplies the lateral part of the subscapularis muscle and the teres major.

Nerve to Latissimus Dorsi

The **nerve to the latissimus dorsi** arises from the back of the posterior cord of the plexus, and receives fibres from the sixth, seventh, and eighth cervical nerves, or from the seventh and eighth nerves only. It is directed downwards and laterally between the two subscapular nerves, behind the axillary artery and over the posterior wall of the axilla, in company with the subscapular artery, to the latissimus dorsi muscle, which it supplies on its anterior (deep) surface.

THORACIC NERVES

The anterior primary rami of the **thoracic nerves** are twelve in number, each nerve emerging below the corresponding vertebra and rib. Eleven of the series are **intercostal**; the twelfth lies below the last rib and is called, therefore, the **subcostal** nerve. The first, second, third, and twelfth nerves present peculiarities in their course and distribution. The other thoracic nerves, as already stated, are simple, and may be regarded as types both in course and distribution.

The anterior primary ramus of the **first thoracic nerve** is the largest of the series. It emerges from the vertebral canal below the neck of the first rib, and divides in the first intercostal space into two very unequal parts. The *superior*

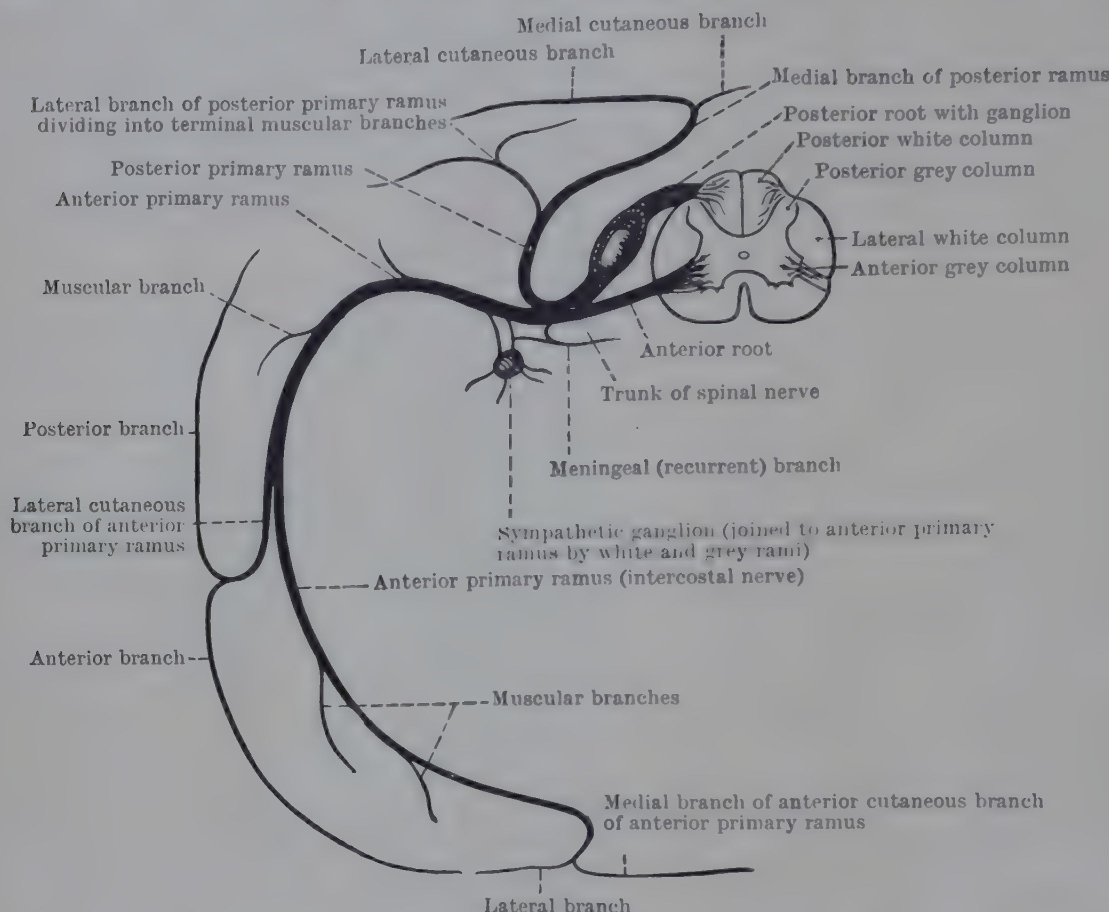

FIG. 935.—DIAGRAM OF ORIGIN AND DISTRIBUTION OF TYPICAL SPINAL NERVE.

Note that the medial branch of the posterior primary ramus is represented as distributed to skin, whilst the lateral branch terminates at a deeper level in muscle. Both branches, however, supply muscles; and in the lower half of the body it is the lateral branch that supplies the skin.

and larger part ascends obliquely across the neck of the first rib, lying lateral to the superior intercostal artery, and enters the neck behind the subclavian artery. It proceeds laterally across the scalenus medius muscle and enters into the formation of the brachial plexus, as already described.

The *inferior* or *intercostal part* of the nerve is much smaller. It courses forwards on the pleural surface of the first rib and enters the first intercostal space near the costal cartilage; it supplies the intercostal muscles. After crossing the internal mammary artery the nerve usually turns forward to terminate in the superficial fascia as the anterior cutaneous branch. A lateral cutaneous branch is inconstant: when present this branch may communicate with the intercosto-brachial nerve or, more rarely, with the medial cutaneous nerve of the arm.

Communications.—Besides its junction with the eighth cervical to enter the brachial plexus, the first thoracic nerve effects the following communications: (*a*) The inferior cervical or the first thoracic ganglion of the sympathetic sends a *grey ramus communicans* to join the nerve on its appearance in the thorax. (*b*) The second thoracic nerve in a majority of cases communicates with the first. That communication varies considerably in size and distribution. It may reinforce the intercostal branch of the nerve; it may

send one branch to the intercostal portion and another to the part of the nerve joining the brachial plexus; or it may consist of a nerve proceeding solely to join the brachial plexus by a junction in the first intercostal space with the part of the first thoracic nerve which is engaged in forming the plexus. Postganglionic sympathetic fibres from the second thoracic ganglion may reach the first thoracic nerve and the brachial plexus by way of this communication. (c) The first *white ramus communicans* in the thoracic region usually connects the first thoracic nerve with the first thoracic ganglion of the sympathetic trunk.

The **second intercostal nerve** is of large size, though much smaller than the first. It passes forwards, lying on the deep aspect of the second rib and covered by the parietal pleura. At a variable point, but usually well forwards, it passes between the innermost and internal intercostal muscles. At the level of the mid-axillary line it gives off a large lateral branch. It then continues its forward course either as a single trunk or as a main nerve in the upper part of

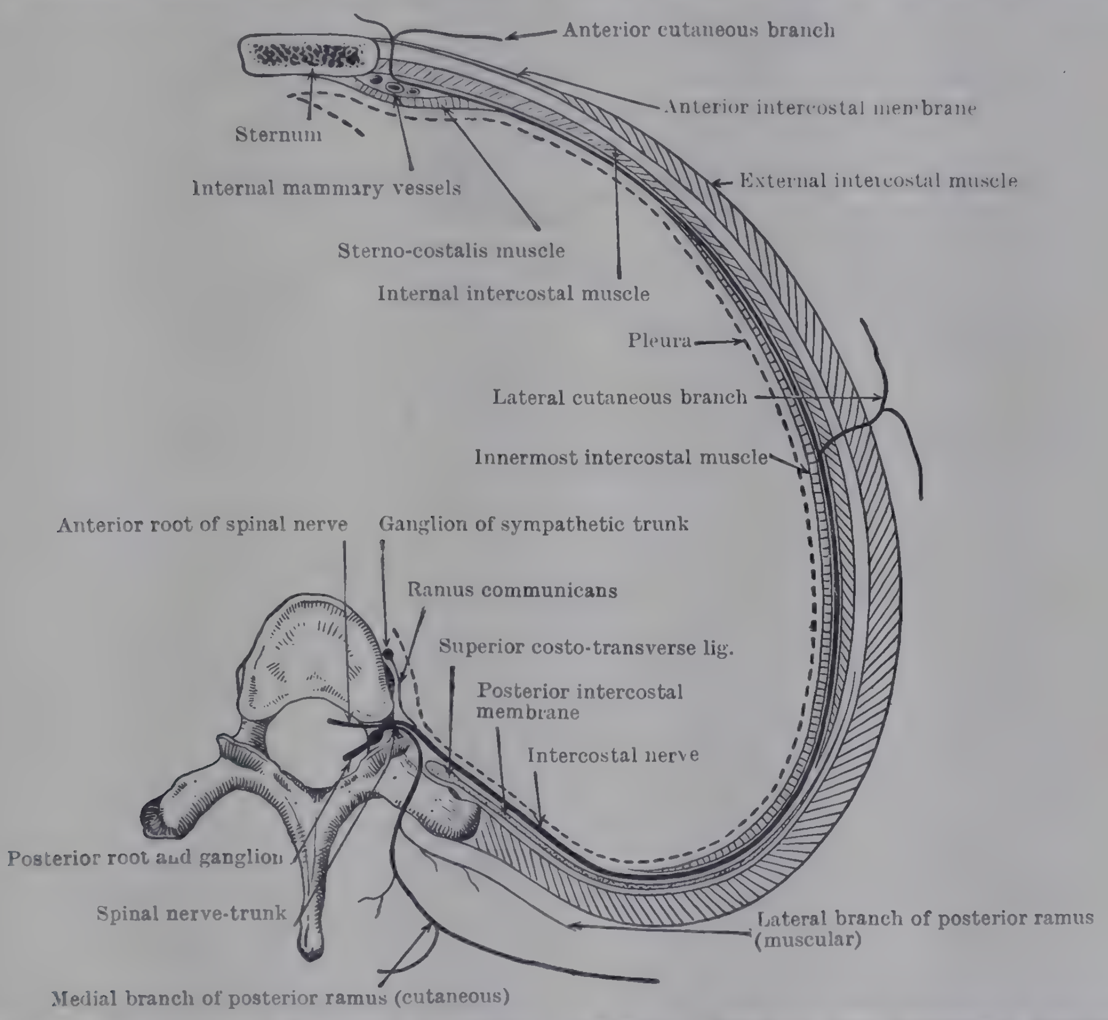

FIG. 936.—DIAGRAM TO SHOW RELATIONS OF TYPICAL INTERCOSTAL NERVE TO THE INTERCOSTAL MUSCLES AND MEMBRANES.

the space with a fine collateral nerve below (p. 1060); at the lateral border of the sternum, having crossed in front of the internal mammary artery, it passes forwards through the internal intercostal muscle, anterior intercostal membrane and pectoralis major, and ends in the front of the chest over the second intercostal space.

The nerve supplies the following branches:—

1. **Muscular branches** to the muscles of the second intercostal space.

2. **Cutaneous branches.** (*a*) Terminal **anterior cutaneous branches** to the skin and fascia over the second intercostal space (Fig. 918). (*b*) A large *lateral cutaneous branch* called the **intercosto-brachial nerve** (Figs. 922, 924). That nerve pierces the intercostal and serratus anterior muscles and crosses the axilla to reach the upper arm. It pierces the deep fascia just beyond the posterior fold of the axilla, and can be traced as far as the interval between the medial epicondyle of the humerus and the olecranon. It supplies an area of skin and fascia stretching across the axilla and along the posterior surface of

the upper arm on the medial side as far as the elbow (Fig. 928, p. 1074). It may supply the *axillary arches* when they are present.

The intercosto-brachial nerve varies in size. It may emerge through the first intercostal space; and it is often divisible into anterior and posterior branches, like the lateral cutaneous branch of an ordinary intercostal nerve.

Communications.—(1) The intercosto-brachial nerve communicates with two adjacent nerves. Either before or after piercing the deep fascia it is joined by the medial cutaneous nerve of the arm. It also communicates with the posterior part of the lateral cutaneous branch of the third intercostal nerve by means of the branches distributed to the floor and boundaries of the axilla. Sometimes it communicates with the lateral cutaneous branch of the first intercostal nerve. (2) Besides the branches referred to, the second thoracic nerve in many cases transmits a nerve to the brachial plexus which becomes incorporated with the first thoracic nerve after passing over the neck of the second rib. That branch is inconstant, as already mentioned (p. 1069). (3) Besides the communications effected by branches of the second thoracic nerve in its course, it receives a *grey ramus communicans* from the second thoracic ganglion of the sympathetic trunk; and it sends a *white ramus communicans* to the sympathetic.

The **third intercostal nerve** differs from a typical thoracic nerve only in one respect. Its **lateral cutaneous branch** divides in the usual way into anterior and posterior parts, of which the latter is carried to the upper arm and supplies an area of skin and fascia on the medial side near the root of the limb. It effects a junction with the intercosto-brachial nerve (Fig. 924, p. 1068).

The **fourth, fifth, and sixth intercostal nerves** have a course and distribution which are simple and typical. Except for the peculiarities above mentioned, the second and third intercostal nerves have a similar distribution.

At first each of these nerves lies in the posterior wall of the thorax between the ribs; then, entering the costal groove of the upper rib, it extends forwards between the innermost and the internal intercostal muscles, lying at a lower level than the intercostal vessels. Beyond the anterior limit of the innermost intercostal muscle the nerve lies in contact with the pleura and the endothoracic fascia, and farther forward passes in front of the sterno-costalis muscle and internal mammary artery. Thereafter, piercing the fibres of the internal intercostal muscle, the anterior intercostal membrane, and the pectoralis major, each nerve ends as an **anterior cutaneous branch,** which supplies the skin and fascia of the front of the chest over an area corresponding to the anterior part of the intercostal space to which it belongs (Fig. 936).

Branches.—Each intercostal nerve supplies, in addition to the terminal anterior cutaneous branches, *muscular branches* to the intercostal muscles, commonly a *collateral branch* (p. 1060) and a **lateral cutaneous branch,** which pierces the intercostal and serratus anterior muscles, and divides into anterior and posterior branches for the innervation of the skin and fascia over the side of the chest. Each area of skin thus innervated is continuous anteriorly with the area innervated by the anterior cutaneous branch of the same nerve, and posteriorly with the area supplied by its posterior ramus.

The upper six intercostal nerves supply the muscles of the first six intercostal spaces and the sterno-costalis (3, 4, 5, 6). The second, third, fourth, fifth, and sixth nerves supply the skin and fascia of the front of the chest: the second is immediately below the level of the sternal angle; the sixth is opposite the base of the xiphoid process. Their lateral branches supply branches to the intercostal muscles and the skin and fascia of the side of the chest, the second (intercosto-brachial) and the third, in part, being drawn out to the upper arm. The fourth supplies the nipple (Fig. 918). The upper six or seven intercostal nerves give numerous fine branches to the parietal pleura.

Communications.—Each of the intercostal nerves communicates with the sympathetic trunk and ganglia by two branches—a *white ramus communicans* to the corresponding sympathetic ganglion or the adjacent part of the sympathetic trunk; and a *grey ramus communicans* which passes to each nerve from the corresponding ganglion.

The **seventh, eighth, ninth, tenth, and eleventh intercostal nerves** differ from the preceding nerves only in regard to a part of their course and distribution. Each has the same course and communications as the preceding nerves

in the thoracic wall. In addition, these nerves have a further course and distribution in the abdominal wall. Each nerve traverses an intercostal space in the way described. At the anterior end of the space the nerve passes between the attachments of the diaphragm and the transversus abdominis muscle to the costal cartilages, and courses forwards in the abdominal wall between the transversus and obliquus internus muscles. The nerve then passes between the rectus abdominis muscle and the posterior wall of its sheath, where it divides into two branches. The larger passes medially behind the rectus, to which it sends a branch, and after breaking up in a plexiform manner gives off a cutaneous branch which pierces the muscle and the anterior wall of its sheath. The smaller division ends in the more lateral part of the rectus muscle.

Muscular Branches.—The lower intercostal nerves supply the intercostal muscles of the spaces in which they lie; and in the abdominal wall they innervate the transversus, obliquus internus and externus, and rectus abdominis. The branches arise from the main trunk as well as from its lateral and anterior branches. (The ninth, tenth, and eleventh nerves are described as assisting in the innervation of the diaphragm by communications with the phrenic nerve, but those fibres are probably afferent in function.)

Cutaneous Branches.—These are lateral and anterior. The **lateral cutaneous branches** divide into anterior and posterior parts, and, becoming superficial along the line of interdigitation of the obliquus externus muscle with the serratus anterior and latissimus dorsi, they are directed more obliquely downwards than the lateral branches of the higher intercostal nerves, and are distributed to the skin and fascia of the loin as far down as the iliac crest. The lateral branch of the eleventh nerve can be traced over the iliac crest into the gluteal region.

The **anterior cutaneous branches** are small. That of the seventh nerve innervates the skin and fascia at the level of the xiphoid process. The eighth and ninth appear between the xiphoid process and the umbilicus; the tenth nerve supplies the region of the umbilicus; and the eleventh, the area immediately below the umbilicus. The dermatomes are not placed horizontally, but tend to be drawn downwards anteriorly as the series is followed from the upper to the lower nerves.

The lower six intercostal nerves supply many fine branches to the parietal peritoneum and extra-peritoneal tissue.

The anterior primary ramus of the twelfth thoracic nerve is the **subcostal nerve**, and is peculiar in its course and distribution. It emerges below the last rib (Fig. 938), and passes laterally and downwards behind the upper part of the psoas muscle and sometimes behind the lowest part of the pleura. It enters the abdomen below the lateral arcuate ligament and crosses in front of the quadratus lumborum muscle. Behind the kidney it pierces the transversus abdominis muscle, and courses forwards in the interval between it and the obliquus internus. As it approaches the median line, it runs in front of the rectus muscle, and its terminal branches pierce the rectus sheath to become cutaneous about midway between the umbilicus and the pubis. The branches of the nerve are **muscular** to the transversus, obliqui, rectus, and pyramidalis muscles of the abdominal wall; and **cutaneous branches**, two in number—a terminal *anterior cutaneous branch*, which supplies the skin and fascia of the anterior abdominal wall midway between the umbilicus and the pubis, and a large *lateral cutaneous branch*, which, passing obliquely downwards through the lateral muscles of the abdominal wall, becomes superficial above the iliac crest, two inches behind the anterior superior spine. It supplies the skin and fascia of the gluteal region as far down as a point below and anterior to the greater trochanter of the femur (Figs. 916, 918).

The subcostal nerve often receives a **communicating branch** from the eleventh intercostal near its origin, and still more frequently it sends a fine branch to join the first lumbar nerve in the psoas muscle. It may communicate also with the ilio-hypogastric nerve as they lie near each other in the abdominal wall.

Intercommunications of the Thoracic Nerves.—It has been noted already that the dermatome supplied by the branches of each thoracic nerve is innervated also by the nerve above and below. Communications also take place between the branches that supply the intercostal muscles, whereby the muscles of a given space derive their innervation from more than one intercostal nerve.

LUMBAR, SACRAL, AND COCCYGEAL PLEXUSES

These plexuses are formed by the union of the anterior primary rami of the remaining spinal nerves (five lumbar, five sacral, and one coccygeal), and are united

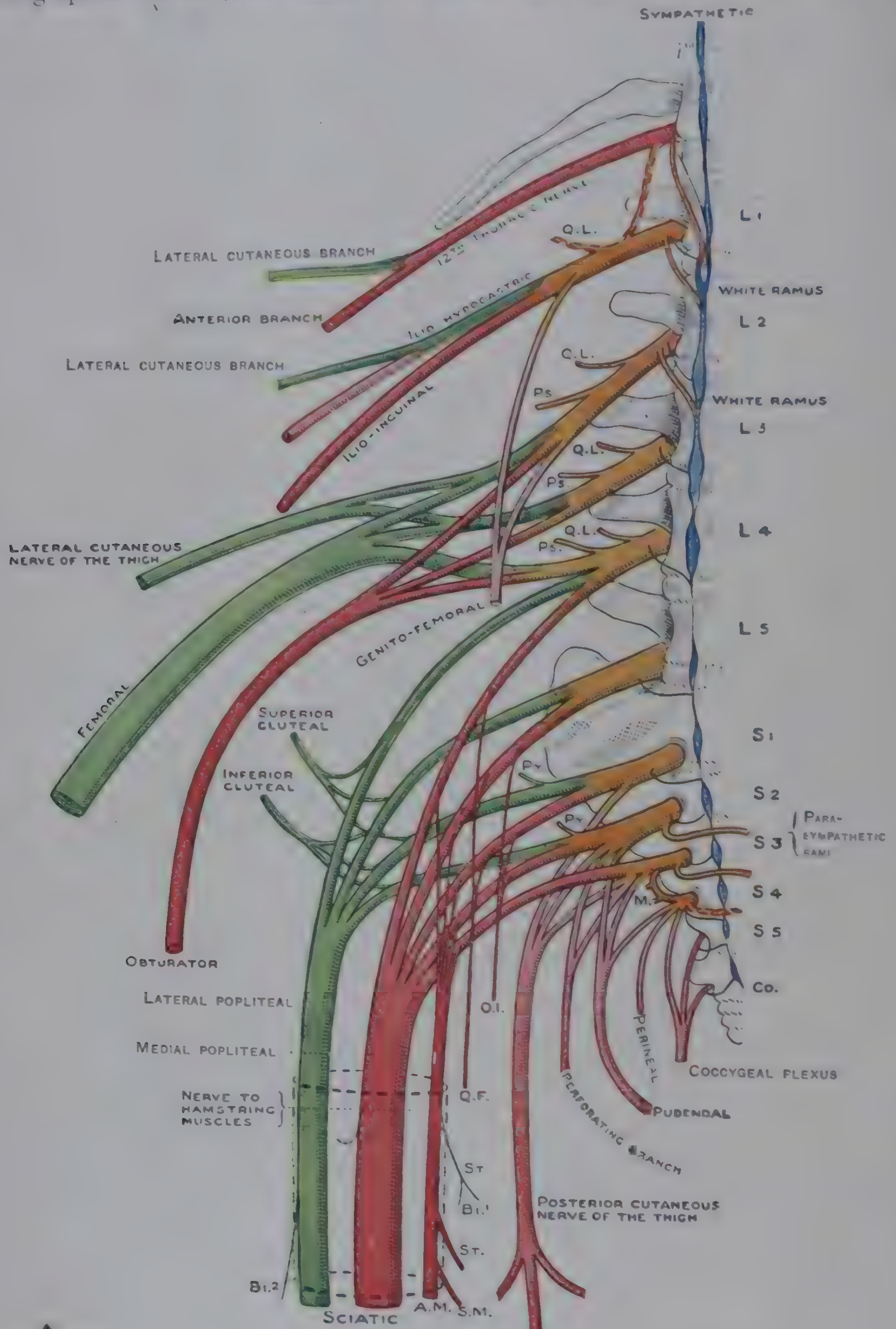

FIG. 937.—NERVES OF THE LUMBAR, SACRAL, AND COCCYGEAL PLEXUSES.

Anterior divisions, *red*; posterior, *green*.

A.M., Adductor magnus.
O.I., Obturator internus.
Q.F., Quadratus femoris.
S.M., Semimembranosus.
Bi., Biceps.
Ps., Psoas.
Q.L., Quadratus lumborum.
S.T., Semitendinosus.
M., Muscular branches to sphincter ani externus.
Py., Piriformis.

with one another—the lower lumbar nerves passing into the sacral plexus and the lower sacral into the coccygeal plexus. Frequently a fine communicating branch of the subcostal nerve joins the first lumbar nerve near its origin.

Of the nerves in question the first sacral is generally the largest in size, the nerves diminishing gradually above that nerve and rapidly below it. The nerves destined for the supply of the lower limb spring from the lumbar and sacral plexuses; in addition, nerves arise at their upper limit to be distributed to the trunk above the level of the limb; and near the lower limit nerves arise for the supply of the perineum.

Lumbar Plexus.—The lumbar plexus is formed by the anterior primary rami of the first four lumbar nerves, and is often joined by a branch from the twelfth thoracic nerve. It is limited below by the fourth lumbar nerve (*n. furcalis*), which enters also into the composition of the sacral plexus. The nerves of the lumbar plexus are formed in the loin, and supply that region as well as part of the lower limb.

Sacral Plexus.—The sacral plexus is formed by the anterior primary rami of the fourth and fifth lumbar and the upper four sacral nerves—the fourth sacral nerve dividing to take part in the coccygeal plexus also. The nerves of the sacral plexus are placed on the dorsal wall of the true pelvis, and are destined for the lower limb and the perineum.

Coccygeal Plexus.—The coccygeal plexus is formed by the anterior primary rami of the coccygeal and fifth sacral nerves and a portion of the fourth. It lies on the coccygeus muscle in the dorsal wall of the pelvis, and its branches are fine filaments to the coccygeus and levator ani and to the skin over the coccyx.

Communications with Autonomic System.—Each of the nerves has communications with the sympathetic trunk in the abdomen and pelvis by means of **grey rami communicantes.** From the lumbar and sacral ganglia, long, slender *grey rami communicantes* are directed backwards and laterally over the bodies of the vertebræ, and (in the lumbar region) behind the origins of the psoas muscle, to reach the spinal nerves. Those branches are irregular in their arrangement. A given nerve may receive branches from two ganglia, or one ganglion may send branches to two nerves. The grey rami are longer in the loin than in the pelvis, owing to the position of the sympathetic trunk.

Certain lumbar nerves are connected with the sympathetic by means of *white rami communicantes* also. From the first two lumbar nerves, and possibly in some cases also the third, white rami are directed forwards, either independently or incorporated with the corresponding grey rami, to join the upper part of the lumbar sympathetic trunk. The lower lumbar nerves and the sacral and coccygeal nerves are unprovided with white rami.

From the anterior primary rami of the second and third or third and fourth sacral nerves, parasympathetic fibres pass medially, and, crossing over (without joining) the sympathetic trunk, enter the pelvic plexuses of the autonomic system.

Variations in Position of Lumbar and Sacral Plexuses

These plexuses show a very considerable variability in position and constitution. Eisler (1891) records concomitant variations in 18 per cent. of the cases examined by him. The variations occur within wide limits. The lumbar plexus may begin at the eleventh or twelfth thoracic or first lumbar nerve. The last nerve in the sciatic cord may be either the second, the third, or the fourth sacral nerve. The position of the *nervus furcalis* is a guide to the arrangement of the plexus. It may be the third, third and fourth, fourth, fourth and fifth, or fifth lumbar nerves. The resulting variations are illustrated by the following extreme cases :—

	(1) *Prefixed Variety.*	(2) *Normal.*	(3) *Postfixed Variety*
Nervus furcalis	L. 3 and 4 (double).	L. 4.	L. 5.
Obturator	L. 1, 2, 3.	L 2, 3, 4.	L. 2, 3, 4, 5.
Femoral	T. 12, L. 1, 2, 3, 4.	L. 2, 3, 4	L. 2, 3, 4, 5.
Med. popliteal	L. 3, 4, 5, S. 1, 2.	L. 4, 5, S. 1, 2, 3.	L. 5, S. 1, 2, 3, 4.
Lat. popliteal	L. 3, 4, 5, S. 1.	L. 4, 5, S. 1, 2.	L. 5, S. 1, 2, 3.

The variations in the constitution of the lumbar and sacral plexuses which are most numerous are those due to the inclusion of nerves more caudally placed. Thus, out of twenty-two variations in the position of the *n. furcalis*, in nineteen Eisler found it to be the fifth lumbar nerve; in two cases only, the third lumbar nerve. There is further evidence that these variations in position are accompanied by variations in the vertebral column itself. Out of the twenty-two abnormal plexuses examined by Eisler, sixteen were coincident with abnormal arrangement of the associated vertebræ.

LUMBAR PLEXUS

The **lumbar plexus** is formed by the anterior primary rami of the first three lumbar nerves and a part of the fourth, with the addition, in half the number of

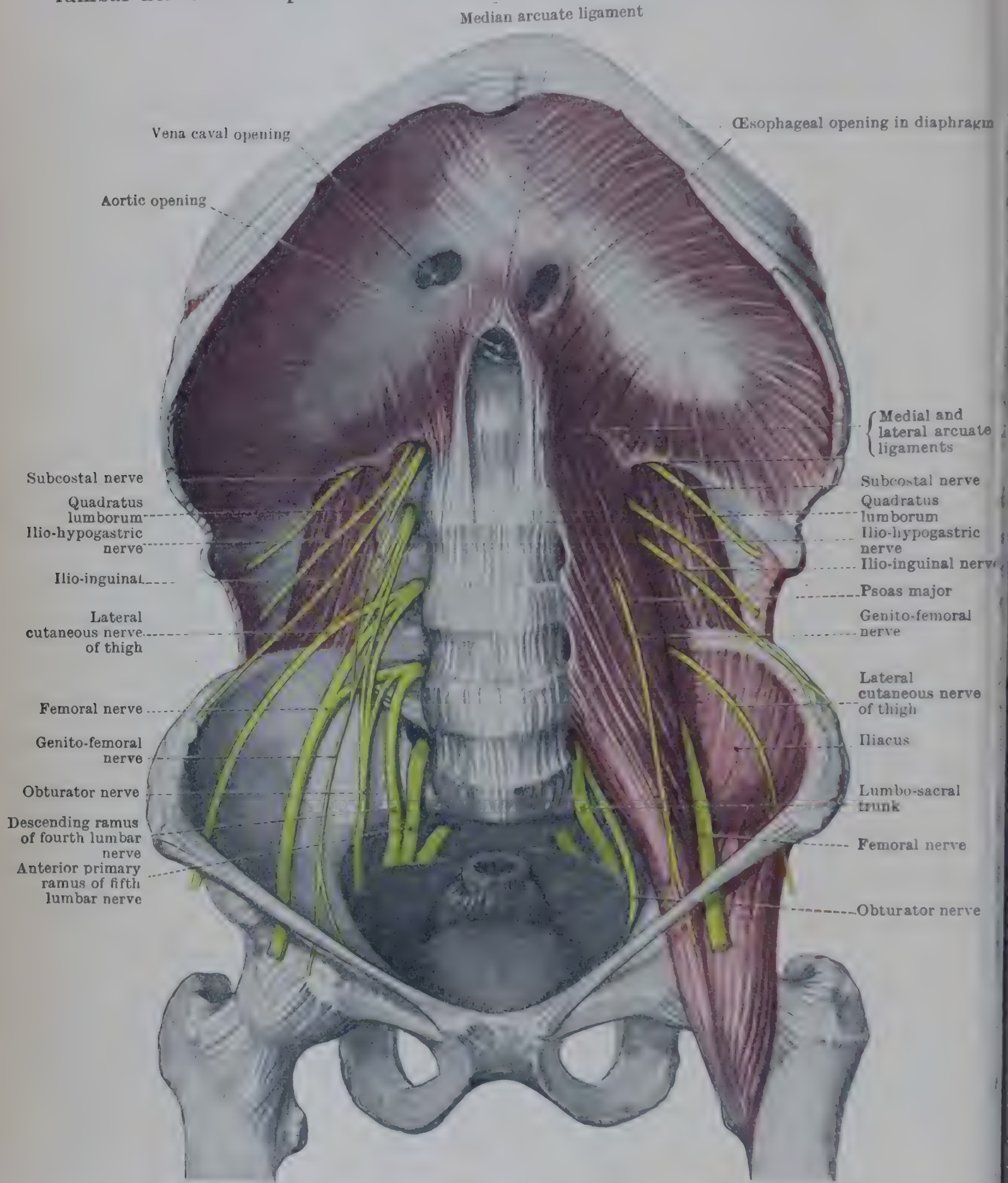

FIG. 938.—MUSCLES AND NERVES ON POSTERIOR ABDOMINAL WALL.

cases, of a small branch from the subcostal nerve. The nerves increase in size from above downwards (Fig. 938).

Position and Constitution.—The plexus is formed in the substance of the psoas major muscle, in front of the transverse processes of the lumbar vertebræ. The nerves, on emerging from the intervertebral foramina, are connected as above described with the sympathetic system, and then divide in the following manner in the substance of the psoas major muscle. The first and second nerves divide into superior and inferior branches. The superior branch of the first nerve (which may

be joined by the branch from the subcostal nerve) forms two nerves, the **ilio-hypogastric** and **ilio-inguinal**. The inferior branch of the first joins the superior branch of the second nerve, to form the **genito-femoral nerve**. The inferior branch of the second nerve, the whole of the third, and that part of the fourth nerve engaged in the constitution of the plexus divide each into two unequal parts—smaller *anterior* and larger *posterior parts*. The anterior portions combine together to form the **obturator nerve**; the root from the second nerve is not always present. The posterior portions of the same nerves combine together to form the **femoral nerve**. From the back of the posterior parts of the second and third nerves the **lateral cutaneous nerve of the thigh** arises. The nerves also provide, near their origins, irregular **muscular branches** for the psoas and quadratus lumborum muscles. The following is a list of the nerves which spring from the lumbar plexus, together with their origins:—

(1) Muscular branches to the quadratus lumborum (L. 1-4) and psoas (L. 2, 3) muscles.
(2) Ilio-hypogastric (? T. 12, L. 1).
(3) Ilio-inguinal (? T. 12, L. 1).
(4) Genito-femoral (L. 1, 2).
(5) Lateral cutaneous (L. 2, 3).
(6) Obturator (L. 2, 3, 4).
(7) Femoral (L. 2, 3, 4).

Muscular Branches.—The nerves to the **quadratus lumborum muscle** arise independently from the first three or four lumbar nerves (and sometimes also from the subcostal nerve). The nerves to the **psoas major** arise from the second and third lumbar nerves, with additions, in some cases, from the first or fourth. They are often associated in their origin with the nerve to the iliacus from the femoral nerve. The **psoas minor**, when present, is innervated by the first or the second lumbar nerve.

The ilio-hypogastric and ilio-inguinal nerves are in series with the subcostal nerve and closely resemble it in their course and distribution.

The **ilio-hypogastric nerve** is the highest branch of the first lumbar nerve. It receives fibres also from the subcostal when that nerve communicates with the first lumbar nerve. After traversing the psoas major muscle obliquely, it appears at its lateral border, on the anterior surface of the quadratus lumborum and behind the kidney. It courses through the loin, lying between the transversus and obliquus abdominis internus muscles, above the iliac crest. About an inch in front of the anterior superior spine it pierces the obliquus internus (Fig. 940), and continues its course in the groin deep to the aponeurosis of the obliquus externus. It finally becomes cutaneous in the anterior abdominal wall by piercing the aponeurosis of the obliquus externus about an inch and a half above the superficial inguinal ring (Fig. 918, p. 1059).

Its **branches** are—(1) *muscular* to the muscles of the abdominal wall; and (2) *cutaneous branches*, two in number. The **lateral cutaneous branch** corresponds to the lateral cutaneous branch of an intercostal nerve. It pierces the obliquus internus and obliquus externus, becomes cutaneous just above the iliac crest, below and behind the lateral cutaneous branch of the subcostal nerve. It is small, and may be absent. It is distributed to the skin and fascia over the upper part of the lateral side of the gluteal region, in contiguity with the cutaneous branch of the posterior primary ramus of the first lumbar nerve. The **anterior cutaneous branch** is the terminal branch of the nerve. It supplies the skin and fascia of the anterior abdominal wall below the level of the subcostal nerve and above the os pubis.

The **ilio-inguinal nerve** is the second branch given off from the first lumbar nerve. It also may receive fibres from the subcostal nerve. Not infrequently the ilio-hypogastric and ilio-inguinal nerves are represented for a longer or shorter part of their course by a single trunk. When separate the nerve takes a course similar to that of the ilio-hypogastric nerve, but at a lower level, as far as the anterior abdominal wall. It appears at the lateral border of the psoas major, after traversing the muscle obliquely, and passes behind the kidney in front of the quadratus lumborum. It extends forwards between the transversus and obliquus internus, and pierces the latter muscle (Fig. 940) farther forward and

lower down than the ilio-hypogastric; it continues forwards deep to the aponeurosis of the obliquus externus, just above the inguinal ligament, and thus comes to lie in the inguinal canal; it becomes superficial after passing through the superficial inguinal ring and external spermatic fascia (Fig. 918). Whilst lying between the transversus and obliquus internus it usually communicates with the ilio-hypogastric nerve.

Its branches are *muscular* to the muscles of the abdominal wall among which it passes, and *cutaneous branches* which innervate the skin and fascia (1) of the anterior abdominal wall over the pubic symphysis, (2) of the thigh over the proximal and medial part of the femoral triangle, and (3) of the superior part of the scrotum, and root and dorsum of the penis in the male (*scrotal branches*), and of the mons pubis and labium majus in the female (*labial branches*). The last-named branches are contiguous to branches of the pudendal nerve. No lateral cutaneous branch arises from the ilio-inguinal nerve. It thus corresponds, like the anterior cutaneous part of the ilio-hypogastric nerve, to the anterior continuation of a typical thoracic nerve.

The **genito-femoral nerve** usually arises from the front of the first and second lumbar nerves by two independent roots which unite in the substance of the psoas major. It appears on the posterior abdominal wall, lying on the front of the psoas major, medial to the psoas minor. It pierces the psoas fascia, and extends behind the ureter and along the lateral side of the common and external iliac arteries downwards, to the inguinal ligament (Fig. 938). At a variable point above that ligament it divides into two branches. 1. The **genital branch** is a small nerve which passes in front of the lower part of the external iliac artery, and enters the inguinal canal through the deep inguinal ring. It ends by supplying small branches to the skin and fascia of the scrotum and adjacent part of the thigh. In the female it accompanies the round ligament to the labium majus. In its course it gives off the following small branches: (1) to the external iliac artery; (2) to the cremaster muscle; (3) to communicate with the testicular plexus of the autonomic system and the ilio-inguinal nerve. 2. The **femoral branch** continues the course of the parent nerve and passes into the thigh behind the inguinal ligament and then lies on the lateral side of the femoral artery. It becomes cutaneous by passing through the saphenous opening or through the fascia lata, and supplies an area of skin and fascia over the femoral triangle, lateral to that supplied by the ilio-inguinal nerve (Fig. 941). It communicates in the thigh with the intermediate cutaneous branch of the femoral nerve. Before piercing the deep fascia it gives a minute branch to the femoral artery.

The **lateral cutaneous nerve of the thigh** is distributed only to skin and fascia. It arises from the back of the lumbar plexus, and usually from the second and third lumbar nerves (Fig. 938). Emerging from the lateral border of the psoas major muscle, the nerve crosses the iliacus muscle, behind the fascia iliaca, to reach the anterior superior iliac spine. It enters the thigh behind the lateral end of the inguinal ligament, and either superficial or deep to the sartorius muscle, or through its upper part (Fig. 940). It extends downwards in the front of the thigh for a few inches, lying at first deep to the fascia lata, and afterwards in a tubular investment of the fascia. It gives off small branches in this part of its course, and finally, piercing the fascia about four inches distal to the anterior superior iliac spine, it separates into anterior and posterior terminal branches. The **anterior branch** is the larger, and is distributed on the lateral part of the front of the thigh as far as the knee, where it may communicate with the patellar plexus. The smaller **posterior branch** supplies the skin and fascia of the lateral side of the buttock, distal to the greater trochanter, and the skin and fascia of the proximal two-thirds of the lateral side of the thigh (Fig. 941).

Obturator Nerve

The **obturator nerve** supplies the muscles on the medial side of the thigh, gives articular branches to the hip and knee joints, and sometimes has also a cutaneous branch. It arises in the substance of the psoas major muscle by three

roots placed in front of those of the femoral nerve, and derived from the second, third, and fourth lumbar nerves (Fig. 938). Sometimes the root from the second nerve is absent. Passing vertically downwards, the nerve emerges from the psoas major at its medial border, behind the common iliac vessels, and on the lateral side of the ureter and internal iliac vessels. It passes forwards below the pelvic brim in contact with the upper part of the obturator internus muscle and in company with the obturator artery to the obturator groove of the obturator

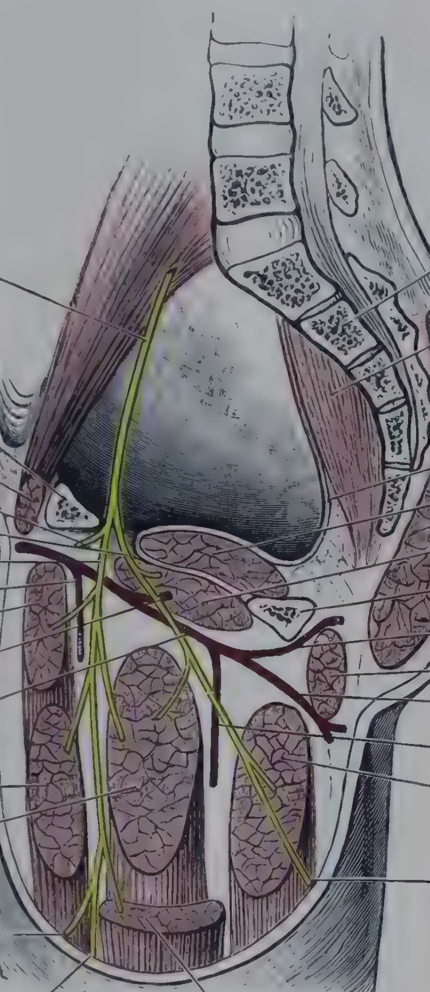

FIG. 939.—SCHEME OF COURSE AND DISTRIBUTION OF OBTURATOR NERVE.

foramen, through which it reaches the thigh. While in the obturator groove, where it lies above the obturator vessels, it separates into its two main branches, named anterior and posterior (Fig. 939).

In the thigh the **anterior branch** lies in front of the obturator externus and adductor brevis muscles, and behind the pectineus and adductor longus (Fig. 940). In the middle third of the thigh it is found coursing along the medial border of the adductor longus; and it finally divides into two slender terminal filaments.

The branches of the **anterior part** of the nerve are:—

1. An **articular branch** to the hip joint which arises from the nerve as soon as it enters the thigh, and supplies the joint through the acetabular notch.

2. **Muscular branches** to the adductor longus, gracilis, adductor brevis (usually), and the pectineus (occasionally).

3. Two *terminal branches*: (*a*) A **cutaneous branch**, of very variable size and often absent, becomes superficial between the gracilis and adductor longus (Fig. 939), in the middle third of the thigh, and may supply the skin and fascia of the distal two-thirds of the thigh on its medial side. It is generally of small size, and is connected with branches of the medial cutaneous nerve of the thigh and the saphenous nerve behind the sartorius muscle to form a plexus. The branch from the saphenous nerve to the plexus passes medially behind the sartorius

after piercing the fascial covering of the subsartorial canal. The branch from the medial cutaneous nerve is generally superficial at the point of formation of the plexus. (*b*) **A branch to the femoral artery** which enters the subsartorial canal along the medial border of the adductor longus, and ramifies over the distal part of the artery.

5. A fine **communicating branch** sometimes joins the femoral nerve in front of the hip joint.

The posterior branch of the obturator nerve reaches the thigh by piercing the obturator externus muscle. It descends between the adductor brevis and adductor magnus muscles. After passing obliquely through the adductor magnus, it enters the popliteal fossa on the popliteal artery, to which it furnishes twigs, and terminates by piercing the oblique posterior ligament of the knee joint.

Its branches are: (1) **muscular branches** to the obturator externus, adductor magnus, and the adductor brevis. The branch to the obturator externus arises in the obturator groove before the nerve enters the muscle. The nerve to the adductor magnus is given off as the obturator nerve passes through the substance of the muscle. (2) The **articular terminal branch** to the posterior part of the knee joint.

Femoral Nerve

The **femoral nerve** is the large nerve of supply for the muscles of the front of the thigh; it gives articular branches to the hip and knee joints; and it has an extensive cutaneous distribution down the medial side of the limb to the foot. It arises in the substance of the psoas major muscle, from the back of the second, third, and fourth lumbar nerves, posterior to the obturator nerve. Passing obliquely through the psoas major muscle, it emerges from its lateral border a little below the iliac crest (Fig. 938), and runs downwards in the groove between the psoas and iliacus to enter the thigh behind the inguinal ligament lateral to the femoral sheath and femoral vessels. In the femoral triangle it soon breaks up into a large number of branches (Fig. 940), among which the lateral circumflex artery passes in a lateral direction.

The **branches** of the femoral nerve, which are (1) muscular, (2) articular, (3) cutaneous, and (4) vascular, arise in the following way:—

In the abdomen a muscular branch arises from the lateral side of the nerve and enters the iliacus muscle, and a vascular branch descends to supply the femoral artery, which vessel also receives branches lower down in the thigh.

In the femoral triangle the terminal muscular, articular and cutaneous branches arise in the form of a large bundle of nerves.

1. The **muscular branches** supply the pectineus, sartorius, and quadriceps. The nerve to the *pectineus* arises close to the inguinal ligament and courses obliquely downwards and medially behind the femoral vessels to enter the muscle near its lateral border. It is not infrequently double. It sometimes gives off a fine communicating branch to the anterior part of the obturator nerve. The nerves to the *sartorius* are in two sets: a lateral set of short branches, associated with the lateral part of the intermediate cutaneous nerve, which supply the proximal part of the muscle; and a medial set of longer branches, which are associated with the medial part of the intermediate cutaneous nerve, and enter the middle of the muscle. The parts of the *quadriceps* are supplied by several branches. The vastus lateralis and rectus femoris are supplied on their deep surface by separate branches which are accompanied by branches of the lateral circumflex artery. The vastus intermedius muscle is supplied superficially by a branch which passes through the muscle, and supplies also the muscle of the knee joint (articularis genu). This muscle receives fibres also from one of the nerves to the vastus medialis. The vastus medialis muscle is supplied by two nerves: a proximal trunk, which supplies the proximal part of the muscle, and sends fibres to the vastus intermedius as well: and a distal trunk, which descends on the lateral side of the femoral artery along with the saphenous nerve; it passes deep to the sartorius, deep or superficial to the aponeurotic covering of the subsartorial canal, and enters the

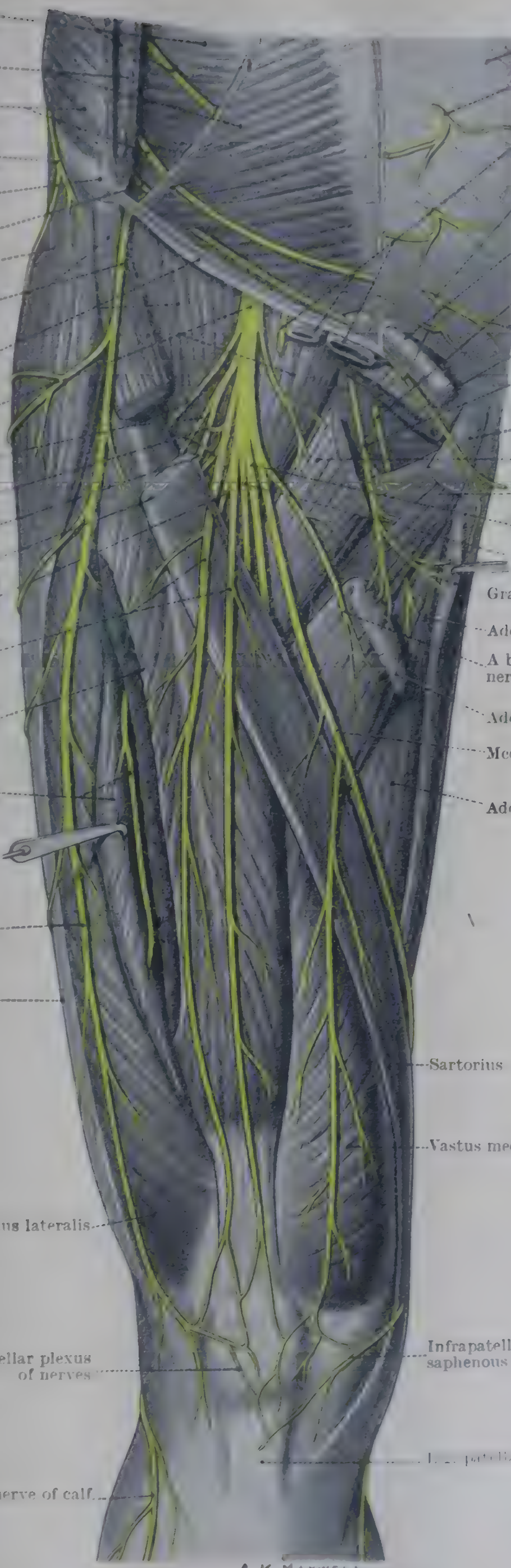

FIG. 940.—NERVES OF FRONT OF THIGH.

medial side of the muscle. That nerve gives off a small branch which enters the nutrient canal of the femur.

2. The **articular branches** supply the hip and knee joints. The articular branch to the hip joint arises from the nerve to the rectus femoris, and is accompanied by branches from the lateral circumflex artery. The articular branches to the knee joint are four in number. Three of them arise from the nerves to the

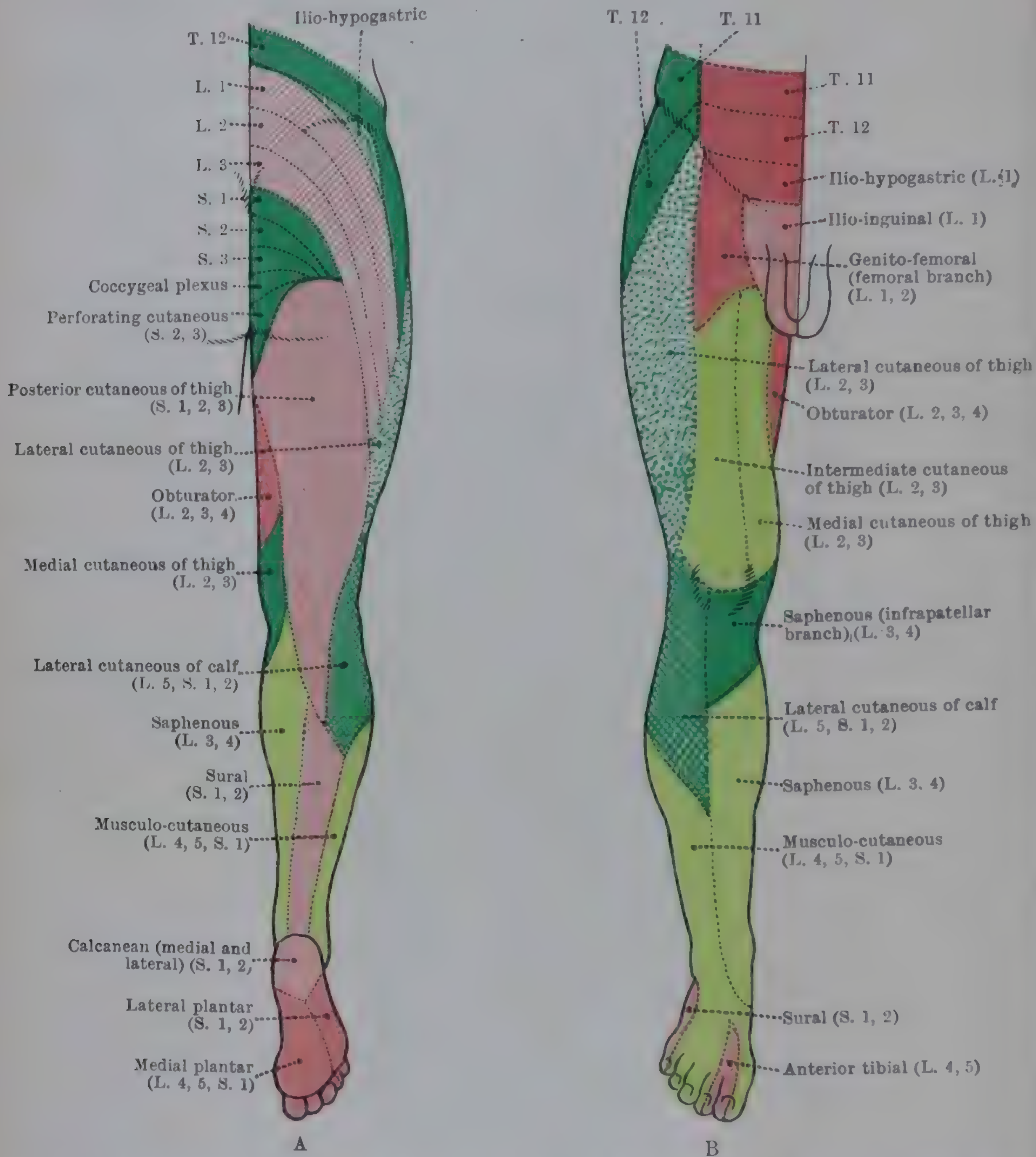

FIG. 941.—DISTRIBUTION OF CUTANEOUS NERVES: A, ON THE BACK: B, ON THE FRONT OF LOWER LIMB. The dorsal surfaces of the terminal phalanges are supplied by the plantar nerves (Fig. 949). The overlapping of nerve-areas, and of dermatomes in Fig. 942, is not shown (see p. 1053). The segmental distribution of individual spinal nerves in the lower part of the trunk and upper part of the thigh is represented, according to more recent clinical data, in the dermatome diagrams in Fig. 942.

vastus lateralis, vastus intermedius, and vastus medialis, which, after the muscular branches are given off, are continued downwards to the knee joint along the front of the femur. A fourth articular branch arises (sometimes) from the saphenous nerve.

3. The **cutaneous branches** are the intermediate and medial cutaneous nerves, and the saphenous nerve (Figs. 940, 941).

The **intermediate cutaneous nerve of the thigh** arises in two parts, a *lateral* and a *medial branch*, in the proximal part of the femoral triangle. The two branches

descend vertically and become cutaneous by piercing the fascia lata over the proximal third of the sartorius muscle. They carry muscular branches to the sartorius, and the lateral branch in many cases pierces the muscle. The two nerves supply the skin and fascia of the distal three-fourths of the front of the thigh, between the lateral cutaneous nerve of the thigh laterally and the medial cutaneous on the medial

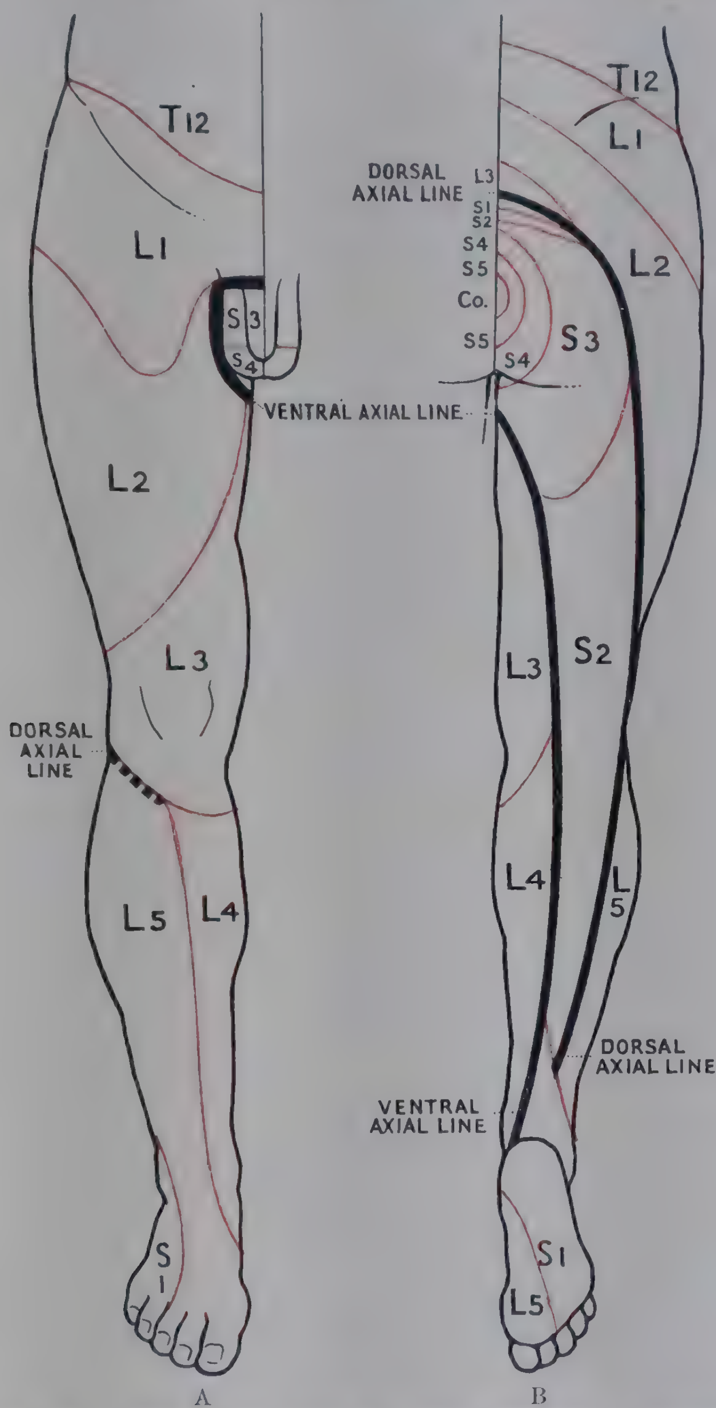

FIG. 942.—DERMATOMES OF LOWER LIMB, SHOWING THE SEGMENTAL CUTANEOUS DISTRIBUTION OF SPINAL NERVES (T 12, L 1-5, S 1-5, Co.) ON A, THE FRONT, AND B, THE BACK OF THE LIMB AND LOWER PART OF TRUNK (AFTER HEAD, 1893 AND FOERSTER, 1933). See p. 1053 for definition of "dermatome" and p. 1114 for more particular reference to the segmental innervation of the lower limb.

side. They reach to the front of the patella, and there assist in the formation of the patellar plexus. The lateral branch communicates, in the proximal third of the thigh, with twigs from the femoral branch of the genito-femoral nerve.

The **medial cutaneous nerve of the thigh** lies at first in the femoral triangle on the lateral side of the femoral vessels. At the apex of the triangle it crosses over the femoral vessels, and is directed downwards superficial to or through the sartorius muscle, and deep to the fascia lata, to the distal third of the thigh. It is distributed to the skin and fascia of the distal two-thirds of the thigh on the medial side by means of three branches—proximal, middle, and distal.

The *proximal branch* may be represented by two or more twigs. It arises from the main nerve near its origin, and pierces the fascia lata near the apex of the femoral triangle. It is distributed to the skin and fascia of the proximal part of the thigh along the line of the long saphenous vein. The *middle* or *anterior branch* is a larger nerve. It separates from the distal branch at the apex of the femoral triangle, and, passing superficial to the sartorius muscle, becomes cutaneous in the middle third of the thigh on the medial side. It supplies the skin and fascia of the distal half of the medial side of the thigh, extending as far as the knee, where it joins in the formation of the patellar plexus.

The *distal branch* represents the termination of the nerve. It passes along the medial side of the thigh superficial to the sartorius muscle, and communicates in the middle third of the thigh with the saphenous and obturator nerves to form a plexus. Piercing the fascia lata on the medial side of the thigh in the distal third, it ramifies over the medial side of the knee, and assists in the formation of the patellar plexus.

The size of the medial cutaneous nerve of the thigh varies with the size of the cutaneous part of the obturator, and of the saphenous nerve.

The **saphenous nerve** may be regarded as the terminal branch of the femoral nerve. It is destined for the skin and fascia of the leg and foot. From its origin in the femoral triangle it descends alongside the femoral vessels to the subsartorial canal. In the canal it crosses obliquely in front of the femoral artery from lateral to medial side. At the distal end of the canal, accompanied by the saphenous branch of the descending genicular artery, it passes anterior to the tendon of the adductor magnus, and becomes cutaneous opposite the medial side of the knee joint by passing between the sartorius and gracilis muscles (Fig. 940). The nerve then extends downwards in the leg with the long saphenous vein, passes over the front of the medial malleolus and terminates at the middle of the medial border of the foot.

Branches.—1. A **communicating branch** arises in the subsartorial canal and, passing medially behind the sartorius, joins with branches of the obturator nerve in forming a plexus.

2. The **infrapatellar branch** arises at the distal end of the subsartorial canal, and, piercing the sartorius muscle, is directed downwards and forwards below the patella and over the medial condyle of the tibia to the front of the knee and proximal part of the leg. It enters into the formation of the patellar plexus.

3. An **articular branch** sometimes arises from the nerve at the medial side of the knee.

4. The **terminal branches** of the saphenous nerve are distributed to the skin and fascia of the front and medial side of the leg and the posterior half of the dorsum and medial side of the foot.

The **patellar plexus** consists of fine communications, beneath the skin in front of the knee, between the branches of the cutaneous nerves supplying that region. The nerves which enter into its formation are the infrapatellar branch of the saphenous, medial and intermediate cutaneous, and sometimes the lateral cutaneous nerve of the thigh.

The **accessory obturator nerve** is only occasionally present (29 per cent, Eisler, 1891). It arises from the third, or third and fourth lumbar nerves, between the roots of the obturator and femoral nerves. It is associated with the obturator nerve, from which, however, it is quite separable. It appears in the abdomen at the medial side of the psoas muscle and passes over the pelvic brim behind the external iliac vessels, leaves the obturator nerve, and enters the thigh in front of the os pubis.

In the thigh, behind the femoral vessels, it usually ends in three branches: a nerve which replaces the branch from the femoral nerve to the pectineus, a nerve to the hip joint, and a nerve which communicates with the anterior part of the obturator nerve. In some cases it supplies only the nerve to the pectineus; more rarely it is of considerable size, and reinforces the obturator nerve in the innervation of the adductor muscles.

It is more closely associated with the femoral than with the obturator. Its origin is behind the roots of the obturator: it is separated, like the femoral, from the obturator by the pubic bone; and its chief branch—the branch to the pectineus muscle—replaces the normal branch from the femoral nerve. On the other hand, for a part of its course it accompanies the obturator, and in rare cases it may replace branches of that nerve.

SACRAL PLEXUS

The sacral plexus is usually formed by the anterior primary rami of the following nerves—a part of the fourth lumbar nerve (n. furcalis), the fifth lumbar, the upper three sacral nerves and part of the fourth.

Position and Constitution.—The plexus is placed on the dorsal wall of the pelvis between the piriformis muscle and its fascia. In front of it there are the internal iliac vessels and the ureter, and, in addition, the pelvic colon on the left side, coils of the ileum on the right side.

The nerves which form the plexus converge towards the inferior part of the greater sciatic foramen, and unite to form a broad triangular band, the apex of which is continued through the greater sciatic foramen below the piriformis muscle into the gluteal region as the **sciatic nerve**. From the anterior and posterior surfaces of the triangular band numerous small branches arise and are distributed to the parts in the neighbourhood of the origin of the nerve.

The sciatic nerve ends in the thigh by dividing into two large nerves—the *medial popliteal* and *lateral popliteal*. In many cases these two nerves are distinct at their origin, and are separated sometimes by fibres of the piriformis muscle. In all cases, on removal of the sheath investing the sciatic nerve, the two divisions can be traced up to the plexus, from which they invariably take origin by distinct and separate roots.

Formation.—The descending branch of the fourth lumbar nerve after emerging from the border of the psoas major muscle, medial to the obturator nerve, divides behind the iliac vessels into anterior and posterior (ventral and dorsal) parts, each of which joins a corresponding part of the fifth lumbar nerve. The anterior primary ramus of the fifth lumbar nerve descends over the ala of the sacrum and in front of the sacro-iliac joint, and divides into anterior and posterior parts, which are joined by the corresponding parts of the fourth lumbar nerve. The two resulting trunks lie close together and are called the **lumbo-sacral trunk**. The first and second sacral nerves pass laterally from the anterior sacral foramina, and divide in front of the piriformis into similar anterior and posterior parts. The third sacral nerve runs laterally to join the second. The fourth divides into two parts, of which the upper joins the sacral plexus and the lower joins the coccygeal plexus. Of those nerves the fifth lumbar and first sacral are the largest; the others diminish in size as they are traced downwards.

The principal nerve that arises from the sacral plexus is the sciatic, and its two components (lateral and medial popliteal) are formed in the following way. Lying in apposition, and converging on the lower part of the greater sciatic foramen, the *posterior* (dorsal) *trunks* of the fourth and fifth lumbar nerves, and of the first and second sacral nerves, combine to form the **lateral popliteal nerve**. The *anterior* (ventral) *trunks* of the fourth and fifth lumbar nerves, and of the first and second sacral nerves, together with part of the third sacral nerve, unite to form the **medial popliteal nerve** (Fig. 937).

Branches.—Besides the sciatic nerve, the sacral plexus gives rise to numerous smaller nerves, some of which arise from the front of it and some from the back.

Anterior Branches.

- Nerve to quadratus femoris and inferior gemellus (L. 4, 5, S. 1)
- Nerve to obturator internus and superior gemellus (L. 5, S. 1, 2)
- Pelvic splanchnic nerves (S. 2, 3, 4)
- Pudendal nerve (S. 2, 3, 4)

Posterior Branches.

- Muscular twigs to piriformis (S. 1, 2) and to coccygeus and levator ani (S. 3, 4)
- Superior gluteal nerve (L. 4, 5, S. 1)
- Inferior gluteal nerve (L. 5, S. 1, 2)
- Posterior cutaneous nerve of thigh (S. 1, 2, 3)
- Perforating cutaneous nerve (S. 2, 3)
- Perineal branch of S. 4.

We shall deal with these *collateral* branches before we trace the course and distribution of the large, *terminal* branch (the sciatic) and its subdivisions.

Collateral Branches of Sacral Plexus

The **nerve to the quadratus femoris** (and **inferior gemellus**) arises from the front of the fourth and fifth lumbar and first sacral nerves. It leaves the pelvis through the lower part of the greater sciatic foramen, passes downwards over the back of the ischium near the capsule of the hip joint (to which it sends a fine branch) deep to the sciatic nerve, gemelli, and obturator internus muscles. It supplies a nerve to the inferior gemellus, and terminates in the deep surface of the

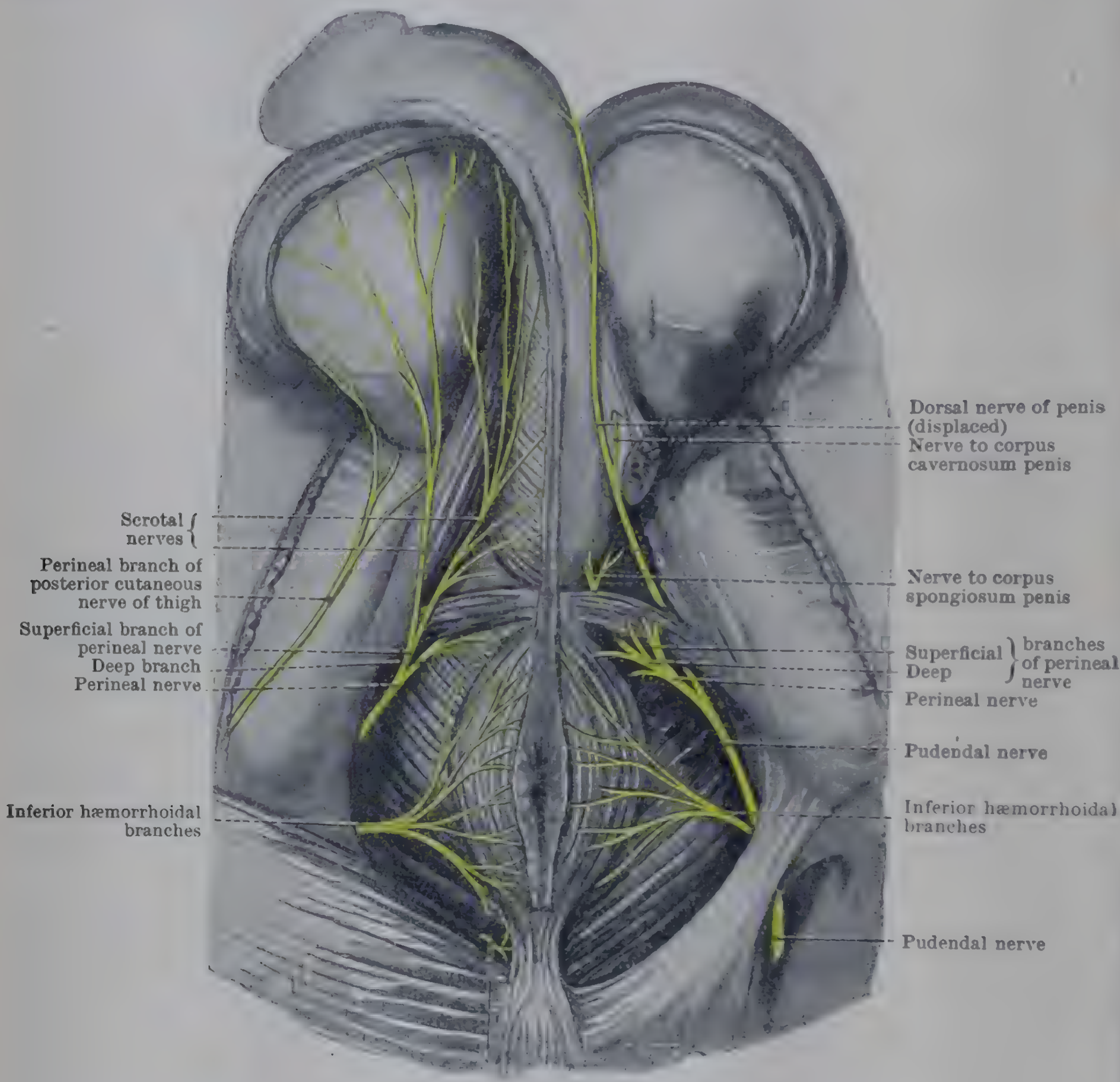

Fig. 943.—Distribution of the Pudendal Nerve.

quadratus femoris. The branch to the hip joint may arise from the medial popliteal part of the sciatic.

The **nerve to the obturator internus** (and **superior gemellus**) arises from the front of the fifth lumbar and first two sacral nerves. In the gluteal region it lies medial to the sciatic nerve on the lateral side of the internal pudendal vessels: crossing the ischial spine, it enters the ischio-rectal fossa through the lesser sciatic foramen. The nerve supplies, in the gluteal region, a branch to the superior gemellus, and it terminates by entering the perineal surface of the obturator internus.

The **pelvic splanchnic nerves**, as mentioned already, are composed of parasympathetic fibres. They are two slender filaments that spring from the second and third or third and fourth sacral nerves, and pass forwards to join the sympathetic plexuses, by which they are distributed to viscera—urogenital organs and the lower part of the large intestine.

The **pudendal nerve** is the principal nerve for the supply of the perineum. It arises in the pelvis usually by three roots from the second, third, and fourth sacral nerves (Fig. 937). The nerve passes to the gluteal region through the greater sciatic foramen, medial to the sciatic nerve, and lies on the sacro-spinous ligament medial to the internal pudendal artery. With that artery, it passes through the lesser sciatic foramen into the perineum and enters the pudendal canal of the obturator fascia, which is deeply placed on the lateral wall of the ischio-rectal fossa. As the nerve enters the canal it gives off the inferior hæmorrhoidal nerve, and shortly afterwards it divides into its terminal branches—the perineal nerve and the dorsal nerve of the penis or clitoris—which run forwards in the pudendal canal towards the posterior border of the perineal membrane.

The branches of the pudendal nerve are essentially the same in the two sexes. As a rule, it gives off no branches until it enters the perineum, but sometimes the inferior hæmorrhoidal nerve has a separate origin from the plexus and merely

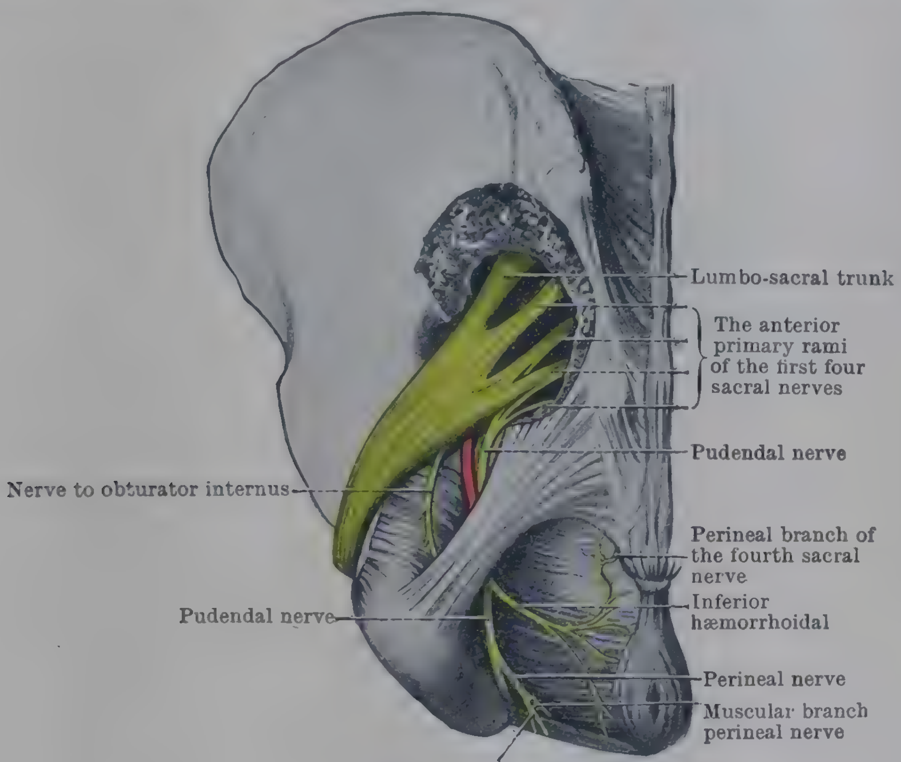

FIG. 944.—ORIGIN AND COURSE OF THE PUDENDAL NERVE.

accompanies the pudendal nerve in the first part of its course; and in exceptional cases the perforating cutaneous nerve is a branch of the pudendal nerve.

The **inferior hæmorrhoidal nerve** arises from the pudendal nerve under cover of the gluteus maximus, at the posterior part of the ischio-rectal fossa. When it has an independent origin from the plexus, it arises from the third and fourth sacral nerves. It crosses the ischio-rectal fossa in company with the inferior rectal vessels, and separates into numerous branches—muscular, cutaneous, and communicating.

The **muscular branches** end in the sphincter ani externus muscle. The **cutaneous branches** supply the skin and fascia around the anus. The **communicating branches** connect the inferior hæmorrhoidal nerve with the perineal branches derived from the posterior cutaneous nerve of the thigh and from the pudendal and fourth sacral nerves.

The **perineal nerve** runs forwards in the pudendal canal towards the posterior border of the perineal membrane, near which it gives off the scrotal or labial branches, and then divides into terminal branches.

The *scrotal* or *labial branches* become superficial and are distributed to the skin and fascia of the perineum and the scrotum or the labium majus. They communicate with the perineal branch of the posterior cutaneous nerve of the thigh and with the inferior hæmorrhoidal nerve.

The *terminal branches* supply the muscles in the deep and superficial perineal pouches, and one of these enters the bulb of the penis and supplies the erectile tissue of the bulb and the corpus spongiosum penis, as well as the mucous membrane of the urethra, as far as the glans penis.

The **dorsal nerve of the penis** or **clitoris** accompanies the internal pudendal artery through the pudendal canal into the deep perineal pouch. There it passes forwards close to the side of the pubic arch, lying under cover of the crus and ischio-cavernosus and perineal membrane, and below the sphincter urethræ muscle. It sends a slender branch through the perineal membrane to supply the erectile tissue of the crus and corpus cavernosum of penis or clitoris: and then, piercing the perineal membrane near its anterior border at the lateral side of the dorsal artery it passes on to the dorsum of the penis or clitoris, to which it is distributed in its distal two-thirds, sending branches round the sides of the organ to reach its under surface. In the female the nerve is much smaller than in the male.

The **nerve to the piriformis muscle** may be double. It arises from the back of the second, or first and second sacral nerves, and at once enters the pelvic surface of the muscle.

The **nerves to coccygeus and levator ani** arise from a loop between the third and fourth sacral nerves and descend to these muscles. The **perineal branch of the fourth sacral nerve** arises from the lower part of the same loop; it descends through the coccygeus, appears in the posterior angle of the ischio-rectal fossa, and runs forwards to end in the posterior part of the external sphincter ani. It gives branches also to the overlying fascia and skin.

The **perforating cutaneous nerve** arises from the second and third sacral nerves (Fig. 937). At its origin it is associated with the lower roots of the posterior cutaneous nerve of the thigh. Passing downwards it pierces the sacro-tuberous ligament, and, after winding round the lower border of the gluteus maximus muscle or piercing its lower fibres, it becomes cutaneous a little distance from the coccyx, and supplies the skin and fascia of the lower part of the buttock and the medial part of the fold of the buttock.

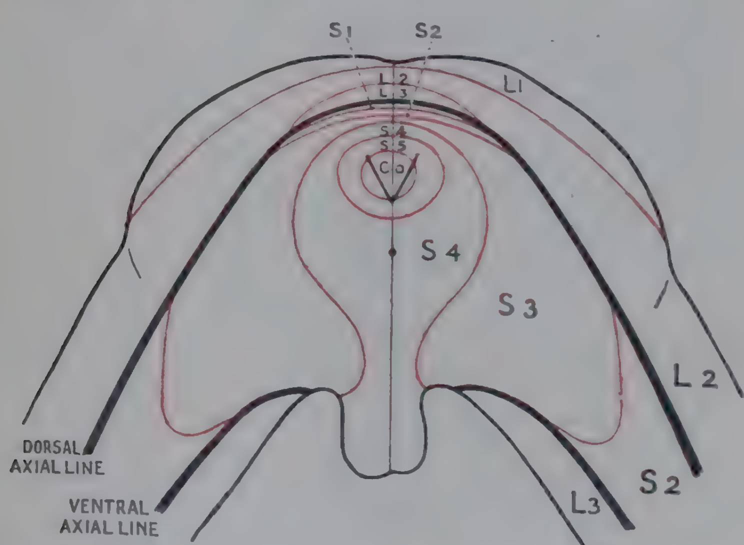

FIG. 945.—PERINEAL DERMATOMES, SHOWING SEGMENTAL CUTANEOUS DISTRIBUTION OF SPINAL NERVES (L 1-3, S 2-5, Co.) TO PERINEUM AND ADJACENT PARTS OF TRUNK AND LOWER LIMB. (After Head & Foerster.)

The perforating cutaneous nerve is not always present. In a minority of cases it is associated at its origin with the pudendal nerve. When absent as a separate nerve, its place is taken by (1) gluteal branches of the posterior cutaneous nerve of the thigh, or (2) a branch from the pudendal nerve, or (3) a small nerve (n. perforans coccygeus major, Eisler, 1891) which arises separately from the third and fourth sacral nerves.

The **superior gluteal nerve** arises from the posterior surface of the fourth and fifth lumbar and first sacral nerves, and is directed backwards and laterally into the gluteal region above the piriformis muscle, along with the superior gluteal artery. Under cover of the gluteus maximus and gluteus medius it passes over the gluteus minimus, along with the inferior branch of the deep division of the superior gluteal artery, to the deep surface of the tensor fasciæ latæ, in which it ends. On its way it supplies branches to the gluteus medius and gluteus minimus muscles.

The **inferior gluteal nerve** arises from the posterior surface of the fifth lumbar and upper two sacral nerves. It appears in the gluteal region at the lower border of

the piriformis muscle, superficial to the sciatic nerve, and at once breaks up into a number of branches for the supply of the gluteus maximus. Till it enters the buttock it is closely associated with the posterior cutaneous nerve of the thigh.

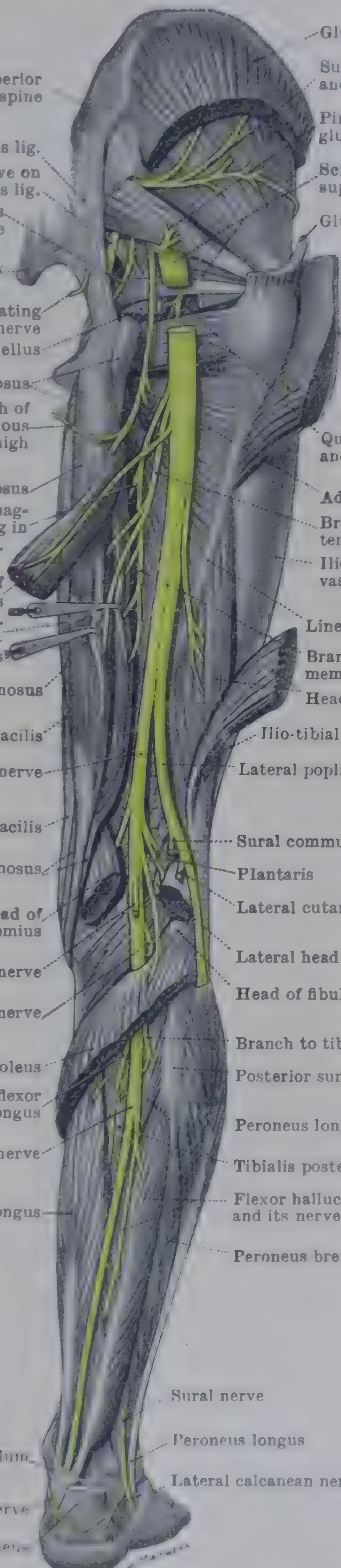

Fig. 946.—Nerves of Back of Lower Limb.

The **posterior cutaneous nerve of the thigh** (Fig. 937) is derived from the upper three sacral nerves or from the second and third. It is distributed to the lower limb and perineum, and is associated with other nerves belonging to both regions. Its higher roots from the first and second sacral nerves are intimately associated with the origin of the inferior gluteal nerve; its lowest root from the third sacral nerve is associated with the origins of the perforating cutaneous or of the pudendal nerve. It enters the gluteal region through the greater sciatic notch, below the piriformis, along with the inferior gluteal artery and nerve. Proceeding downwards with the sciatic nerve, it enters the thigh at the lower border of the gluteus maximus muscle, where it gives off considerable branches. Becoming gradually smaller as it descends over the hamstring muscles to the popliteal fossa, it finally pierces the deep fascia as one or more cutaneous branches which supply the skin and fascia over the calf of the leg for a variable distance (Fig. 941).

Branches.—The nerve is distributed solely to skin and fascia. It supplies branches to the perineum, buttock, thigh, and leg.

The *perineal branch* arises at the lower border of the gluteus maximus muscle (Fig. 947). It sweeps in a medial direction across the hamstring muscles

below the ischial tuberosity towards the perineum; and, becoming subcutaneous after passing over the pubic arch, its terminal branches supply the skin and fascia of the scrotum and root of the penis, or, in the female, the labium majus and clitoris, communicating with branches of the ilio-inguinal nerve. Some of them pass backwards towards the anus and the perineal body and communicate with the inferior hæmorrhoidal and perineal branches of the pudendal nerve. In its course to the perineum the nerve gives off *collateral branches* to the upper medial part of the thigh (Fig. 943).

The *gluteal branches*, large and numerous, arise from the nerve deep to the gluteus maximus and become subcutaneous by piercing the fascia lata at different points along its lower border. They supply the skin and fascia of the lower half of the buttock. The most lateral branches, reaching to the back of the greater trochanter, overlap the terminal filaments of the gluteal branches of the lateral cutaneous nerve of the thigh and the posterior primary rami of the upper three lumbar nerves. The most medial branches, which may pierce the sacro-tuberous ligament, reach nearly to the coccyx, and are co-extensive in their distribution with the branches of the perforating cutaneous nerve, which they reinforce and may replace.

The *branches to the thigh* pierce the fascia lata at intervals, and supply the skin and fascia of the back of the thigh.

The *branches to the calf* are two or more slender nerves which pierce the fascia over the popliteal fossa and are distributed to the fascia and skin for a variable extent over the back of the leg. They may stop short over the popliteal fossa, or may reach as far as the ankle. Usually they extend as far as the middle of the calf and communicate with the sural nerve.

When the sciatic nerve is naturally divided at its origin into medial and lateral popliteal nerves (*e.g.*, by the piriformis muscle), the posterior cutaneous nerve also is separated into two parts: a **posterior part**, associated with the lateral popliteal nerve and arising in common with the lower roots of the inferior gluteal nerve (usually from the first and second sacral nerves), and comprising the branches to the gluteal region and lateral part of the back of the thigh and leg; and an **anterior part**, associated with the medial popliteal nerve and arising usually from the second and third sacral nerves, along with the perforating cutaneous and pudendal nerves, and comprising the branches to the perineum and medial part of the limb.

Sciatic Nerve

The **sciatic nerve** is the thickest nerve in the body. It consists of two nerves —the medial and lateral popliteal—bound together by an investing sheath, which contains, in addition to these nerves, a branch from each, viz., the nerve to the hamstring muscles from the medial popliteal nerve, and the nerve to the short head of the biceps femoris from the lateral popliteal nerve. From the account given of the origin of the fibres of the medial and lateral popliteal nerves, it follows that the fibres of the sciatic nerve are derived from the fourth and fifth lumbar and first, second, and third sacral nerves. A thick band about half an inch in breadth is formed, consisting, from the medial to the lateral side, of (1) the nerve to the hamstring muscles, (2) the medial popliteal nerve, (3) the lateral popliteal nerve, (4) the nerve to the short head of the biceps femoris.

The sciatic nerve leaves the pelvis and enters the gluteal region through the greater sciatic foramen between the piriformis and the superior gemellus (Fig. 947). It runs laterally and then downwards through the gluteal region, in the hollow between the greater trochanter of the femur and the ischial tuberosity, accompanied by the inferior gluteal artery and its own companion artery. It is covered posteriorly by the gluteus maximus, and is in relation anteriorly with the following structures, from above downwards: (1) the posterior surface of the ischium and the nerve to the quadratus femoris, (2) the superior gemellus, (3) the obturator internus, (4) the inferior gemellus, (5) the quadratus femoris.

The nerve enters the thigh at the lower border of the quadratus femoris and lies at first in the angle between the lower border of the gluteus maximus above and laterally, and the hamstring muscles medially. It then runs down the back

of the thigh, on the posterior surface of the adductor magnus, and is covered by the long head of the biceps femoris, which crosses behind the nerve from the medial to the lateral side.

It usually terminates at the proximal angle of the popliteal fossa by

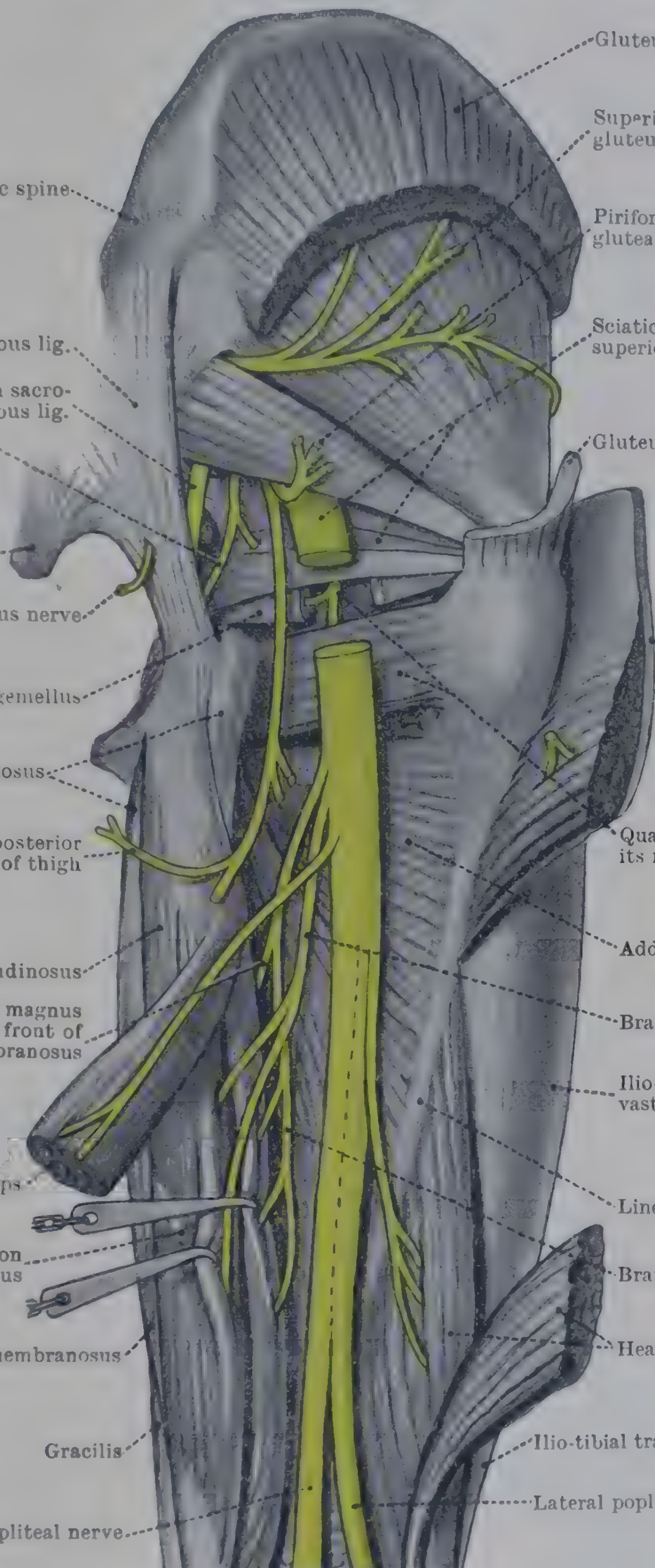

FIG. 947.—NERVES OF GLUTEAL REGION AND BACK OF THIGH.

dividing into the medial and lateral popliteal nerves (Figs. 946, 947); but the separation may occur at any higher level, and, as already noted, these two nerves may even be distinct at their origin, in which case the lateral popliteal usually pierces the piriformis.

The **nerve to the hamstring muscles** forms the most medial part of the sciatic trunk in the lower part of the buttock. It arises from all the roots of the medial popliteal nerve on their anterior aspect, viz., from the fourth and fifth

lumbar and the first three sacral nerves. The fibres from the different roots unite to form a cord which is at first closely associated with the medial popliteal part of the sciatic nerve, but leaves it just below the quadratus femoris to be distributed to the hamstring muscles (except the short head of the biceps) by a series of branches which, however, may be given off separately by the sciatic nerve (Fig. 947). The nerve to the semitendinosus is double, and the branch to the part above the tendinous intersection may be associated with the nerve to the long head of the biceps. The nerve to the ischial portion of the adductor magnus arises in common with the nerve to the semimembranosus, which runs downwards in front of the lateral margin of its muscle, giving several branches to it.

The **nerve to the short head of the biceps** springs from the lateral side of the lateral popliteal trunk in the proximal part of the thigh. When traced to its origin, it is found to arise (sometimes in combination with the inferior gluteal nerve) from the fifth lumbar and first two sacral nerves. In its course it is closely applied to the lateral popliteal nerve, from which it separates in the middle third of the thigh, usually in combination with the articular branches of that nerve for the knee joint. In some cases it has an independent course in the thigh, and it may be associated in the buttock with the inferior gluteal nerve.

An **articular branch** for the lateral and anterior parts of the knee joint generally arises from the lateral popliteal nerve in common with the nerve to the short head of the biceps. When traced up to the plexus, it is found to arise from the posterior surface of the fourth and fifth lumbar and first sacral nerves. It passes through the proximal part of the popliteal fossa concealed by the biceps muscle, and separates into proximal and distal branches, which accompany the superior and inferior lateral articular arteries to the knee joint.

Terminal Branches of Sciatic Nerve.—The **lateral popliteal** and **medial popliteal nerves** are the two main trunks resulting from the combination of the posterior and anterior cords respectively of the sacral plexus. The lateral popliteal nerve is homologous with the radial nerve of the upper limb; the medial popliteal nerve represents a median-ulnar trunk.

Lateral Popliteal Nerve

The **lateral popliteal nerve** arises from the posterior part of the sacral plexus from the fourth and fifth lumbar and first two sacral nerves. Incorporated in the sciatic nerve in the gluteal region and proximal part of the thigh, it descends from the bifurcation of that nerve through the popliteal fossa to its termination at a point about an inch distal to the head of the fibula. It is concealed at first by the biceps muscle. Following the tendon of that muscle, it passes obliquely through the proximal and lateral part of the popliteal fossa and over the lateral head of the gastrocnemius muscle to the back of the head of the fibula. In the distal part of its course it is quite superficial except at its termination, where it is covered by the peroneus longus muscle and lies between that muscle and the neck of the fibula, round which it winds (Figs. 947, 948, 950).

Collateral Branches.—They are divided into two sets: (*a*) *Nerves arising while it is in combination with the medial popliteal nerve in the sciatic trunk.* They have been already described as a **muscular branch** to the short head of the biceps and an **articular branch** to the knee joint. (*b*) *Nerves arising in the popliteal fossa.* Those are **cutaneous branches**, viz., the lateral cutaneous nerve of the calf and the sural communicating branch.

The **lateral cutaneous nerve of the calf of the leg** is inconstant in size and distribution, and may be represented by two or more branches. It arises from the lateral popliteal nerve in the popliteal fossa, often in common with the succeeding nerve, pierces the deep fascia over the lateral head of the gastrocnemius, and is distributed to the skin and fascia on the lateral part of the back of the leg in the proximal two-thirds (Fig. 941). The extent of its distribution varies with that of the posterior cutaneous nerve of the thigh and the sural nerve.

The **sural communicating branch** begins in the popliteal fossa, passes over the lateral head of the gastrocnemius, deep to the deep fascia, to the middle third of the

leg, where it joins the sural nerve. The two branches do not always unite. The sural communicating branch then may be limited in its distribution to the skin and fascia of the lateral side of the leg, or it may be distributed to the area usually supplied by the sural nerve.

A small *recurrent branch* arises immediately above the division of the lateral popliteal nerve into its two terminal branches. Passing forwards under cover of the origin of the peroneus longus muscle and through the extensor digitorum longus, the recurrent branch divides, just below the lateral condyle of the tibia, into branches which supply the proximal fibres of the tibialis anterior muscle, the superior tibio-fibular joint, and the knee joint (Fig. 948).

Terminal Branches.—The terminal branches of the lateral popliteal nerve are two in number: anterior tibial and musculo-cutaneous. They begin immediately below the head of the fibula, and are directed forwards, diverging in their course, under cover of the peroneus longus muscle.

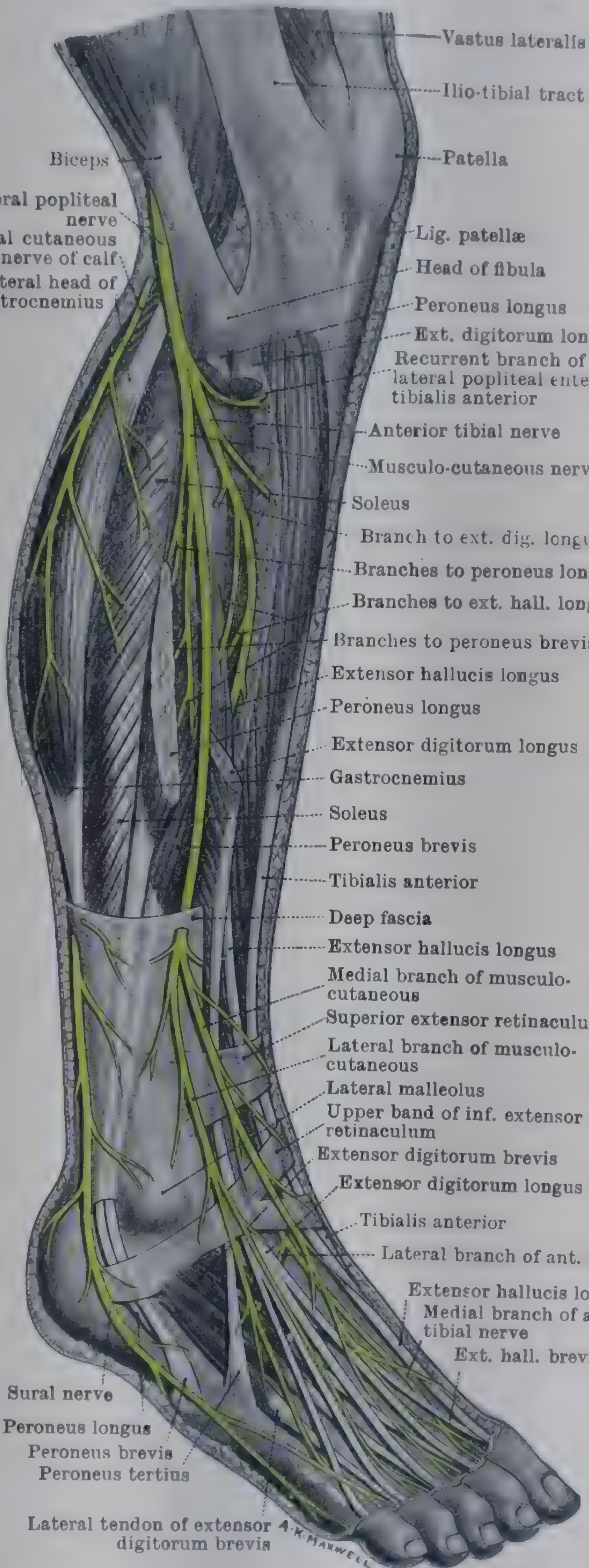

FIG. 948.—NERVES OF FRONT AND LATERAL SIDE OF LEG AND DORSUM OF FOOT.

ANTERIOR TIBIAL NERVE

The **anterior tibial nerve** passes obliquely downwards, under cover of the peroneus longus, extensor digitorum longus, and extensor hallucis longus muscles, to the front of the leg. In its course it is deeply placed on the interosseous membrane and the distal part of the tibia, in company with the anterior tibial artery, lying first lateral to the vessel, then anterior, and then lateral to it again. At the ankle it lies under cover of the superior extensor retinaculum and the tendon of the extensor hallucis longus, and, after crossing the ankle joint, it divides on the dorsum of the foot into its terminal branches.

1. **Collateral Branches** (in the leg).—These are given off to the muscles between which the nerve passes, namely: tibialis anterior, extensor hallucis longus, extensor digitorum longus, and peroneus tertius. A fine articular branch supplies the ankle joint.

2. **Terminal Branches** (on the foot).—The terminal branches are medial and lateral. The **medial (digital) branch** passes over the dorsum of the foot, along the lateral side of the dorsalis pedis artery, to the first interosseous space, where it divides into two *dorsal digital branches* for the supply of the skin and fascia of the lateral side of the big toe and the medial side of the second toe. Each of these branches communicates with branches of the musculo-cutaneous nerve. It gives off one or two branches which supply the medial tarso-metatarsal and metatarso-phalangeal joints, and enter the first dorsal interosseous muscle.

The **lateral branch** passes obliquely over the tarsus under cover of the extensor digitorum brevis, and ends in a gangliform enlargement (similar to the gangliform enlargement on the interosseous nerve of the forearm at the back of the wrist). From the enlargement, muscular branches arise for the supply of the extensor digitorum brevis, along with branches for the tarsal, tarso-metatarsal, and metatarso-phalangeal joints. Its *articular branches* may be as many as four in number. Of those the lateral two, extremely small, may only reach the tarso-metatarsal joints. The medial two are fine branches, which, besides supplying the joints, may give branches (probably afferent) to the second and third dorsal interosseous muscles.

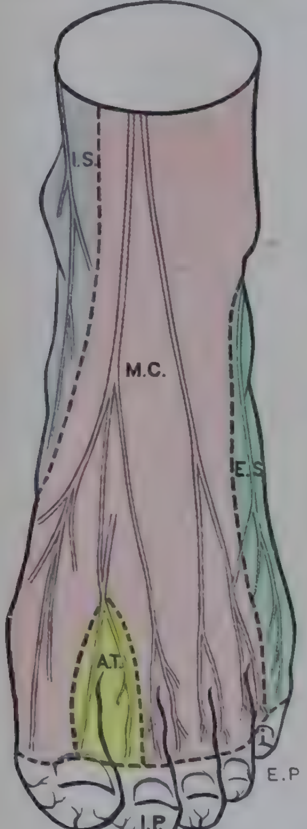

FIG. 949.—DISTRIBUTION OF CUTANEOUS NERVES ON DORSUM OF THE FOOT.

S., Saphenous nerve; M.C., Musculo-cutaneous nerve; A.T., Anterior tibial nerve; E.S., Sural nerve. The extremities of the toes are supplied by the medial and lateral plantar nerves (I.P., E.P.).

MUSCULO-CUTANEOUS NERVE

The **musculo-cutaneous nerve** passes downwards in front of the fibula, in a sheath in the intermuscular septum between the peronei and the extensor digitorum longus, to the distal third of the leg, where its two terminal branches pierce the deep fascia.

Its branches are: (1) *collateral* muscular branches distributed to the peroneus longus and peroneus brevis, as the nerve lies in relation to these muscles; (2) *terminal* cutaneous branches, medial and lateral.

The **medial branch** courses downwards over the extensor retinacula, and after supplying offsets to the distal third of the leg and to the dorsum of the foot divides into three branches. (1) The most medial branch supplies the skin and fascia of the dorsum of the foot and the medial side of the big toe, and communicates with the saphenous nerve. (2) The intermediate branch passes to the interval between the big toe and the second, and divides into two branches which communicate with the medial branch of the anterior tibial nerve. (3) The lateral branch passes to the interval between the second and third toes, and divides into *dorsal digital branches* to supply the adjacent sides of these toes.

The **lateral branch** of the musculo-cutaneous nerve also passes over the extensor retinacula, and after supplying branches to the distal part of the leg and to the dorsum of the foot divides into two parts, which, passing to the intervals between the third and fourth, and fourth and fifth toes, divide into *dorsal digital branches* for the adjacent sides of these toes. The latter branches communicate with offsets of the sural nerve.

The arrangement of the cutaneous branches of the musculo-cutaneous nerve is liable to considerable variation. The lateral division of the nerve may be increased in size, and may supply the nerve to the adjacent sides of the second and third toes; or it may be reduced in size, in which case the sural nerve takes its place on the dorsum of the foot, often supplying as many as two and a half toes (Kosinski, 1926).

The cutaneous nerves on the dorsum of the toes are much smaller than the corresponding plantar digital nerves. They are reinforced on the dorsum of the terminal phalanges by twigs from the plantar nerves, which supply the tips of the toes and the nails.

Medial Popliteal Nerve

The **medial popliteal nerve** arises from the anterior surface of the sacral plexus, usually from the fourth and fifth lumbar and first three sacral nerves (Fig. 937, p. 1088). It is incorporated in the sciatic trunk in the gluteal region and proximal part of the thigh. At the bifurcation of the sciatic nerve it passes onwards through the popliteal fossa and becomes the *posterior tibial nerve* at the lower border of the popliteus muscle. The course of the nerve through the gluteal region and thigh has already been described (p. 1104). In the popliteal fossa it is concealed at first by the semimembranosus and the other hamstring muscles. It passes behind the popliteal vessels from the lateral to the medial side, and is thereafter found behind the popliteus muscle, under cover of the gastrocnemius and plantaris (Fig. 950).

The **collateral branches** are divided into two sets:—(*a*) *Nerves arising while it is incorporated in the Sciatic Nerve.*—They have been already described as *the nerve to the hamstring muscles*, and an occasional *articular branch* to the hip joint. (*b*) *Nerves arising in the Popliteal Fossa.*—These are in three sets—articular, muscular, cutaneous. Vascular branches to the popliteal artery also are described.

1. The **articular branches** are slender nerves, variable in number. There are usually two, one of which pierces the oblique ligament of the knee joint, while the other, a long fine nerve, crosses the popliteal vessels, and descends to accompany the inferior medial articular artery to the knee joint. In its course it sometimes gives off a fine branch which accompanies the superior medial articular artery.

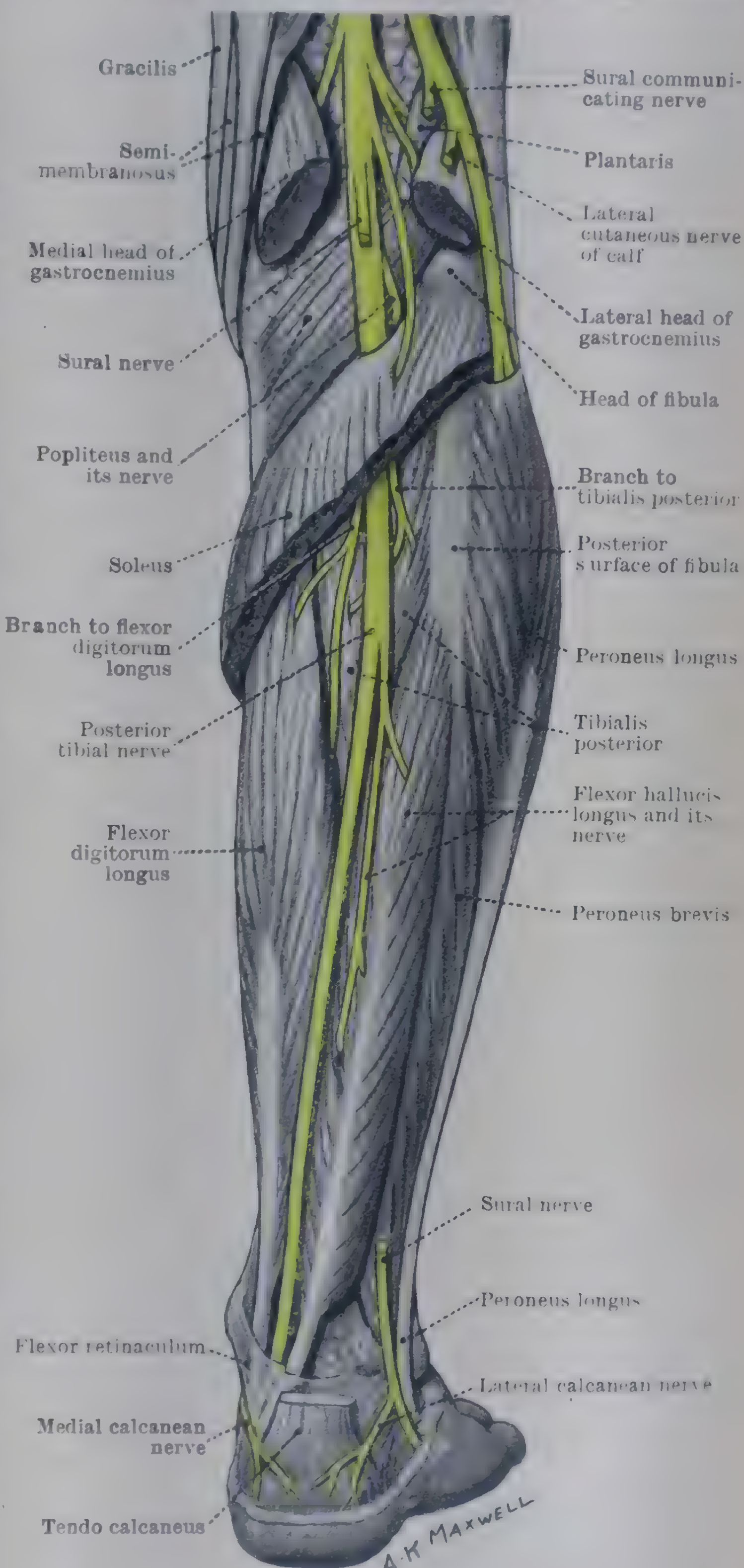

Fig. 950.—Nerves of Popliteal Fossa and Back of Leg.

2. The **muscular branches** are five in number. Nerves for the two heads of the *gastrocnemius*, and for the *plantaris* enter those muscles at the borders of the popliteal fossa. A nerve for the *soleus* enters the superficial surface of the muscle. A nerve to the *popliteus* muscle passes behind that muscle, and, after winding round its distal border, supplies it on its anterior surface; as this nerve curves round the lower border of the popliteus it supplies branches to the *tibialis posterior*, a branch for the interosseous membrane, which can be traced as far as the inferior tibio-fibular joint, an *articular*

branch for the superior tibio-fibular joint, and a *medullary* branch for the shaft of the tibia.

3. The **cutaneous branch** is the **sural nerve.** That nerve passes from the popliteal fossa in the groove between the two heads of the gastrocnemius muscle, and afterwards lies on the tendo calcaneus. It pierces the deep fascia in the middle third of the back of the leg, and is joined immediately afterwards by the sural communicating branch from the lateral popliteal nerve. The sural nerve reaches the foot by winding round the back of the lateral malleolus along with the short saphenous vein. It supplies cutaneous branches to the lateral side and back of the distal third of the leg, the ankle and heel (*lateral calcanean branches*) and the lateral border of the foot, as well as articular branches to the ankle joint and the tarsal joints.

The sural nerve communicates on the foot with the musculo-cutaneous nerve (Fig. 949), and its size varies with the size of that nerve. It may extend on to the dorsum of the foot for a considerable distance, and may either reinforce or replace the branches of the musculo-cutaneous nerve to the intervals between the fourth and fifth and the third and fourth toes. Frequently the sural communicating branch does not join the sural nerve, and in such cases the sural communicating branch may sometimes be distributed to the area usually supplied by the sural nerve.

Posterior Tibial Nerve

The **posterior tibial nerve** is a direct continuation of the medial popliteal, and begins at the distal border of the popliteus muscle. As the nerve passes downwards from this point it lies on the tibialis posterior muscle and the tibia, and, along with the posterior tibial vessels, occupies a sheath in the intermuscular septum separating the superficial and deep muscles of the back of the leg (Fig. 950). In the proximal part of the leg the nerve is medial to the posterior tibial vessels, but, crossing behind them, it lies on their lateral side in the distal portion of its course. It terminates under cover of the flexor retinaculum by dividing into the lateral and medial plantar nerves.

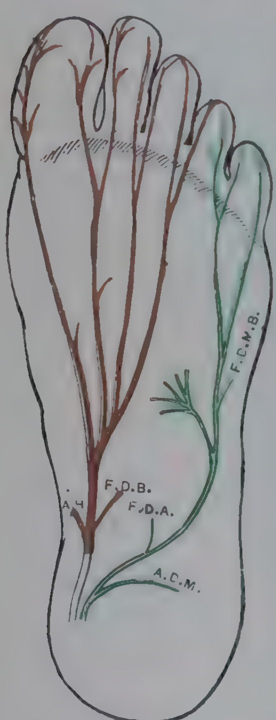

FIG. 951.—SCHEME OF DISTRIBUTION OF THE PLANTAR NERVES.

In brown, medial plantar nerve, and its cutaneous and muscular branches; F.D.B., Flex. dig. brev.; A.H., Abd. hall.; Flex. hall. brev. and 1st lumbrical shown but not lettered. *In green*, lateral plantar nerve, and its cutaneous and muscular branches; F.D A., Flex. dig. access.; A.D.M., Abd. dig. min.; F.D.M.B., Flex. dig. min. brev.

The branches are muscular, cutaneous and terminal.

The **muscular branches** are four in number, comprising nerves to the soleus (entering its deep surface) and tibialis posterior, often arising by a common trunk, and nerves to the flexor digitorum longus and flexor hallucis longus, the latter generally accompanying (and supplying) the peroneal artery for some distance. The nerve to the tibialis posterior supplies twigs to the posterior tibial artery.

The **cutaneous branches** are the **medial calcanean branches**, which pierce the flexor retinaculum, and are distributed to the skin and fascia of the heel and posterior part of the sole of the foot.

In addition, a *medullary nerve* to the fibula and a small *articular branch* to the ankle joint are supplied by the posterior tibial nerve.

The terminal branches of the posterior tibial nerve are the *medial* and *lateral plantar nerves*.

Medial Plantar Nerve

The **medial plantar nerve** is homologous with the median nerve in the hand and is rather larger than the lateral plantar (Figs. 951, 952). It courses forwards in the sole of the foot, under cover of the flexor retinaculum and abductor hallucis, to the interval between that muscle and the flexor digitorum brevis, in company with the medial plantar artery.

The **collateral branches** are muscular, cutaneous, articular and vascular. The *muscular* branches supply the abductor hallucis and the flexor digitorum brevis. The plantar *cutaneous* branches are small twigs which pierce the deep fascia in the interval between the above-mentioned muscles to supply the medial part of the

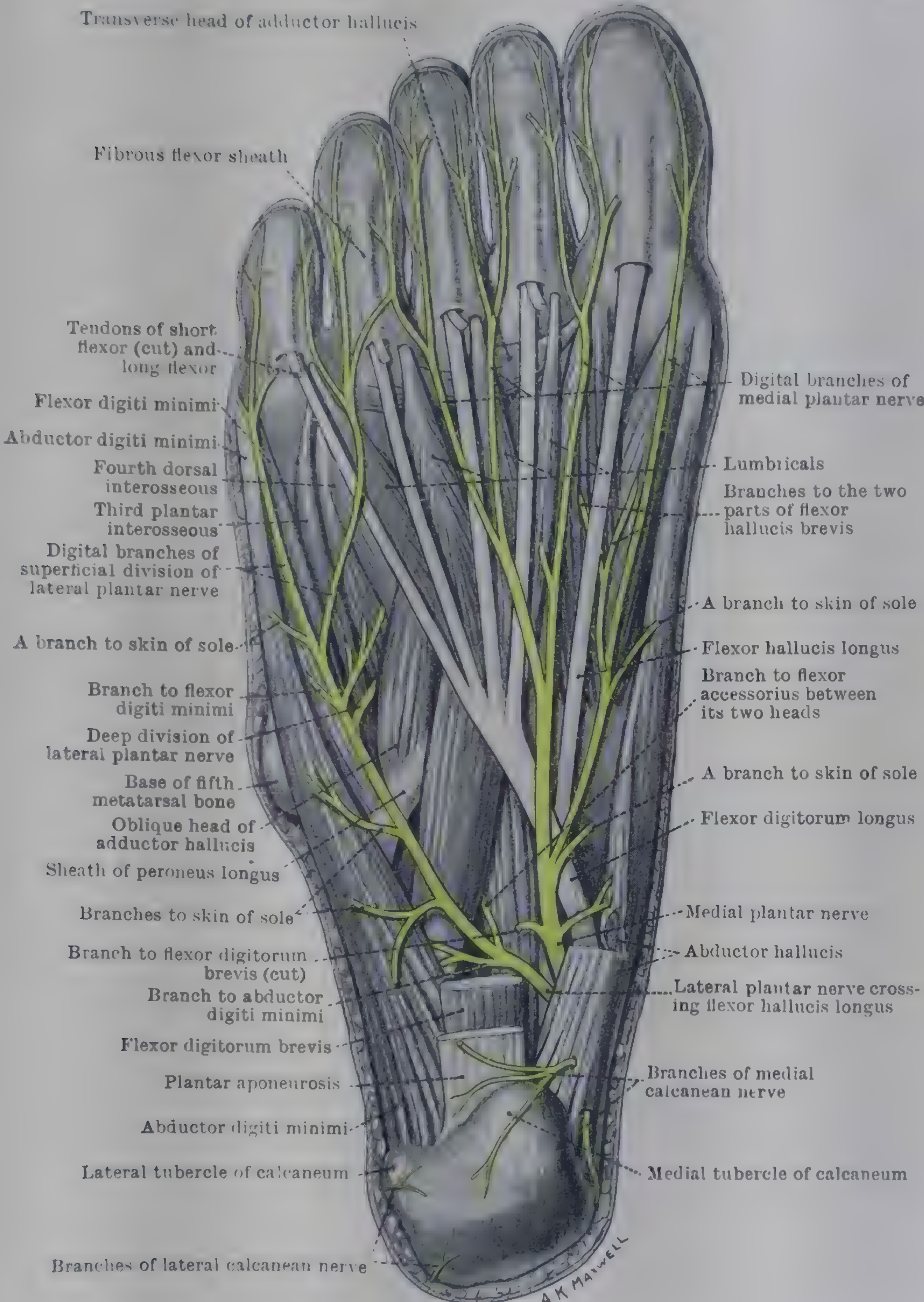

FIG. 952.—PLANTAR NERVES.

sole of the foot. The *articular* branches are minute twigs which supply the tarsal and tarso-metatarsal joints. *Vascular branches* are given to the neighbouring arteries by the main nerve and its branches.

The **terminal branches** are four in number—the *plantar digital nerves*—and may be designated first, second, third, and fourth, from medial to lateral side.

The **first** (most medial) branch separates from the nerve before the others, and pierces the deep fascia behind the ball of the big toe. It supplies a muscular branch to the flexor hallucis brevis and cutaneous branches to the medial side of the foot and ball of the big toe. It terminates as the plantar digital nerve for the medial side of the big toe.

The **second branch** arises along with the third and fourth; after supplying a

branch to the first lumbrical muscle, it becomes superficial in the interval between the first and second toes, and terminates by dividing into two digital nerves for the supply of the adjacent sides of these toes.

The **third** and **fourth branches** are distributed to skin and fascia and certain joints of the toes. They become superficial in the intervals between the second and third and the third and fourth toes, respectively, and there divide into branches for the supply of the adjacent sides of these toes.

Lateral Plantar Nerve

The **lateral plantar nerve** is homologous with the ulnar nerve in the hand. From its origin, under cover of the flexor retinaculum, it extends forwards and laterally in the sole, along the medial side of the lateral plantar artery, between the flexor digitorum brevis and the flexor digitorum accessorius towards the base of the fifth metatarsal bone. There it ends by dividing into superficial and deep terminal branches (Fig. 952).

Collateral Branches.—*Muscular branches* are given off from the undivided nerve to the flexor digitorum accessorius and abductor digiti minimi muscles. *Cutaneous branches* pierce the plantar fascia at intervals along the line of the intermuscular septum between the flexor digitorum brevis and abductor digiti minimi. *Vascular filaments* are given to neighbouring arteries by the lateral plantar nerve and its branches.

Terminal Branches.—The **superficial branch** is mainly cutaneous. Passing forwards between the flexor digitorum brevis and abductor digiti minimi, it divides into lateral and medial parts.

The lateral part, after supplying the flexor digiti minimi brevis muscle, and sometimes one or both interossei of the fourth space, becomes superficial behind the ball of the little toe, and supplies cutaneous twigs to the sole of the foot and ball of the toe. It ends as the *plantar digital nerve* for the lateral side of the little toe.

The medial part passes forwards to the interval between the fourth and fifth toes, where it becomes cutaneous and divides into two branches (*plantar digital nerves*) for the supply of the adjacent sides of those toes. It communicates with the fourth terminal branch of the medial plantar nerve. Both branches provide filaments to the joints of the toes to which they are distributed.

The **deep branch** of the lateral plantar nerve runs medially along with the lateral plantar artery towards the big toe, under cover of (*i.e.*, dorsal to) the flexor digitorum accessorius and oblique head of the adductor hallucis. It gives off *articular branches* to the tarsal and tarso-metatarsal joints and *muscular branches* to the interossei of each space (except in some cases the muscles of the fourth space), to the adductor hallucis, and the lateral three lumbrical muscles. The muscular branches enter the deep surfaces of the muscles, that to the second lumbrical reaching its muscle after passing forwards dorsal to the transverse head of the adductor hallucis.

Plantar digital nerves.—These nerves arise from both medial and lateral plantar nerves. They supply the whole length of the toes on the plantar surface, and, in relation to the distal phalanges, furnish minute dorsal offsets for the supply of the nails and tips of the toes on their dorsal surfaces. Filaments from the digital nerves supply the metatarso-phalangeal and interphalangeal joints.

Coccygeal Plexus

By the union of part of the anterior primary ramus of the fourth with those of the fifth sacral and coccygeal nerves, the **coccygeal plexus** is formed. A fine branch of the fourth sacral nerve descends to join the fifth sacral nerve, which then descends alongside the coccyx and is joined by the coccygeal nerve, so that a plexiform cord results, homologous with the inferior caudal trunk of tailed animals. Fine twigs arise from it, some of which enter the coccygeus and adjoining part of the levator ani, while others pierce the coccygeus and the overlying ligaments to supply the skin and fascia in the neighbourhood of the coccyx and behind the anus, medial to the branches of the perforating cutaneous nerve.

Communications with Autonomic System.—Like the other spinal nerves, the fourth and fifth sacral and coccygeal nerves are provided with fine *grey rami communicantes* from the sacral sympathetic trunk which join them after a short course on the front of the sacrum.

Morphology of Nerves of Perineum

The structures which occupy the perineum are placed in the ventral axis of the body, and comprise, from before backwards, the penis and scrotum, or mons pubis and vulva, the perineal body, the anus and ischio-rectal fossa, and the coccyx. They are placed on the medial side of the attachment of the lower limbs—the penis or mons pubis in relation to the preaxial border of the limb, the coccyx in relation to the postaxial border.

The nerves of the perineum, thus reaching the ventral axis of the trunk, are homologous with the anterior (ventral) terminations of other nerves. They are separable into two series. The perineum is supplied mainly by the lower four sacral nerves and the coccygeal nerve, but it is also innervated to a minor extent by the first lumbar nerve through the ilio-inguinal nerve, which reaches the root of the penis and the scrotum. The region is thus supplied by two series of widely separated nerves which have their meeting-place on the dorsum and side of the penis and scrotum. This junction of the ilio-inguinal and pudendal nerves constitutes the beginning of the **ventral axial line** (Fig. 953), which extends peripherally along the medial side of the lower limb. Apart from this break in their distribution, a definite numerical order may be followed in the arrangement of the perineal nerves. The higher parts of the perineum are innervated by the higher spinal nerves; the lower parts, by the lower nerves. This is best exemplified in the distribution of the cutaneous nerves. The base of the penis and scrotum (or mons pubis) is supplied by the first lumbar nerve (ilio-inguinal). The dorsal nerve of the penis (or clitoris), when traced back, is found to come from the second sacral nerve, and to a less extent from the third; the scrotal or labial nerves (perineal branches of the pudendal and posterior cutaneous nerve of the thigh) similarly arise from the third sacral nerve, and to a less extent from the second; the skin of the ischio-rectal fossa and anus is innervated by the inferior hæmorrhoidal (third and fourth sacral nerves), and the perineal branch of the fourth sacral nerve. The coccygeal plexus, lastly, supplies the skin and fascia round the coccyx (fourth and fifth sacral and coccygeal nerves).

Judged from its nerve-supply the perineum is to be regarded as occupying, for the most part, a position behind or more caudal than that of the lower limb in relation to the trunk, and there is a remarkable gap in the numerical sequence of the nerves that supply the ventral axis of the body. All the nerves between the first lumbar and the second sacral fail to reach the mid-ventral line of the trunk and are wholly concerned in the innervation of the lower limb.

At the preaxial border of the limb (groin) the first lumbar nerve—the highest nerve supplying the perineum—is concerned also in innervating the skin and fascia of the limb. At the postaxial border of the limb (fold of the buttock and back of the thigh), the second and third sacral nerves are also implicated in innervating that border of the limb. The fourth sacral nerve is concerned only to a very slight extent in the innervation of the limb by means of the perineal branch, which reaches the beginning of its postaxial border; the last two spinal nerves are wholly unrepresented in the limb proper and end entirely in the trunk behind the limb.

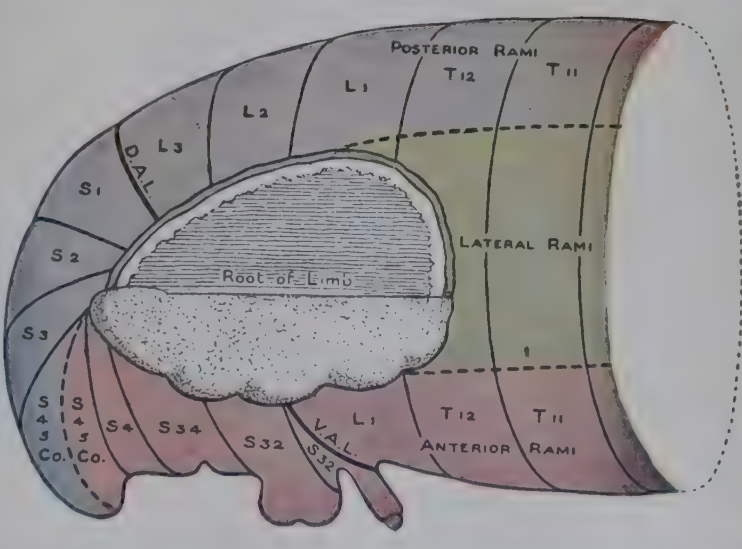

Fig. 953.—Scheme of Innervation of Hinder Portion of Trunk and of Perineum. The scheme shows the interruption of the segmental arrangement of the nerves due to the formation of the limb. See also Figs. 942 and 945.

Distribution of Spinal Nerves to Muscles and Skin of the Limbs

By dissection, experiment, and clinical observation, it is conclusively proved that, as a rule, each nerve of distribution in the limb, whether to muscle or skin, is made up of fibres derived from more than one spinal nerve; and, further, that in cutaneous distribution a considerable overlapping occurs in the course of the several peripheral nerves. Moreover, the arrangement of the distribution of the nerves to skin and to muscles is not identical. In the case of the skin of the limbs, by the covering of the limb being drawn on to it from adjacent parts in the process of growth, cutaneous nerves are engaged which are derived from sources not represented in the muscular innervation of the limbs. Again, among the

muscles, some have undergone fusion, others have become vestigial, and others again have altered their position in the limb.

Innervation of Skin of the Limbs

While the scheme of cutaneous innervation of the limbs is fundamentally segmental, yet the arrangement is confused and complicated by various causes. The growth of the limb from the trunk has caused the skin to be drawn out over it like a stretched sheet of india-rubber (Herringham, 1886), and at the same time the extent of either the dorsal or the ventral area of the limb is increased at the expense of the other. The central nerves of the plexus remain buried deeply in the substance of the limb, coming to the surface only towards the periphery. The proximal parts of both surfaces of the limb thus become innervated by cutaneous nerves otherwise not necessarily concerned in the innervation of the limbs. Herringham has shown that: *(a) of two spots on the skin, that nearer the preaxial border tends to be supplied by the higher nerve: (b) of two spots in the preaxial area, the lower tends to be supplied by the lower nerve; and of two spots in the postaxial area, the lower tends to be supplied by the higher nerve.* In other words, from the root of the limb along the preaxial border to its distal extremity, and along the postaxial border to the root of the limb again, there is a definite numerical sequence of spinal nerves supplying skin-areas through nerves of the limb-plexuses, as is illustrated, for example, in Fig. 941, p. 1096. A similar numerical sequence in the arrangement of the nerves is also found extending over the dorsal and ventral surfaces of the limbs from preaxial to postaxial border, except in certain situations.

On the dorsal and ventral surfaces of both upper and lower limbs there is a hiatus, for a certain distance, in the numerical sequence of the spinal nerves in their cutaneous distribution, explicable on the ground that the central nerves of the plexus, which fail to reach the surface in those situations, are replaced by cutaneous branches from neighbouring nerves. This hiatus has been named the *axial line.*

In the upper limb the *dorsal axial line* extends from the median line of the back, opposite the vertebra prominens, downwards on the back of the arm towards the elbow. The *ventral axial line* extends anteriorly from the median plane of the trunk, at the manubrio-sternal joint, across the chest, and downwards along the front of the upper arm and forearm.

In the lower limb the *dorsal axial line* may be traced from the median plane of the back over the posterior superior iliac spine, across the gluteal region and thigh, to the head of the fibula and the lateral side of the leg. A *ventral axial line* can also be traced from the root of the penis along the medial side of the thigh and knee, and along the back of the leg to the heel.

Those lines represent the meeting-place and overlapping of nerves which are not in numerical sequence; and it is only at the peripheral parts of the limbs, on the dorsal and ventral surfaces, that the nerves appear in numerical sequence from the preaxial to the postaxial border. In the case of the upper limb the hiatus is caused, in both surfaces of the limb, by the absence of cutaneous branches of the seventh cervical nerve; in the case of the lower limb the hiatus is due to the absence of branches from the fifth lumbar nerve on both surfaces of the limb, and the absence of branches from the fourth lumbar nerve, in addition, on the dorsal surface.

These points in the innervation of the skin of the limbs are illustrated by Figs. 928, (p. 1074), 929, and Figs. 941 (p. 1096), 942.

Innervation of Muscles of the Limbs

The following laws appear to be applicable to the upper and lower limbs alike:—

1. *No limb-muscle receives its nerve-supply from posterior primary rami.*

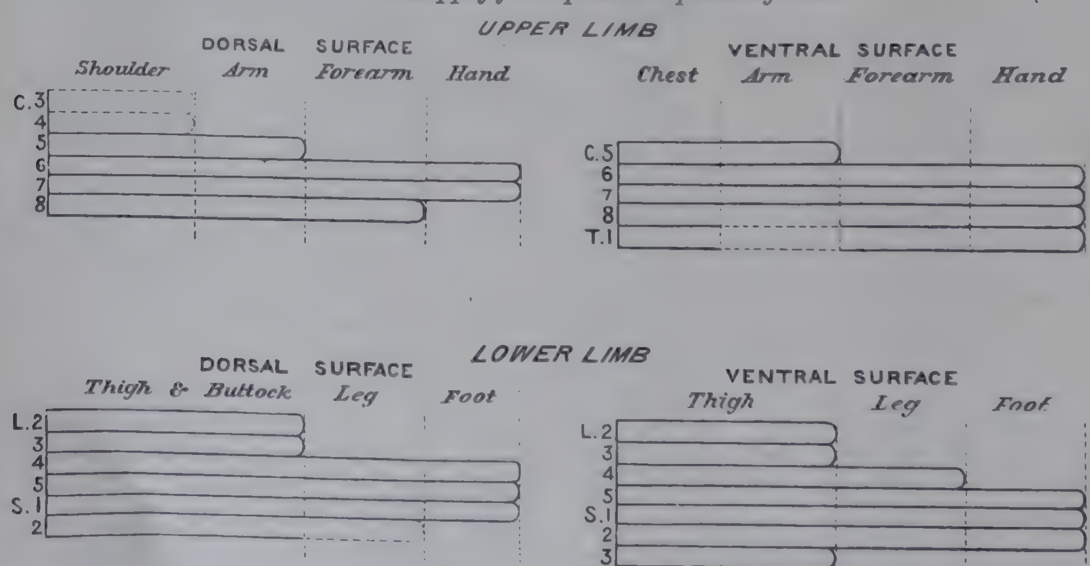

Fig. 954.—Diagram of Segmental Distribution of the Muscular Nerves of Upper and Lower Limbs.

2. *The dorsal and ventral strata of muscles are always supplied by the corresponding dorsal and ventral branches of the nerves concerned. The ventral muscular stratum is more extensive than the*

dorsal; the ventral nerves are the more numerous, and the additional nerves are postaxially placed. The spinal nerves supplying muscles of the upper limb are C. 5, 6, 7, 8 (dorsal), and C. 5, 6, 7, 8, T. 1 (ventral); the nerves for the muscles of the lower limb are L. 2, 3, 4, 5, S. 1, 2 (dorsal), and L. 2, 3, 4, 5, S. 1, 2, 3 (ventral).

3. *The dorsal and ventral trunks of the nerves are distributed in the limb in a continuous, segmental manner*; so that, "of two muscles, that nearer the head end of the body tends to be supplied by the higher nerve, and that nearer the tail end by the lower nerve" (Herringham, 1886).

4. *The nerves placed most centrally in the plexus extend farthest into the limb, and the more preaxial nerves terminate sooner in the limb than the more postaxial nerves.*

The only exception to this rule is on the ventral (anterior) surface of the upper arm, where a suppression of the muscle-elements leads to an absence of the regular series of segmental nerves (C. 8, T. 1) on its postaxial border. These nerves reappear in the forearm, and the occasional "axillary arches" may be regarded as the muscular elements usually suppressed, and, when present, supplied by these nerves. (See also the Tables of the segmental innervation of the limb-muscles in the Surface and Surgical Section.)

Muscles with Double Nerve-Supply.—The existence of more than one nerve to a muscle indicates usually that the muscle is composite and is the representative of originally separate elements belonging to more than one segment or to both surfaces of the limb. In the case of the pectoralis major, subscapularis and flexor digitorum profundus, adductor magnus, and soleus, parts of the same (ventral or dorsal) stratum have fused, to form muscles innervated from the corresponding ventral or dorsal nerves. The other muscles having a double nerve-supply—biceps femoris, and (sometimes) pectineus—are examples of fusion at the preaxial or postaxial border of muscular elements derived from the dorsal and ventral surfaces of the limb, which are correspondingly innervated by branches from both dorsal and ventral series: *e.g.*, the biceps femoris by the lateral popliteal (short head) and medial popliteal nerves (long head); and the pectineus, by the femoral and (sometimes) obturator nerves. The brachialis commonly receives branches from both the musculo-cutaneous and the radial nerves, but electrical tests have shown that the fibres from the radial are afferent ones.

Composition of Limb-Plexuses

In all mammals the same definite plan underlies the constitution of the limb-plexuses (Paterson, 1887). The nerves concerned are the anterior primary rami of certain segmental spinal nerves, which (with certain exceptions at the preaxial and postaxial borders) are destined wholly and solely for the innervation of the limb. Each of the anterior rami engaged divides into a pair of **secondary trunks,** named **dorsal** or posterior, **ventral** or anterior. The dorsal and ventral trunks again subdivide into **tertiary trunks** which combine with the corresponding subdivisions of neighbouring dorsal and ventral trunks to form the **nerves of distribution**. The combinations of *dorsal trunks* provide a series of nerves for the supply of that part of the limb which is derived from the *dorsal surface* of the embryonic limb-bud; the combinations of *ventral trunks* give rise to nerves of distribution to the regions corresponding to its *ventral surface.* Cutaneous nerves are less strictly dorsal and ventral than motor nerves. In the upper limb (Fig. 928, p. 1074) ventral offsets of the plexus tend to overlap the dorsal surface; whilst in the lower limb (Fig. 941, p. 1096) the dorsal offsets tend to overlap the ventral (*i.e.*, flexor) surface.

Intraneural Plexuses

With certain exceptions, such as the anterior and posterior spinal nerve-roots and the motor and sensory roots of the fifth nerve, the majority of peripheral nerves show progressive changes in the arrangement of their constituent fibres and bundles of fibres as they are traced peripherally. Within the peripheral nerves the fibres are disposed in fasciculi separated by perineurium. The fascicular pattern is continually modified along the entire course of the nerve by the repeated division, anastomosis and migration of bundles and there is no predictable plan of fasciculation. The confluence of the various nerve-fibres which will form a particular branch of a nerve occurs proximal to the point at which the branch leaves the parent nerve, but the distance run by such a branch within the parent nerve is, though at times considerable, quite variable. The pattern of fasciculation cannot therefore be explained wholly on the necessity for a regrouping of fibres relative to their ultimate peripheral distribution. (O'Connell, 1936; Sunderland, 1945 *d.*)

Blood-Supply of Peripheral Nerves

All nerves are supplied with blood-vessels which are essential to their normal functioning. Deprivation of blood-supply, by spasm, thrombosis or embolism, may induce sensory or motor loss and the nerve affected may even show degenerative changes.

The arteries supplying a nerve are derived from adjacent vessels and most often they are of small size and only of moderate regularity of position. On reaching a nerve the nutrient artery breaks up into ascending and descending branches which anastomose in the epineurium with similar branches from other nutrient arteries. From such epineural vessels branches penetrate into the perineurium where further anastomoses occur and finally smaller vessels penetrate into the fasciculi and form there a rich longitudinally disposed capillary network which runs

up and down the nerve in unbroken continuity. **This intrafascicular network is reinforced along its length by the contributions from the various nutrient vessels which reach the epineurium, but** *no part of the intrafascicular plexus may be regarded as being dominated by any one nutrient artery* (Durward, 1948). Some nerves, *e.g.*, the sciatic and median, may have associated arteries of considerable size; such vessels are to be regarded as embryological persistences and do not imply any preferential supply. Sympathetic nerve-fibres, presumably vasomotor in function, accompany the arteries which supply nerves. (Adams, 1942, 1943; Sunderland, 1945 *a*, *b* and *c*.)

Veins leave the capillary plexus of the nerve but do not generally unite to form a common channel; most often they drain into adjacent muscular veins rather than to superficial veins—an arrangement which has been claimed to assist in the circulation within the nerve.

DEVELOPMENT OF SPINAL NERVES AND GANGLIA

I. Origin of Spinal Nerve-Roots.—Whilst both the posterior and anterior roots are developed from cells of the neural plate, they differ as regards their exact site of origin.

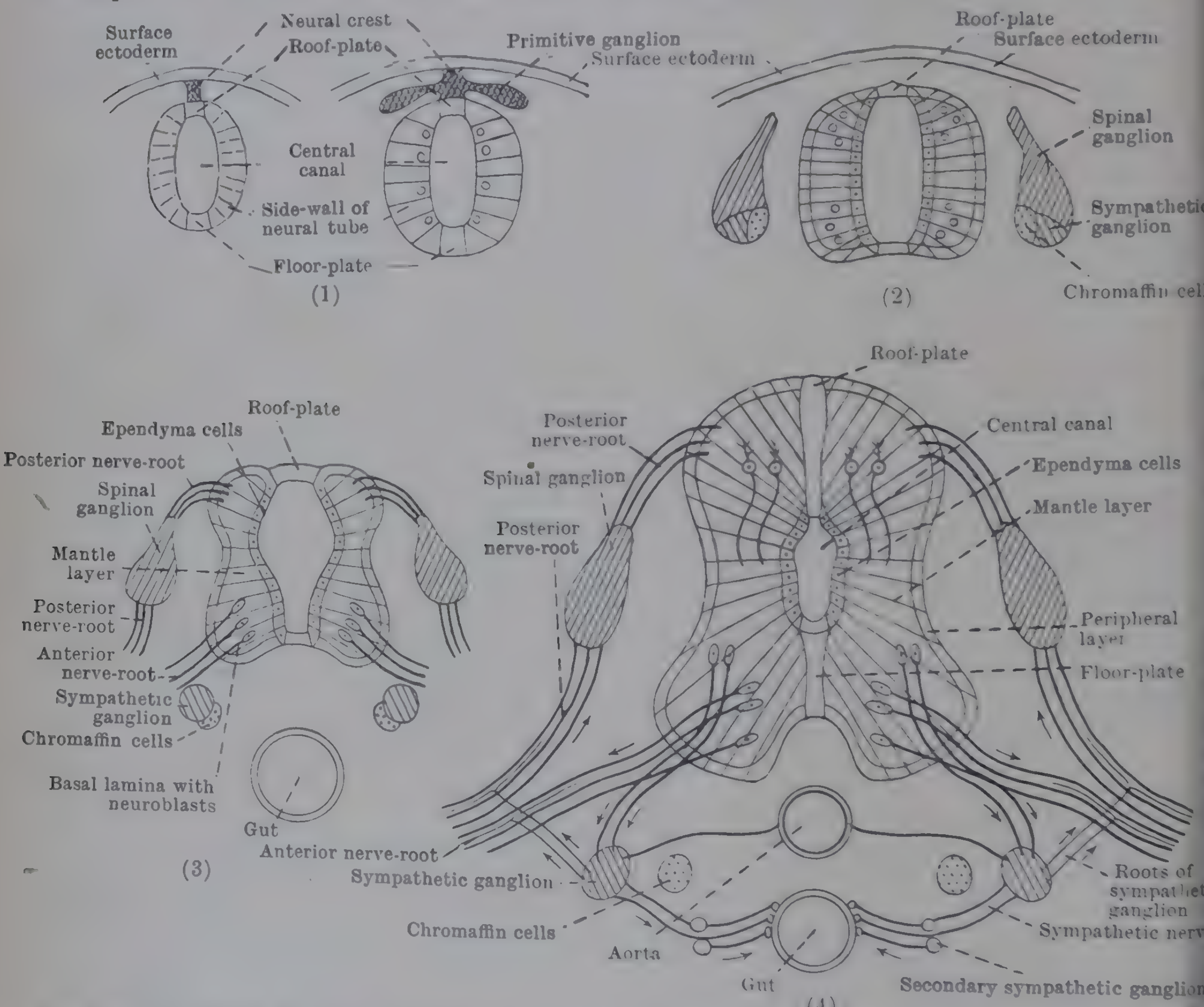

FIG. 955.—DIAGRAMS illustrating:—(1) The formation of the rudiments of the primitive ganglia from the neural crest. (2) The differentiation of different parts of the primitive ganglion into permanent root ganglion, sympathetic ganglion, and masses of chromaffin cells. (3) The formation of the anterior and posterior nerve-roots. (4) The differentiation of the walls of the neural tube into ependymal and peripheral layers.

The cells of the primitive ganglion which form the neurolemmal sheaths of the nerves are not shown.

The **posterior roots** are derived entirely **from the neural crest, the origin of which from the** cells of the lateral margin of the neural plate is described in the Section on Human Embryology (p. 60). At the time when they first appear, **the neural crest is a flattened cellular band which** extends from the auditory vesicle along the **dorsal border of the neural tube to its caudal** extremity. In the spinal region the crest shows segmental ganglionic enlargements along its **ventral border, whilst its dorsal border** shows a continuous cellular bridge throughout its length.

The cells comprising the crest are, from the viewpoint of their ultimate fate, of several types and, amongst them, the following groups of cells are of interest in relation to the development of the peripheral nervous system. (1) The majority of the cells are *neuroblasts* and develop into receptor neurons. Each such cell sends a central process dorsally, which grows into the

alar lamina of the neural tube. The central processes enter the cord in bundles and gradually the continuous bridge of crest material disappears and each ganglion is connected with the cord by only the nerve-strands composed of the central processes of the neuroblasts. Further, from each cell a peripheral process grows ventrally and joins up with the outward-growing processes of the cells in the basal lamina of the neural tube, *i.e.*, the ventral nerve-root, to form a spinal nerve. Such peripheral processes will ultimately reach some sensory area and so link it with the cord. The neuroblasts are therefore in the first place bipolar cells, but in development the central and peripheral processes, close to the cell, become approximated to produce a typical pseudo-unipolar cell of the spinal ganglion (Fig. 734, p. 847). Other cells of the crest produce (2) *sympathoblasts*, which, though developing into nervous elements, differ from the neuroblasts

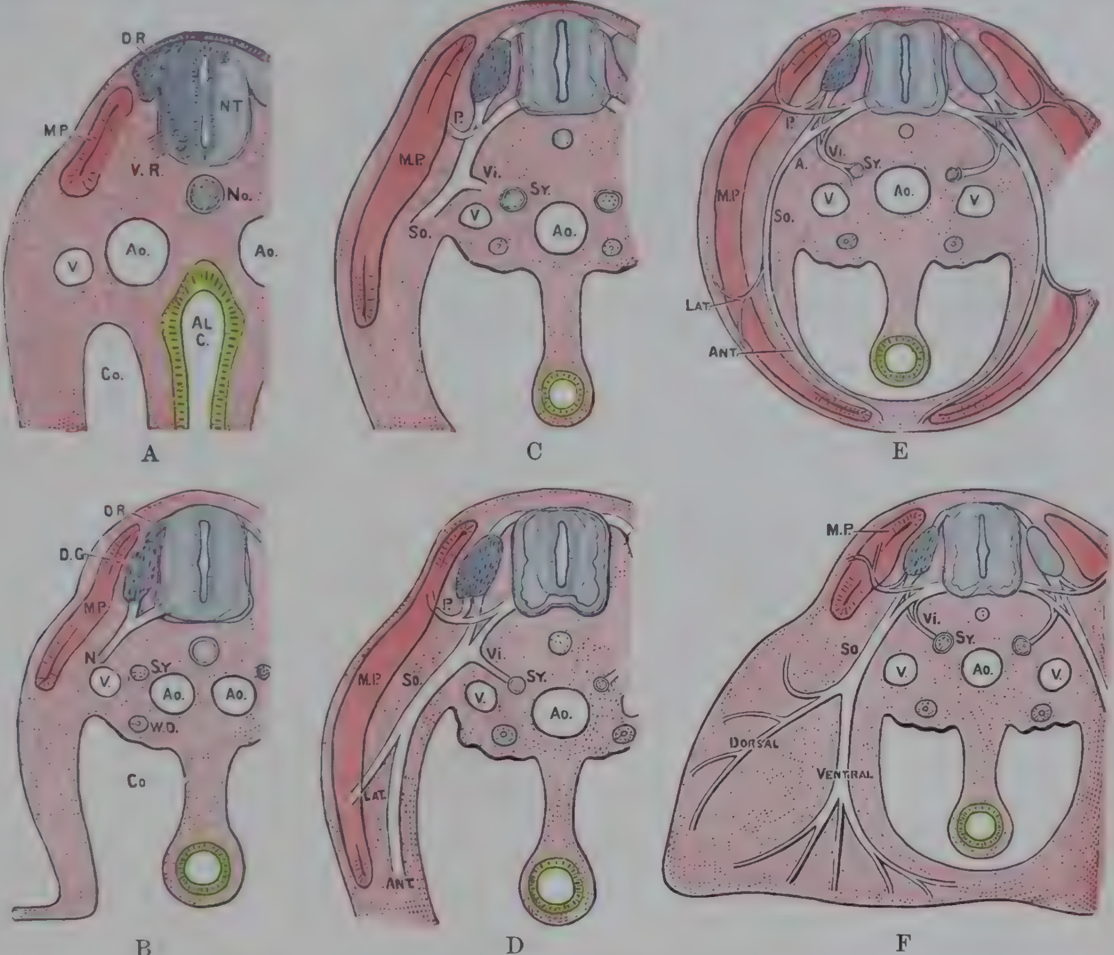

FIG. 956.—STAGES IN DEVELOPMENT OF SPINAL NERVES.

A, Formation of nerve-roots.

D.R., Posterior root.
V.R., Anterior root.
N.T., Neural tube.
No., Notochord.

Al.C., Alimentary canal.
Ao., Aorta.
V., Cardinal vein.
M.P., Muscle-plate.

B, Formation of nerve-trunk (N).

D.G., Spinal ganglion.
Sy., Sympathetic trunk.
W.D., Mesonephric duct.
Co., Cœlom.

C, Formation of nerves.

So., Somatic division.
Vi., Visceral branch.
P., Posterior ramus.

D, E, Formation of subordinate branches.

Lat., Lateral, and
Ant., Anterior, branches.

F, Formation of nerve-trunks in relation to the limb: dorsal and ventral trunks corresponding to lateral and anterior trunks in D and E.

described above in migrating away from the region of the spinal ganglia to form ganglion-cells in the sympathetic trunk and plexuses (Fig. 955). They are further discussed on p. 1146. (3) Certain cells which ultimately form the chromaffin tissue of the body are located in the neural crest; they are known as *phæochromoblasts* and they, like the sympathoblasts, migrate to other regions to form isolated clumps of chromaffin tissue; such tissue may be found associated with sympathetic ganglia but it is best exemplified by the medullary tissue of the suprarenal glands. (4) Certain cells with no nervous potentialities form the neurolemmal sheath-cells (Schwann cells) of the nerve-fibres in peripheral nerves and the capsular cells in spinal and sympathetic ganglia. These are known as spongioblasts or *lemnoblasts*. They too of course must migrate since they form the neurolemmal sheaths of outward-growing nerve-processes in both posterior and anterior nerve-roots and their continuations—the peripheral nerves (Harrison, 1924). See pp. 1146-1147 for further discussion of neural crest derivatives.

The **anterior roots**, on the contrary, are developed from the neural tube, which is a derivative of the neural plate. Processes from the neuroblasts situated in the mantle zone of the basal lamina grow out in small bundles which pierce the external limiting membrane and emerge in a continuous longitudinal series of rootlets from the ventro-lateral wall of the tube. Outside the tube the rootlets are grouped into segmental bundles—the anterior roots—which join the posterior roots just peripheral to the spinal ganglia.

II. **Formation of Spinal Nerve.**—The fibres of the spinal ganglion and the anterior root grow by extension from the cells with which they are respectively connected, and meet in the space between the myotome and the side of the neural tube to form the **spinal nerve.** In the adult there is a fundamental primary division of the spinal nerve into posterior and anterior rami. In the process of development the separation is even more obvious. As the fibres of the posterior and anterior roots approximate, they separate at the same time, each into two unequal portions: the smaller parts of the two roots unite together to form the **posterior primary ramus** of the spinal nerve, and the larger parts unite to form the **anterior primary ramus.**

The **posterior primary ramus,** curving laterally and backwards, passes through the myotome and is connected with it. In the substance of the myotome it separates into branches as it proceeds towards the dorsal wall of the embryo. At a later stage, the branches are definitely arranged into a lateral and a medial series.

The **anterior primary ramus** grows gradually in a ventral direction under cover of the growing myotome towards the somato-splanchnic angle of the cœlom (Fig. 956). It spreads out at its distal end and eventually separates into two portions: a smaller, splanchnic or visceral; and a larger, somatic or parietal portion. (1) The **splanchnic** or **visceral portion** grows inwards to be connected through the sympathetic trunk with the innervation of organs in the splanchnic area. That branch of the spinal nerve becomes the **white ramus communicans** of the sympathetic. It is not present in the case of all the spinal nerves, but only in relation to the thoracic and upper lumbar and the third and second or fourth sacral nerves. It will be referred to again in connection with the sympathetic system. (2) The **somatic** or **parietal portion** becomes the main part of the anterior primary ramus of the nerve. It continues the original ventral course of the nerve, and, reaching the body-wall, divides into two terminal branches—a *lateral branch,* which grows laterally and downwards and reaches the side of the trunk after piercing the myotome; and a ventral or *anterior branch,* which grows onwards in the body-wall to reach the ventral axis. That arrangement is met with in the trunk between the limbs and in the neck.

III. **Formation of Limb-Plexuses.**—The method of growth of the spinal nerves, just described, is modified in the regions where the limbs are developed. In relation to the limbs, which exist in the form of buds of undifferentiated cellular mesoderm before the spinal nerves have any connexion with them, the development of the anterior primary ramus of the nerve proceeds exactly in the way described, up to the point of formation of somatic and splanchnic branches. The **somatic branches** then stream out into the limb-bud, passing into it below the ends of the myotomes and spreading out into a bundle of fibres at the basal attachment of the limb. Later, the nerves separate, each into a pair of definite trunks, named posterior or **dorsal** and anterior or **ventral,** which proceed into the limb-bud on the dorsal and ventral surfaces respectively of the central core of mesoderm. While that process is going on, a *secondary union* takes place between parts of adjacent dorsal and ventral trunks. Dorsal trunks unite with dorsal trunks, ventral trunks unite with ventral trunks, to form the nerves distributed ultimately to the surfaces and periphery of the limb. These **dorsal and ventral trunks** are homologous with the **lateral** and **ventral branches** of the somatic nerves in other regions.

AUTONOMIC NERVOUS SYSTEM

The **autonomic nervous system,** like the rest of the peripheral nervous system, is a dependency of the central nervous system and linked with it by both afferent and efferent systems of fibres. It is indeed impossible to define any precise boundary between the autonomic and the cerebro-spinal nervous systems, for the two mechanisms are closely interconnected, particularly within the brain and spinal cord. In the periphery, however, the autonomic system acquires a greater or less degree of individuality in different parts of the body. The details of those parts of the autonomic system that lie within the cerebro-spinal axis have been dealt with elsewhere.

The autonomic nervous system is peculiar in that it is concerned in the main with the automatic or non-voluntary control of visceral structures, *e.g.,* glands, blood-vessels, and gut, and not with peripheral mechanisms, such as skeletal muscles, which are under more apparent voluntary control. For this reason the autonomic system has been called the "involuntary" nervous system—just as plain or visceral muscle is commonly known as "involuntary" muscle—but the use of this expression is not advisable since the autonomic system is frequently interlinked functionally in mechanisms which are in large measure voluntary, *e.g.,* micturition. It has been described as that part of the nervous system primarily concerned with the regulation of the internal environment of the body and the maintenance of its stability. (See the standard works of Delmas & Laux (1933); White & Smithwick (1942); and Kuntz, 1946.)

As originally described by Langley (1921), the autonomic system was regarded as an efferent system and no account was taken of the afferent neurons which pass centrally from the various visceral structures under autonomic control. Much less is known of these afferent fibres—the splanchnic or visceral afferents—but it seems expedient to regard them as the afferent counterpart of the classic efferent autonomic system of Langley. If we include the splanchnic afferent fibres, the autonomic system differs from the rest of the nervous system, as in the case of efferent fibres, in that the incoming impulses subserve different kinds of sensation from those carried by ordinary somatic peripheral nerves; they do not generally arouse any, or any highly coloured, conscious state. Moreover, they

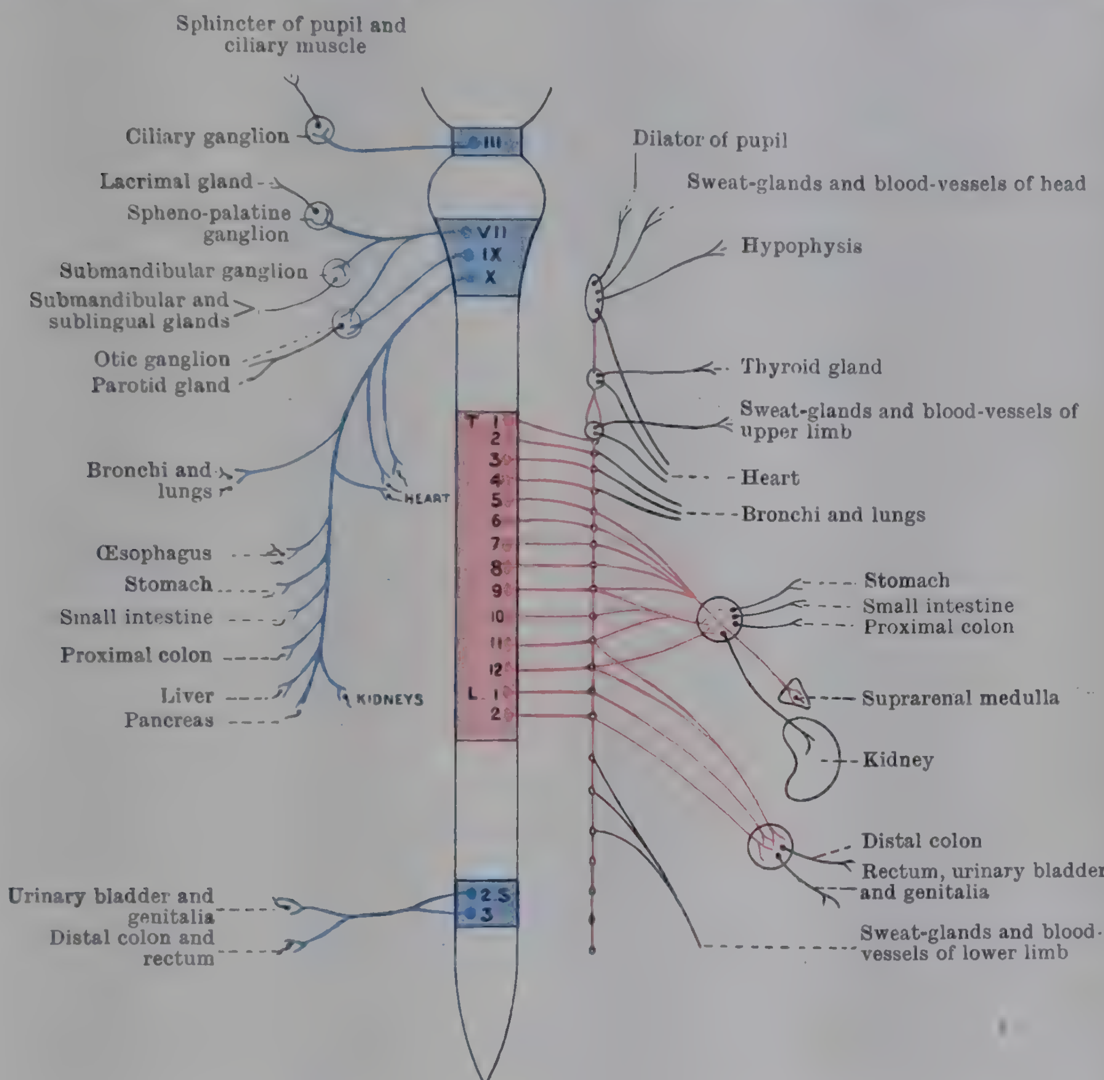

FIG. 957.—SCHEME OF GENERAL ARRANGEMENT OF AUTONOMIC NERVOUS SYSTEM.
Preganglionic fibres of the parasympathetic system in *blue* and of the sympathetic system in *red*. Postganglionic fibres of both systems in *black*. Afferent fibres are not included.

come from regions within the body, *e.g.*, lungs, gut, vessels, which are not normally exposed to the same range of stimuli as somatic peripheral nerves. They may, however, under normal conditions arouse conscious states, *e.g.*, the feeling of fullness in the stomach or bladder or perhaps even a feeling of well-being under appropriate stimulation; and under abnormal conditions otherwise unnoticed impulses from the viscera may arouse conscious appreciation. It may then be said that the efferent side of the autonomic nervous system is generally divorced from any apparent voluntary control and that the afferent side is most often concerned with impulses which, though of great significance in visceral reflex mechanisms, do not as a rule enter consciousness. The autonomic nervous system is widely distributed throughout the body, and it consists of neurons arranged as ganglia and strands of fibres which often produce plexuses by interlacement. The main aggregations of autonomic elements are found in the thorax and abdomen close by the viscera to be supplied, but all parts of the

body are served by autonomic fibres, which in their course often associate themselves with the blood-vessels and peripheral nerves of the regions concerned.

We have seen how in the somatic nerves the final motor neuron had its origin in a cell within the central nervous system and its axon passed out in some peripheral nerve to the effector agent, *e.g.*, skeletal muscle. In the autonomic system there is a very characteristic difference in that two neurons are interposed between the brain or cord on the one hand and the peripheral effector on the other. The first of these has its cell-body within the brain-stem or the cord, from which its axon passes out to reach a ganglion or gangliated plexus of the autonomic system where it terminates in a synapse with the second or excitor neuron. This second or excitor neuron then influences some effector agent, *e.g.*, plain muscle or gland. There is therefore a peripheral synapse separating a **preganglionic neuron** from a **postganglionic neuron.** This arrangement is fundamental and constitutes the most striking anatomical difference between splanchnic and somatic efferent nerves. Further, in the ganglia and plexuses there are many more postganglionic neurons than there are preganglionic fibres leaving the central nervous system; this arrangement is admirably suited to the wide diffusion of autonomic effects.

Splanchnic afferent fibres proceed towards the brain or cord, and, like other afferent neurons, have their cell-bodies in the spinal ganglia or in the ganglia associated with certain cranial nerves. In their course centrally they may accompany somatic nerves or run through autonomic plexuses and ganglia, where, of course, they do not have any synaptic interruption. Our knowledge of the distribution and of the central connexions of such splanchnic afferent fibres is much less complete than for the efferent part of the autonomic system.

Mainly on the basis of functional differences the autonomic system has been divided into two components—sympathetic and parasympathetic (Figs. 957, 962).

The **Sympathetic System** is connected with the cord in the thoraco-lumbar region by fibres which constitute the *thoraco-lumbar outflow.*

The **Parasympathetic System** is connected with the central nervous system through certain cranial and sacral nerves by fibres which constitute the *cranio-sacral outflow.*

These two components of the autonomic system are distinguished not so much by their place of origin as by the fundamentally different effects of their activity and by different reactions to certain drugs. Both are very widely distributed, and commonly their fibres run side by side to the same organ, where they are capable of producing antagonistic effects. For example, both systems supply the heart, whose rate is increased by the sympathetic system and decreased by the parasympathetic; or, again, the sympathetic supply to the eyeball dilates the pupil while the parasympathetic regulates its degree of constriction. In the alimentary tract the parasympathetic system is the main motor agency for the control of the onward movement of the contents, whereas the sympathetic effects a cessation of peristalsis and closure of the sphincters. In the integuments the sympathetic produces sudomotor and pilomotor effects, and on blood-vessels generally the sympathetic causes constriction with a consequent rise in blood-pressure. It has therefore been suggested that the sympathetic system, which tends to produce widespread effects in the body, prepares the individual for a struggle or puts the internal environment in tune with some external crisis, whereas the parasympathetic is concerned rather with conservation and the building-up of energy. This generalization is useful, and many other examples might be quoted to support it; but it must be clearly understood that the two systems are not acting antagonistically in respect of the individual's well-being, but rather by their harmonious interaction they strike a balance and allow of multiple gradations between the extremes that each system if acting alone might produce. It should be noted, too, that not all organs are innervated by both systems.

The theory of the humoral transmission of nervous impulses (Elliott, 1905; Loewi, 1935; Dale, 1934, 1938) has been worked out in large measure on the autonomic system and there would appear to be pronounced differences in the nature of the chemical substances liberated at the termination of the excitor neurons. Sympathetic excitor (*i.e.*, postgang-

lionic) neurons liberate an adrenalin-like substance which is claimed to act as a sort of deputy between the neuron and the effector agent, *e.g.*, plain muscle. They have therefore been called *adrenergic* fibres in contrast to parasympathetic postganglionic neurons which liberate at their termination acetyl-choline or similar substance and are therefore known as *cholinergic* fibres. This classification, which gains considerable physiological acceptance to-day, is not, however, to be regarded merely as a basis for an alternative nomenclature for parasympathetic and sympathetic, because the two conceptions overlap in several instances, *e.g.*, the sympathetic system undoubtedly activates the sweat-glands, but the chemical mediator is acetyl-choline and not an adrenalin-like substance. A physiological monograph should be consulted for detailed discussion of these and related matters.

PARASYMPATHETIC SYSTEM

Much of the topographical anatomy of this system has been covered already in the description of some of the cranial and sacral nerves. It remains to review

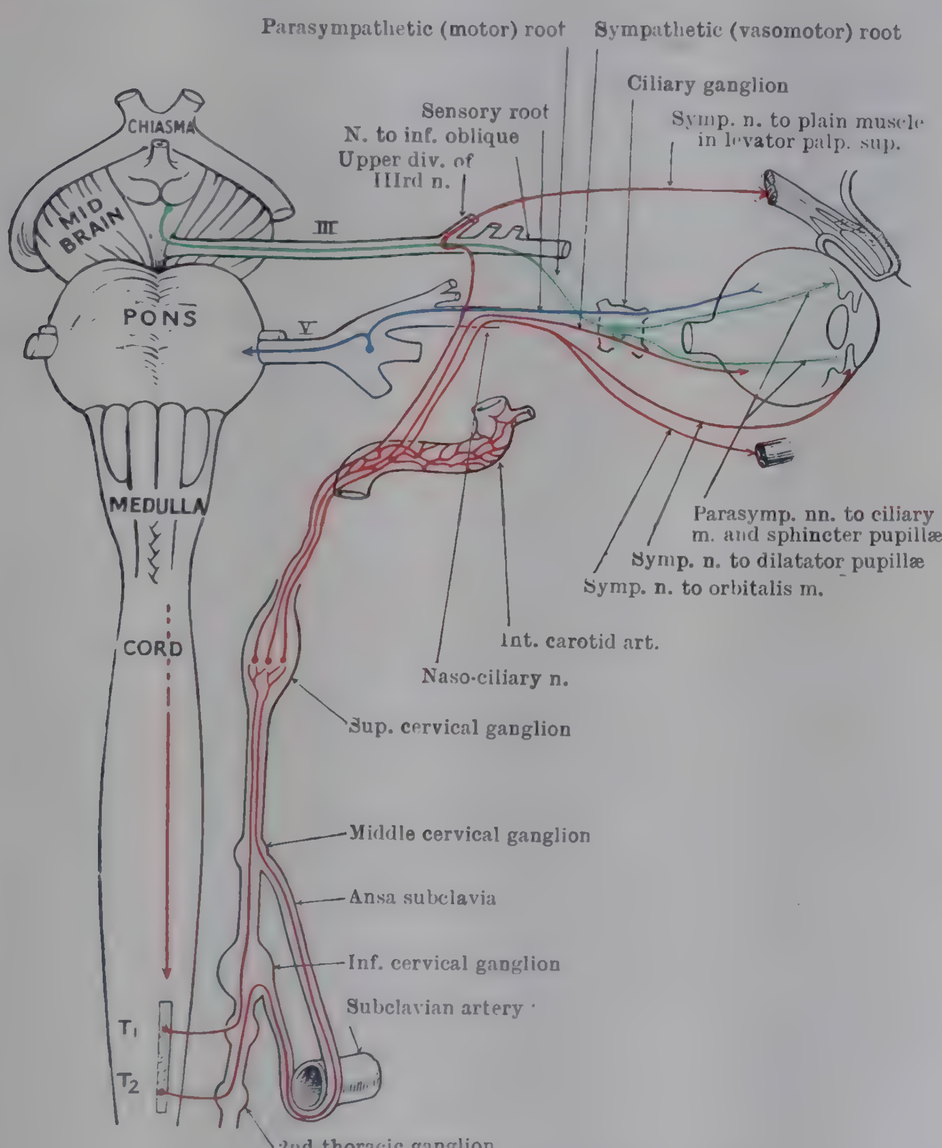

Fig. 958.—Diagram of Ciliary Ganglion and Connexions of Autonomic Nervous System with the Eye.

all the components and to discuss the parasympathetic in more detail as a system. It is customary to subdivide it into two main parts (Fig. 957):—

1. The **Cranial Parasympathetic** or cranial outflow. This is linked with the brain-stem by the following nerves: the oculomotor, the facial, the glosso-pharyngeal, and the vagus.
2. The **Sacral Parasympathetic** or sacral outflow linked with the spinal cord by the second and third (or third and fourth) sacral anterior primary rami.

Neither of these parts has any direct association with the sympathetic trunk, although not uncommonly parasympathetic and sympathetic fibres ultimately reach a viscus in a common bundle and are indistinguishable from each other. As in the sympathetic, so here we have the same fundamental arrangement of pre- and post-ganglionic neurons. The former are located within the central nervous system and their axons leave it to meet the postganglionic neurons in peripheral ganglia. A distinctive feature is that generally the parasympathetic ganglia are situated close to the viscus concerned and not infrequently in the wall of the viscus; the post-ganglionic neuron therefore is commonly a short one. Further, the various peripheral parts of the parasympathetic system tend to remain discrete and the effects are therefore much more localized than in the case of the sympathetic, where a preganglionic neuron may influence many postgang-

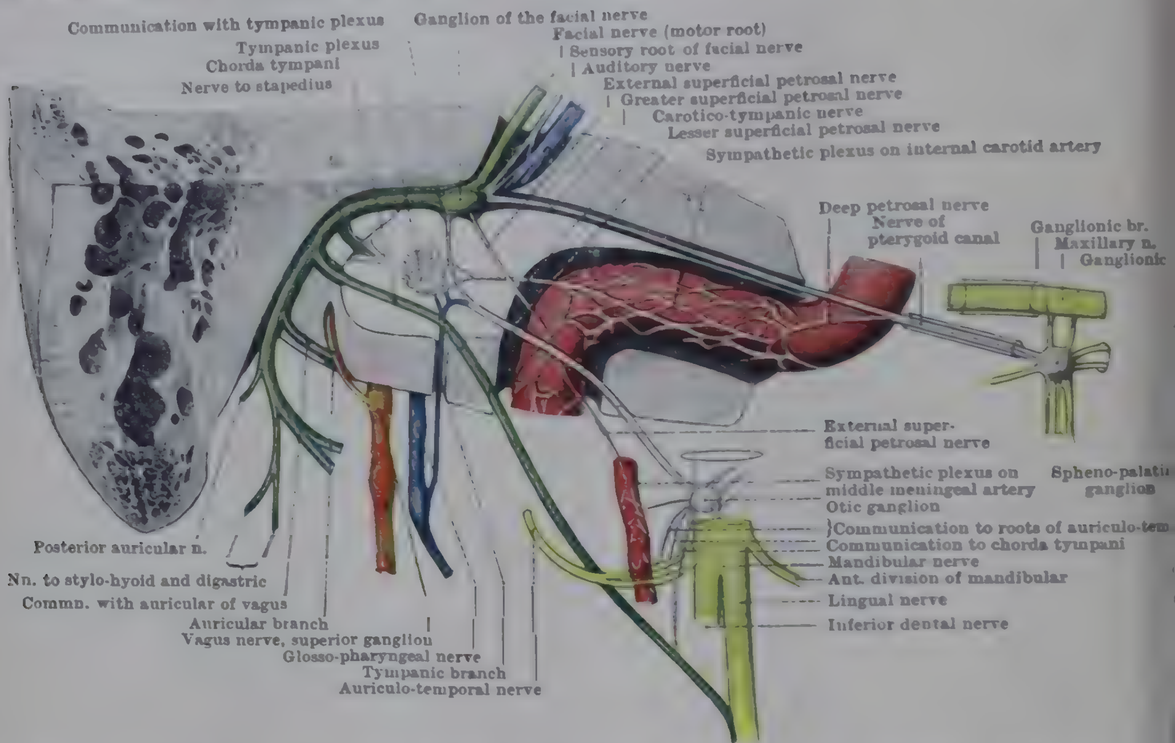

Fig. 959.—Branches of Facial and Glosso-Pharyngeal Nerves in the Temporal Bone, and Connexions of Spheno-Palatine and Otic Ganglia.

lionic neurons at different levels and so produce a much more widespread and diffuse effect.

The wide separation of the two parasympathetic outflows—cranial and sacral—necessitates the very extensive distribution of certain of its components. The fibres associated with the third, seventh, and ninth nerves have a rather localized field in the head region and are linked with certain ocular and ingestive mechanisms there. The tenth nerve, however, has a very wide distribution in the head, neck, thorax, and abdomen, and extends downwards indeed until it meets the sacral outflow. The sacral outflow is concerned in the main with the terminal parts of the alimentary and urogenital systems and plays an important rôle in emptying them.

CRANIAL PARASYMPATHETIC

Oculomotor Nerve.—The parasympathetic or splanchnic efferent fibres that run with this nerve arise probably from the Edinger-Westphal component of the oculomotor nuclear complex in the mid-brain (see p. 935). They accompany the oculomotor nerve into the orbit and then (from the branch to the inferior oblique muscle) they proceed as a delicate twig to the *ciliary ganglion*, constituting its parasympathetic or motor root (Fig. 958). Here, the preganglionic fibres end in synapses with the nerve-cells of the ganglion. A few ganglion cells may be found above the eyeball (Nathan & Turner, 1942) and are to be regarded as detached portions of the ciliary ganglion. The new, postganglionic fibres proceed

in short ciliary nerves to the eyeball, where, after piercing the sclera, they proceed forwards between it and the choroid to supply the ciliary muscle and the circular muscle of the iris (sphincter pupillæ). They can thus influence the convexity of the lens, and, by varying the tonus of the circular muscle of the iris, they are responsible for the control of pupillary size. It is of interest to note the association together in the third nerve of the fibres responsible, during accommodation, for convergence (somatic fibres to medial rectus muscle) and the fibres (parasympathetic) which

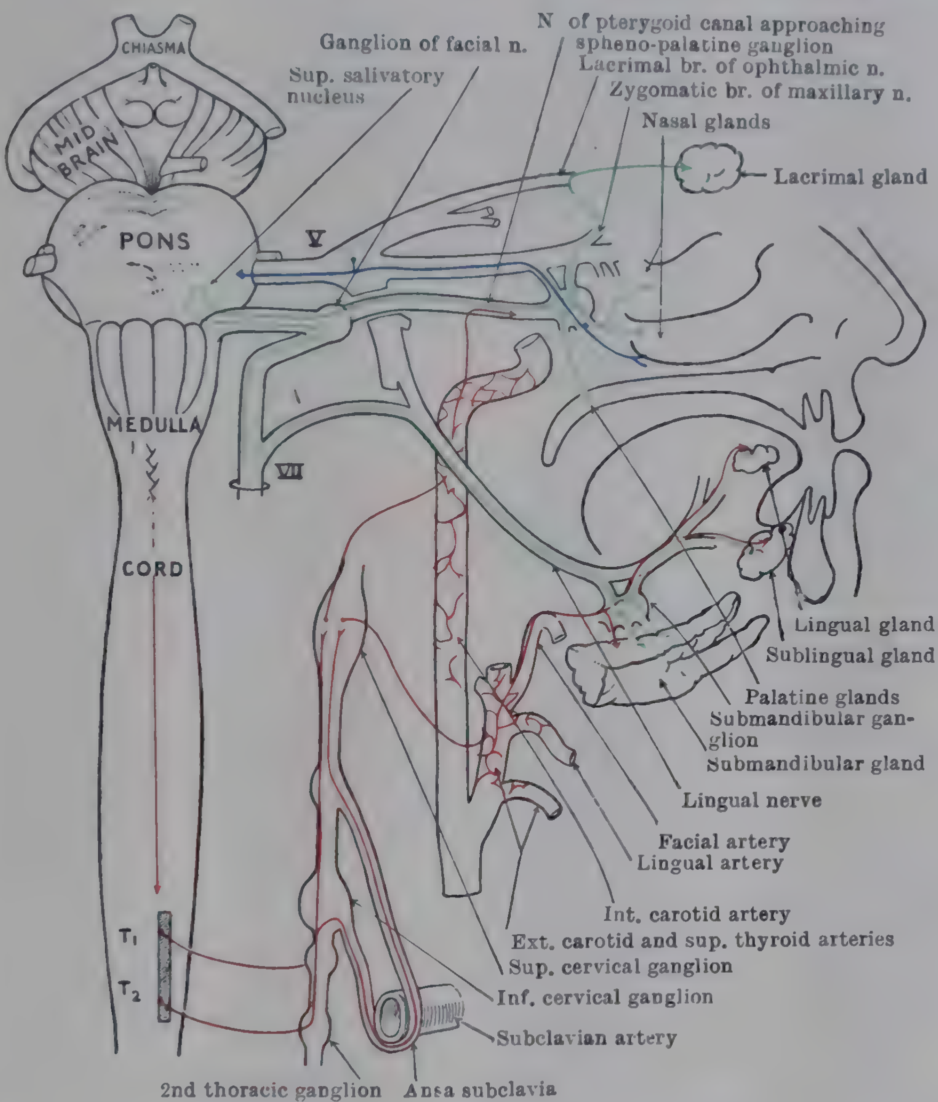

FIG. 960.—DIAGRAM OF CONNEXIONS OF SPHENO-PALATINE AND SUBMANDIBULAR GANGLIA WITH DISTRIBUTION OF PARASYMPATHETIC COMPONENTS OF SEVENTH CRANIAL NERVE.

produce changes in the lens and pupil. For the disposition of pupillo-constrictor fibres in the third nerve, see p. 1016.

Facial Nerve.—The splanchnic efferent fibres associated with the seventh nerve arise from a group of nerve-cells, alongside its motor nucleus in the pons, known as the *superior salivatory nucleus.* The preganglionic fibres leave the brain in the sensory root and in the temporal bone they leave that root in two of its branches—greater superficial petrosal and chorda tympani (Fig. 959).

1. The **greater superficial petrosal nerve**. After a course in the middle cranial fossa, foramen lacerum and pterygoid canal during which it receives sympathetic additions, this nerve reaches the *spheno-palatine ganglion.* Here the parasympathetic preganglionic neurons end in synapses around nerve-cells whose postganglionic fibres proceed to the lacrimal gland as its secreto-motor supply (Fig. 960) and to the glands of the nasal cavity and the palate.
2. The **chorda tympani** arises from the descending part of the seventh nerve in the temporal bone and, after a course through the middle ear, it emerges through the petro-tympanic fissure and shortly joins the

lingual branch of the mandibular division of the trigeminal, with which it runs towards the tongue. On the hyoglossus muscle the parasympathetic preganglionic fibres leave the lingual nerve to join the *submandibular ganglion*, where they end in synapses. From the ganglion, postganglionic fibres proceed directly to the submandibular gland or run back to the lingual nerve for distribution to the sublingual gland and glands of the tongue as their secreto-motor supply (Fig. 960). Some of the preganglionic fibres may proceed beyond the ganglion to meet scattered ganglionic cells in the glands concerned. Amongst the chorda tympani fibres are some which on stimulation cause vasodilatation of blood-vessels in its field of distribution. Kuntz & Richins (1946) suggest, however, that the parasympathetic supply to salivary glands is essentially glandular and that the sympathetic supply is vasomotor.

Accompanying these groups of secreto-motor parasympathetic fibres are afferent fibres concerned with taste in the anterior parts of the tongue and perhaps with taste-impulses from the palate. Their cell-bodies are in the ganglion of the seventh nerve, from which the central processes proceed towards the brain with the sensory root. They are special splanchnic afferent fibres, and may be regarded functionally as the afferent counterpart of the essentially motor parasympathetic fibres described above. Their connexions within the brain-stem are discussed elsewhere (p. 930).

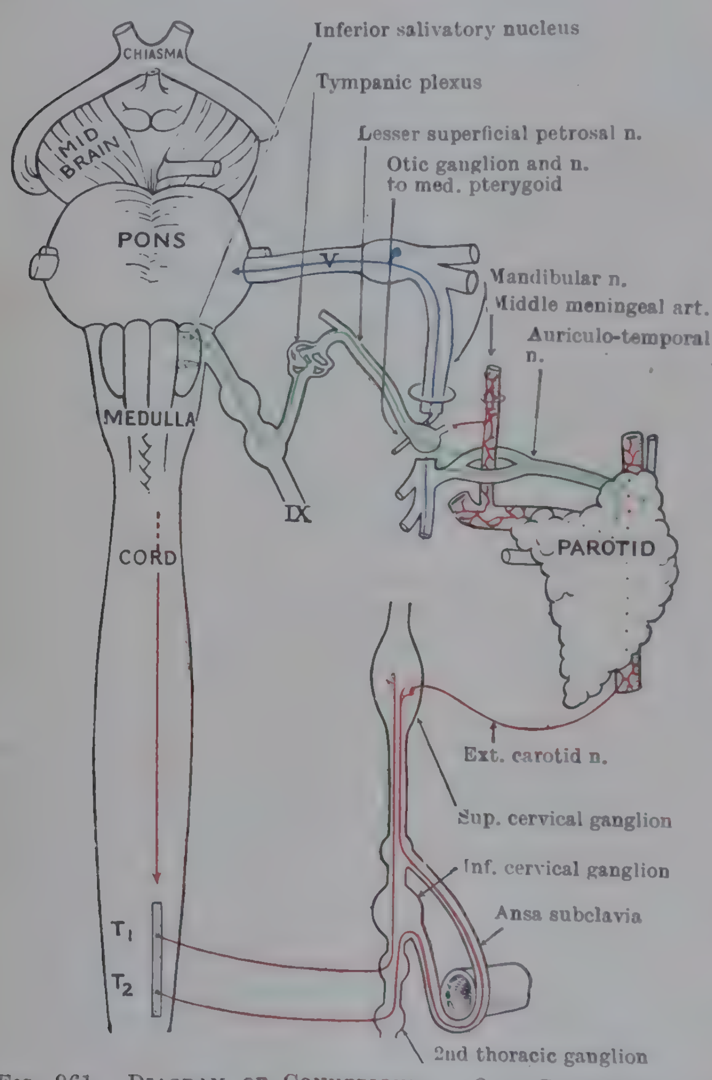

FIG. 961.—DIAGRAM OF CONNEXIONS OF OTIC GANGLION WITH DISTRIBUTION OF PARASYMPATHETIC COMPONENTS OF NINTH CRANIAL NERVE.

A communication is described between the seventh nerve and the tympanic plexus in the temporal bone by which preganglionic fibres of the seventh may be conveyed to the lesser superficial petrosal nerve and so to the otic ganglion. If this is so, then these fibres could conceivably influence the parotid gland through its supply from the otic ganglion.

Glosso-Pharyngeal Nerve.—Parasympathetic fibres which arise in the *inferior salivatory nucleus* in the medulla oblongata emerge from the brain-stem in the glossopharyngeal nerve and leave it below the skull in its tympanic branch. After a course through the temporal bone, they form the lesser superficial petrosal nerve, which ultimately joins the *otic ganglion*. Here the preganglionic fibres end in synapses around nerve-cells whose postganglionic axons proceed in the auriculo-temporal nerve to the parotid gland as its secreto-motor supply (Fig. 961).

The ninth nerve conveys to the brain many afferent fibres concerned with taste from the posterior part of the tongue and adjacent regions. These are special splanchnic afferent fibres and, as in the case of the seventh nerve, they may in

large measure be regarded as the afferent counterpart of the splanchnic efferent fibres described above. Their connexions within the brain-stem are described elsewhere (p. 929).

An important group of vaso-sensory fibres (the sino-carotid nerve) is carried centrally by the ninth nerve from the carotid sinus and the carotid body (Fig. 689, p. 808) (Sheehan, Mulholland, & Shafiroff, 1941).

Vagus Nerve.—This is the largest member of the cranial parasympathetic group and has a very wide distribution. It is composed of various types of fibres which include a large number of splanchnic efferent (parasympathetic) fibres and also many splanchnic afferents.

The parasympathetic efferent fibres differ from those in other cranial nerves in not passing to obvious dissectable ganglia, but to ganglion-cells in diffuse plexuses such as the cardiac or in the walls of viscera supplied. The chief fields of distribution are the heart, the alimentary tract, and the lungs. In general, the various branches of the vagus both in the thorax and the abdomen become intimately associated with sympathetic fibres and it is quite impossible by dissection to unravel the two sets: functionally, however, each retains its individuality and, as explained previously, their actions on a particular viscus are different.

In the alimentary system the various branches—œsophageal, gastric, and intestinal—derived from the vagus nerves provide the nervous pathway for impulses which control motility of the gut and the onward movement of its contents. Secreto-motor fibres induce secretion of the associated glands; other fibres are inhibitory to sphincters, *e.g.*, pyloric and ileo-colic. Such branches extend to the distal colon, after which the sacral parasympathetic system is the source of control.

In the respiratory system vagal fibres induce broncho-constriction, and in the heart they decrease the rate of contraction.

The many splanchnic afferent fibres incorporated in the vagus have a field of distribution equally wide—from the alimentary and respiratory tracts and from the heart. A great many of these are "silent" afferent fibres in that they generally give rise to no conscious state, but others, *e.g.*, from pharynx and larynx and to a less extent from the œsophagus, provoke obvious conscious states and also provide the afferent side of reflex mechanisms such as coughing. Other afferents from vessels provide the afferent side of important cardio-vascular reflexes —*e.g.*, from the aortic arch and its associated glomus aorticum, vaso-sensory impulses are conveyed by the vagus to the medulla. All the various afferent fibres have their cell-bodies in the vagal ganglia.

The details of the course of the vagus nerve and its various branches and the position of the plexuses are covered in the description of the vagus nerve (pp. 1037-1042) and in the section dealing with the sympathetic plexuses of thorax (p. 1138) and abdomen (p. 1140). These sections should be studied in conjunction with the above remarks.

SACRAL PARASYMPATHETIC

The sacral parasympathetic nerves arise as a number of delicate branches from the anterior primary rami of the second and third, or third and fourth sacral nerves. Sheehan (1941) found that the sacral outflow was carried most commonly by the third and fourth sacral nerves; the second and the fifth were not regularly implicated. Their cells of origin are in the sacral part of the spinal cord, and they have therefore a considerable course in the cauda equina before they appear in the pelvis. These two or three strands, known as the **pelvic splanchnic nerves**, are composed of medullated preganglionic fibres (comparable therefore with white rami communicantes) which proceed to the pelvic plexuses in association with sympathetic fibres. They meet their postganglionic neurons either in these plexuses or in the walls of the viscera which they supply, viz., distal colon and rectum, and the pelvic parts of the urogenital system. Further details of the course of the fibres concerned are given with the sympathetic system in the pelvis (p. 1144).

The sacral parasympathetic replaces the vagus probably in the region of the descending colon and is concerned with the emptying-mechanisms of the various hollow viscera—rectum, uterus, and bladder—and also with the phenomenon of erection (vaso-dilatation) of the genital organs and the neuro-muscular control of ejaculation. In comparison with the cranial outflow and with the thoraco-lumbar outflow the sacral is small and also more variable.

SYMPATHETIC SYSTEM

The foundation of the sympathetic nervous system is laid by *splanchnic efferent fibres* which emerge from a sharply limited region of the spinal cord between the first thoracic and the second lumbar segments. These efferent fibres arise from cells in the lateral grey column of the cord and pass outwards in the anterior nerve-roots to reach the anterior primary rami of the spinal nerves concerned. They leave the anterior ramus (Fig. 963) as a bundle of fibres, generally medullated, known as the **white ramus communicans**, which joins the gangliated **sympathetic trunk**. These fibres are preganglionic fibres and collectively constitute what is known as the *thoraco-lumbar outflow*. They meet the postganglionic neurons either in the ganglia of the sympathetic trunk or in the gangliated plexuses associated with the trunk. It is important to understand from the outset that each preganglionic fibre may effect synaptic contact with a number of postganglionic neurons; this accounts for the greater number of postganglionic neurons and also for the wide diffusion of sympathetic effects. Further, all sympathetic elements, wherever found in the body, derive their efferent connexion from the central nervous system through this limited region of the cord between the origins of the two great limb-plexuses from the cervical and lumbar enlargements. So, from this thoraco-lumbar source, there has to be a means of distributing fibres upwards to the neck and head, and downwards to the lumbar and pelvic regions, as well as locally in the thoraco-lumbar zone. We find that the sympathetic trunk continues upwards and downwards along the whole length of the vertebral column, composed of groups of postganglionic cells—the ganglia—linked by strands of fibres, but that no accession of preganglionic fibres reaches it beyond the limits of the thoraco-lumbar outflow; its extensions upwards and downwards are a means of distributing the preganglionic neurons to levels where no preganglionic outflow exists. Further, the continuity of the trunk from level to level permits a preganglionic neuron, by means of its collaterals, to influence numerous postganglionic neurons.

A. The **ganglia** are composed of aggregations of nerve-cells mostly of the multipolar variety, though a few may be bipolar or pseudo-unipolar. They are all excitor neurons, and their axons are the postganglionic fibres of the sympathetic. There is no adequate evidence that the cell-bodies of receptor neurons are found in sympathetic ganglia.

Each ganglion-cell is enclosed in a nucleated capsule and is provided with one axon and a number of dendrites. Some of the dendrites ramify beneath the capsule and hence are termed intracapsular; they may form a network round the cell or may be localized in the form of a glomerulus. Other dendrites are extracapsular; they pierce the capsule and run throughout the ganglion, taking part in the formation of an intercellular plexus and making contact with the capsules of other cells. This plexus is joined by the ramifications of the entering preganglionic fibres, some of which also pierce the capsules of the cells to meet the intracapsular dendrites. One preganglionic fibre can, in that way, influence many postganglionic neurons, which explains the difference between the comparatively small number of fibres that enters the ganglion and the large number that leaves it. There appears to be no evidence of commissural neurons or of sensori-motor synapses among ganglion-cells. The axon of a ganglion-cell (a postganglionic fibre) is usually non-medullated, though this need not hold throughout its length.

The ganglia are classified as follows:—

(1) The **paravertebral** or **central ganglia** are more or less segmental in position but variable in number, form, and size. They are all interconnected by narrow cords formed of ascending and descending fibres and in that way a gangliated

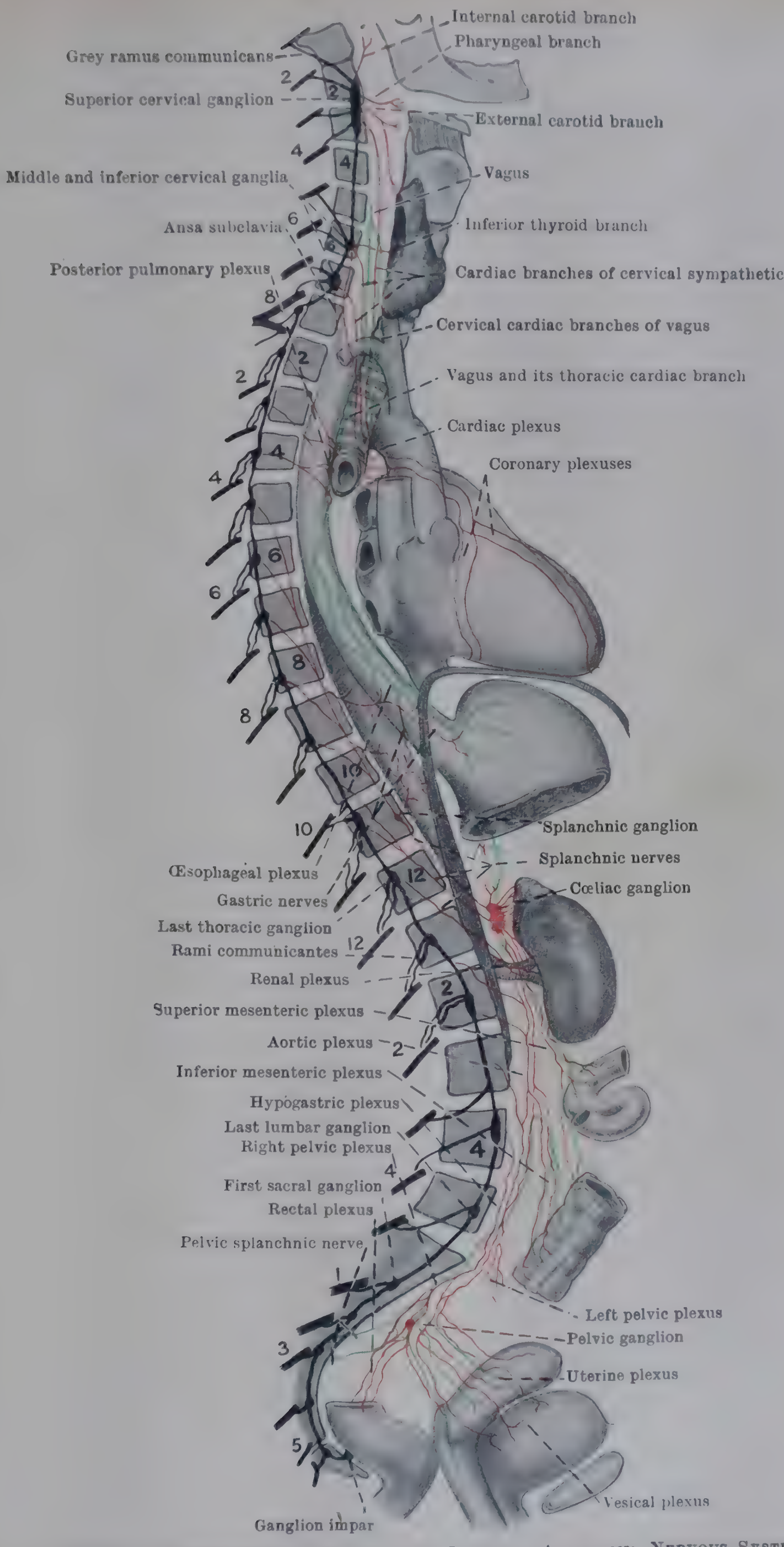

FIG. 962.—TOPOGRAPHICAL PLAN OF MAIN PARTS OF AUTONOMIC NERVOUS SYSTEM.

The spinal nerves, sympathetic trunk, and rami communicantes are shown in *black*; sympathetic branches of distribution and plexuses in *red*; parasympathetic nerves (vagus and sacral) in *green*. The vertebræ and spinal nerves are numbered.

sympathetic trunk is formed on each side, flanking the vertebral column. The connecting strand between any two ganglia may be duplicated. There are twenty-one or twenty-two ganglia in each trunk of which three are associated with cervical nerves, ten or eleven with the thoracic, four with the lumbar, and four with the sacral nerves. At their lower ends the two sympathetic trunks unite either by communicating strands or in a single, median ganglion placed on the front of the coccyx—the *ganglion impar*. At the upper end each sympathetic trunk is continued into the cranial cavity in the form of plexuses around the internal carotid artery and it thereby establishes relations with certain cranial nerves. There are no communications between the trunks of the two sides except occasionally towards their lower ends.

(2) **Collateral (prevertebral) ganglia** are found in connexion with the great prevertebral plexuses of the thorax and abdomen. They are much more diffuse than the paravertebral ganglia and must be regarded rather as gangliated plexuses. They are not arranged in a segmental manner but permit fibres to be collected for distribution to one organ or to a group of organs physiologically related to one another.

(3) **Terminal ganglia** may be found on or in the walls of viscera; but these belong mainly to the parasympathetic system.

B. The **nerve-fibres** in the sympathetic system may be medullated or non-medullated. Preganglionic fibres, which link up the central nervous system with the sympathetic trunk, are medullated but rather smaller than somatic efferent fibres. The fibres that arise from cells of the sympathetic ganglia are postganglionic and generally non-medullated or very finely medullated, or they may be medullated in part and non-medullated elsewhere along their length. Fibres of the above types (efferent) as well as medullated afferent fibres are found in the rami communicantes, in the interganglionic cords, and in the branches of distribution from the trunk. These may now be considered severally (Fig. 962).

(1) **White rami communicantes** are the only true rami communicantes since they alone provide an efferent connexion between the central nervous system and the sympathetic system. They are composed of finely medullated fibres and arise from the anterior primary rami of the spinal nerves from the first thoracic to the second lumbar inclusive. The cervical, lower lumbar, and the sacral nerves do not give off white rami to the sympathetic system—*i.e.*, they are beyond the limits of the thoraco-lumbar outflow. The fibres of the white rami pass through both posterior and anterior roots of the spinal nerves but mainly through the anterior. The *fibres from the anterior root* are of small size and are axons of nerve-cells situated in the lateral grey column of the cord. After running in the anterior roots, the anterior primary rami, and the white rami communicantes, they terminate in arborizations around cells of sympathetic ganglia: they are therefore preganglionic fibres. Three courses are open to such a fibre (Fig. 963): (*a*) it may end in the ganglion immediately adjacent to the ramus; (*b*) it may course upwards or downwards to reach neighbouring ganglia; (*c*) it may pass beyond the sympathetic trunk to end in relation with cells of some collateral ganglion. All the above are preganglionic **splanchnic efferent fibres**. The *fibres from the posterior root* of the spinal nerve which enter into the composition of the white ramus are the peripheral processes of the cells of a spinal ganglion and are **splanchnic afferent fibres** from viscera and vessels. They traverse the various branches of the sympathetic trunk and the trunk itself, but have no synaptic relationship with the cells of the sympathetic ganglia: they terminate in the grey matter of the cord. It is not certain that afferent fibres of this category are found only in nerves provided with distinct white rami; similar medullated fibres are found also in grey rami communicantes.

(2) The **interganglionic cords** of the trunk are composed of white and grey fibres arranged as one or more connecting links between the ganglia. The *white fibres* are: (i) **splanchnic efferent fibres** passing to a ganglion above or below their points of entrance to the sympathetic system; (ii) **splanchnic afferent fibres** passing along the connecting cord and over or through the ganglia on their way to the posterior nerve-root and spinal cord. The *grey fibres* are axons of sympathetic ganglion-cells and they may pass up or down the sympathetic trunk

before leaving it as one of its branches. There is no evidence of purely associative neurons uniting one ganglion of the trunk with another.

(3) **Fibres of distribution** may leave the trunk by several routes: they may join spinal nerves (grey rami communicantes) or certain cranial nerves; they may travel along blood-vessels; or they may pass as direct visceral or splanchnic

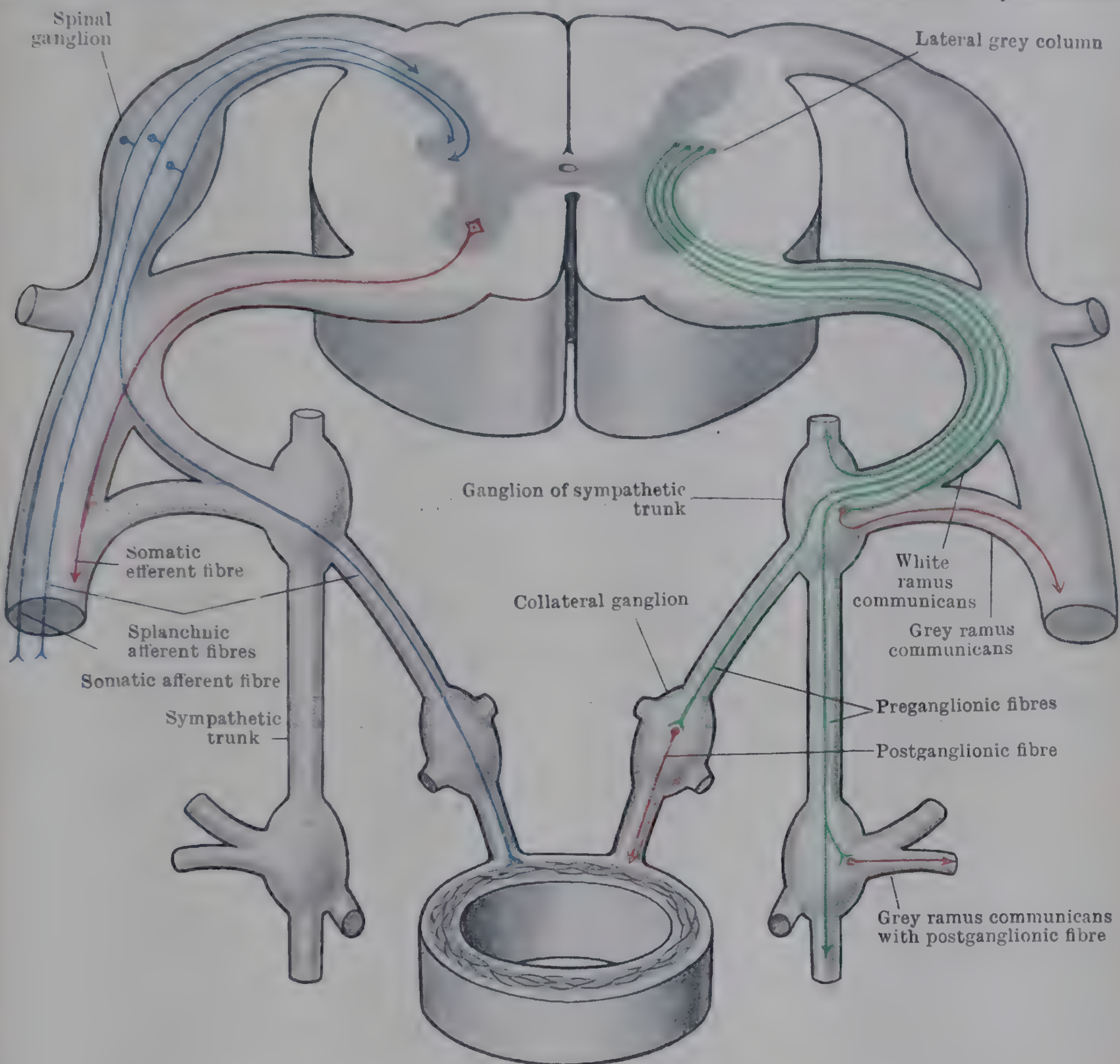

Fig. 963.—Scheme showing Relation of Sympathetic System to Spinal Nerves and Spinal Cord.

Splanchnic efferent fibres (preganglionic, *green*; postganglionic, *red*) are shown on the right side; a somatic efferent fibre (*red*) and somatic and splanchnic afferent fibres (*blue*) on the left. For the relative position of white and grey rami, see p. 1130. Compare with Fig. 730, p. 845 and Fig. 910, p. 1046.

branches to some peripheral plexus and thence to viscera. Each of these possibilities may be considered in greater detail.

(*a*) **Accompanying Nerves.**—Such fibres are all *postganglionic* branches from cells of the paravertebral ganglia. In the head-region some branches of this type join with certain cranial nerves to be distributed along with them as vasomotor, pilomotor, and sudomotor fibres. The vast majority, however, are distributed with spinal nerves and this latter group form the branches of the trunk known as the **grey rami communicantes**. The name is unfortunate for, in contrast to white rami communicantes, they are not communications with the central nervous system, but are purely branches of distribution. Further, unlike the white rami communicantes, the grey are composed predominantly of non-medullated fibres (some are finely medullated) and they link the sympathetic trunk to each and every spinal nerve. Their arrangement tends to be irregular; they arise either from ganglia or from interganglionic cords and they may be multiple—going to adjacent spinal nerves—so that a spinal nerve may receive rami from more than one ganglion. In the thoraco-lumbar region, where both white and grey rami are present, it is the white

ramus which joins the spinal nerve the more distally, the grey ramus more proximally (Pick & Sheehan, 1946). These authors have confirmed the observation of Botár (1932) that in the lower thoracic and upper lumbar regions the grey ramus is normally transverse, running between a ganglion and the nerve of the same segment, whilst the white ramus passes obliquely between a nerve and the ganglion of the next lower segment. Not uncommonly rami of the two categories show some degree of admixture.

(*b*) **Accompanying Blood-Vessels.**—Offsets from various parts of the sympathetic trunk associate themselves with blood-vessels and proceed along such vessels, their branches often forming perivascular plexuses. Such fibres are again postganglionic axons of splanchnic efferent cells in the paravertebral ganglia.

(*c*) **Direct Visceral Branches.**—From each level of the sympathetic trunk—cervical, thoracic, lumbar, and sacral—there are given off branches which proceed to viscera usually after passage through a plexus. The visceral branches from the trunk are composed in the main of preganglionic fibres, and these undergo synapse sooner or later with postganglionic neurons scattered irregularly in the visceral branches and the plexuses. At times the postganglionic cells are aggregated into dissectable groups to which names have been given, but it must be clearly understood that the visceral branches, before they reach the so-called plexuses, also contain ganglion-cells, and that the whole arrangement constitutes a diffuse gangliated plexus. Somewhere in this system the preganglionic fibre makes synaptic contact with postganglionic neurons. It follows, therefore, that grey and white fibres will be found side by side in such situations. The final passage of the postganglionic fibres to viscera is often in the form of perivascular nerves.

Accompanying all the branches of distribution mentioned above are splanchnic afferent fibres. These are medullated and pass centrally through plexuses, the trunk and rami (grey and white) to reach the posterior nerve-roots. Their unipolar cell-bodies are situated in spinal ganglia ; and the central processes end in the grey matter of the cord.

It will now be appreciated that in many sympathetic nerves medullation or non-medullation as such helps little in the identification of fibres of different functional types—*e.g.*, in a visceral branch there may be running side by side medullated preganglionic fibres, non-medullated preganglionic fibres, postganglionic, both non-medullated and finely medullated, and splanchnic afferent medullated fibres. Further, in their ultimate peripheral distribution, sympathetic fibres are quite commonly associated with parasympathetic fibres. Finally, it should be noted that a fibre may be in one part medullated and elsewhere in its course devoid of any myelin sheath.

SYMPATHETIC TRUNK

Cervical Part of Trunk.—The sympathetic trunk in the neck is to be regarded as an upward extension of the thoracic part, from which all its preganglionic fibres come ; *it has no white rami communicantes.* Developmentally, it is composed of segmentally arranged ganglia, but fusion of the ganglia has reduced their number to three—the superior, middle, and inferior cervical ganglia. Failure of the fusion may occasionally leave four ganglia, or at times the process may proceed so far as to reduce the number to two.

The cervical part of the trunk lies on the prevertebral muscles and behind the carotid vessels (Fig. 964). It consists of a slender strand of fibres, both medullated and non-medullated, connecting the three ganglia. Superiorly, it is continued into the cranium in the form of branches accompanying the internal carotid artery ; and inferiorly it is continuous with the thoracic part in front of the neck of the first rib, where there is a pronounced change in direction of the trunk as it passes backwards into the thorax.

The **superior cervical ganglion** is an elongated fusiform structure 1 inch or more in length, placed behind the neuro-vascular bundle formed by the internal carotid artery, internal jugular vein, and the last four cranial nerves, and lying on the fascia of the longus capitis muscle, to which it tends to adhere. It extends above to within 2 cm. of the entrance of the carotid canal, its upper pole lying deep to

the posterior belly of the digastric muscle, and below it reaches the level of the angle of the jaw; its lower pole varies somewhat in level according as the bifurcation of the common carotid is high or low. It is formed by fusion of the upper four cervical segmental ganglia.

The **middle cervical ganglion** is the smallest and most variable of the cervical ganglia. At times it may not be recognizable or it may be greatly reduced in size owing to complete or partial fusion with the inferior ganglion. It probably represents the fifth and sixth cervical segmental ganglia. Its most usual position is close to the inferior thyroid artery as the latter passes behind the common carotid trunk at the level of the sixth cervical transverse process; it may lie in front of the inferior thyroid artery or behind it, or even at times be wrapped around that vessel. A lower position is not unusual, in which case it generally lies on the vertebral artery (Axford, 1928).

The **inferior cervical ganglion** is a large, irregularly shaped mass formed by fusion of the lower two (or more) cervical segmental ganglia and commonly the first thoracic ganglion (or even the first and second) as well. (The term "stellate" ganglion, though often applied to the inferior cervical ganglion, properly refers to the ganglion when thoracic ganglionic elements are incorporated in it as is common in some animals, *e.g.*, the cat.) It is situated at the junction of the cervical and thoracic portions of the trunk, and, in accordance with the marked change in direction of the whole chain at this point, the ganglion lies with its long axis almost antero-posteriorly. It occupies a space bounded in front by the vertebral artery and the associated veins, below by the dome of the pleura, and behind by the neck of the first rib and transverse process of the seventh cervical vertebra. The termination of the costo-cervical trunk will normally have a relationship to the lower pole of the ganglion (Fig. 964). Quite frequently the antero-superior pole of the ganglion may be in front of the vertebral artery and be joined to the remaining and major part of the inferior cervical ganglion by nerve strands encircling the artery. This is known as the "ganglion intermediare" and represents a fusion of some part of the middle ganglion with the inferior ganglion. Irregularities at the inferior pole are likewise due to variations in degree of fusion involving the uppermost thoracic ganglia. Linking the middle and inferior ganglia is the usual interganglionic cord. An additional connexion exists which loops downwards in front of and below the subclavian artery forming the *ansa subclavia*. If the middle ganglion is in part incorporated in the inferior the ansa may then run from the superior pole to the inferior pole of the inferior ganglion.

Thoracic Part of Trunk.—The thoracic part of the sympathetic trunk (Fig. 965) descends under cover of the pleura in front of the intercostal vessels. In the upper part of the thorax it lies on the necks of the ribs, but at mid-thoracic level it is found over the costo-vertebral joints and in the lower part of the thorax it is on the sides of the vertebræ. This change of position relative to the ribs and vertebræ is to be associated with the progressive widening of the lower thoracic vertebræ. The number of ganglia on the thoracic trunk is usually ten or eleven; but the first—and sometimes others—may be so fused with neighbouring ganglia as to reduce the number still further. They are joined together by interganglionic cords of considerable thickness which are not uncommonly duplicated between adjacent ganglia.

The change in direction of the trunk at the junction of the thoracic and cervical parts has been mentioned already. At its lower end the thoracic chain passes behind the medial arcuate ligament to become continuous with the lumbar part.

The thoracic part of the trunk receives the vast majority of the preganglionic fibres which emerge from the spinal cord. Each thoracic nerve sends a white ramus to the trunk, but a great many of the fibres in these rami are not for local distribution; some ascend to provide the preganglionic supply to the cervical part of the trunk, others descend to assist the first and second lumbar nerves in supplying preganglionic fibres to the lower lumbar and sacral parts. There is suggestive evidence that preganglionic fibres concerned with particular peripheral structures emerge at constant levels from the spinal cord, and this is of some surgical import.

Preganglionic fibres for the **head and neck** leave the cord in the upper two

thoracic nerves and proceed *via* the white rami communicantes to the sympathetic trunk, in which they ascend to the superior cervical ganglion for synapse.

Fibres destined to influence the **heart** emerge through the second and third thoracic nerves (and perhaps through some lower nerves as well) and ascend to all three cervical ganglia whence branches run to the cardiac plexuses. Some small cardiac branches pass directly from the thoracic sympathetic trunk to the cardiac plexuses (p. 1136). Splanchnic afferents of cardiac origin run in the middle and inferior cervical cardiac nerves as well as in the thoracic cardiac nerves. They enter the spinal cord between the levels of the second and fifth thoracic nerves.

Abdominal structures—viscera and blood-vessels—are controlled by the preganglionic outflow from the lower half of the thoracic cord *via* the splanchnic nerves. The preganglionic supply to the pelvic viscera arises from the upper lumbar nerves.

The preganglionic fibres destined to influence the **upper limbs** emerge from the cord between the levels of the third to the seventh thoracic nerves and undergo synapse in the first thoracic and inferior cervical ganglia, and probably also in the middle cervical ganglion. For the **lower limbs** preganglionic fibres emerge from the level of the tenth thoracic to the second lumbar, and they have their synapses in the ganglia of the trunk from third lumbar to third sacral inclusive.

Lumbar Part of Trunk.—On entering the abdomen the sympathetic trunk is directed somewhat medially and in conformity with the lumbar curvature comes to lie on a plane rather anterior to that of the thoracic chain (Fig. 967). It extends downwards on the bodies of the lumbar vertebræ medial to the psoas muscle. On the right side it lies under cover of the inferior vena cava and on the left it is overlapped by aortic lymph-glands. The two trunks tend to converge as they pass downwards. Usually the trunk lies in front of the lumbar vessels; but the occasional presence of some lumbar veins in front of the trunk is noteworthy in connexion with the operation of "lumbar sympathectomy". Inferiorly the lumbar part continues into the pelvis behind the common iliac artery. The number of ganglia is typically irregular (Pick & Sheehan, 1946; Cowley & Yeager, 1949). Usually there are four, but variations leading to increase or decrease are not uncommon.

The prevertebral position of the lumbar trunk, rather than the paravertebral position which in general characterizes the thoracic part, may be associated with the massive psoas muscle arising from the sides of the lumbar column. This displacement forwards of the chain separates it by a considerable interval from the lumbar nerves and necessitates the much greater length of the lumbar rami communicantes. The upper two (or three) lumbar nerves send white rami communicantes to the sympathetic trunk. They are not infrequently intermingled with grey. Boyd & Monro (1949) have called attention to the presence of "intermediate ganglia", situated between the first three lumbar nerves and the sympathetic trunk, and concealed by the psoas muscle, as the explanation of partial retention of autonomic function after sympathectomy.

Pelvic Part of Trunk.—This part of the sympathetic trunk lies on the pelvic surface of the sacrum and coccyx (Fig. 967). It commences above under the common iliac vessels and extends downwards and a little medially. The trunk is placed medial to the sacral foramina above: at the level of the fourth foramen it overlaps the foramen and lies on the fourth sacral nerve. Below this the two trunks end, sometimes by irregular connexions across the terminal piece of the sacrum and the coccyx, sometimes in a small swelling—the *ganglion impar*—on the front of the coccyx; or they may occasionally end quite independently. On each sacral portion there are generally four ganglia which diminish in size gradually from above downwards.

BRANCHES OF DISTRIBUTION FROM SYMPATHETIC TRUNK

The branches of distribution from the sympathetic trunk having been classified (p. 1129), it now remains to take each segment—cervical, thoracic, lumbar, and pelvic—and to consider in greater detail the distribution from each (Potts, 1925).

I. Branches from Cervical Part of Trunk

(*a*) **Accompanying Nerves.**—(1) **Grey rami communicantes** are given to all cervical nerves. The superior ganglion supplies them to the first four, the middle ganglion or adjacent trunk to the fifth and sixth, and the inferior ganglion to the seventh and eighth. These are postganglionic fibres, and they accompany the nerves which they join to be distributed in their field of supply as vasomotor, pilomotor, and sudomotor fibres.

(2) Close to the skull the *superior cervical ganglion* gives branches directly to

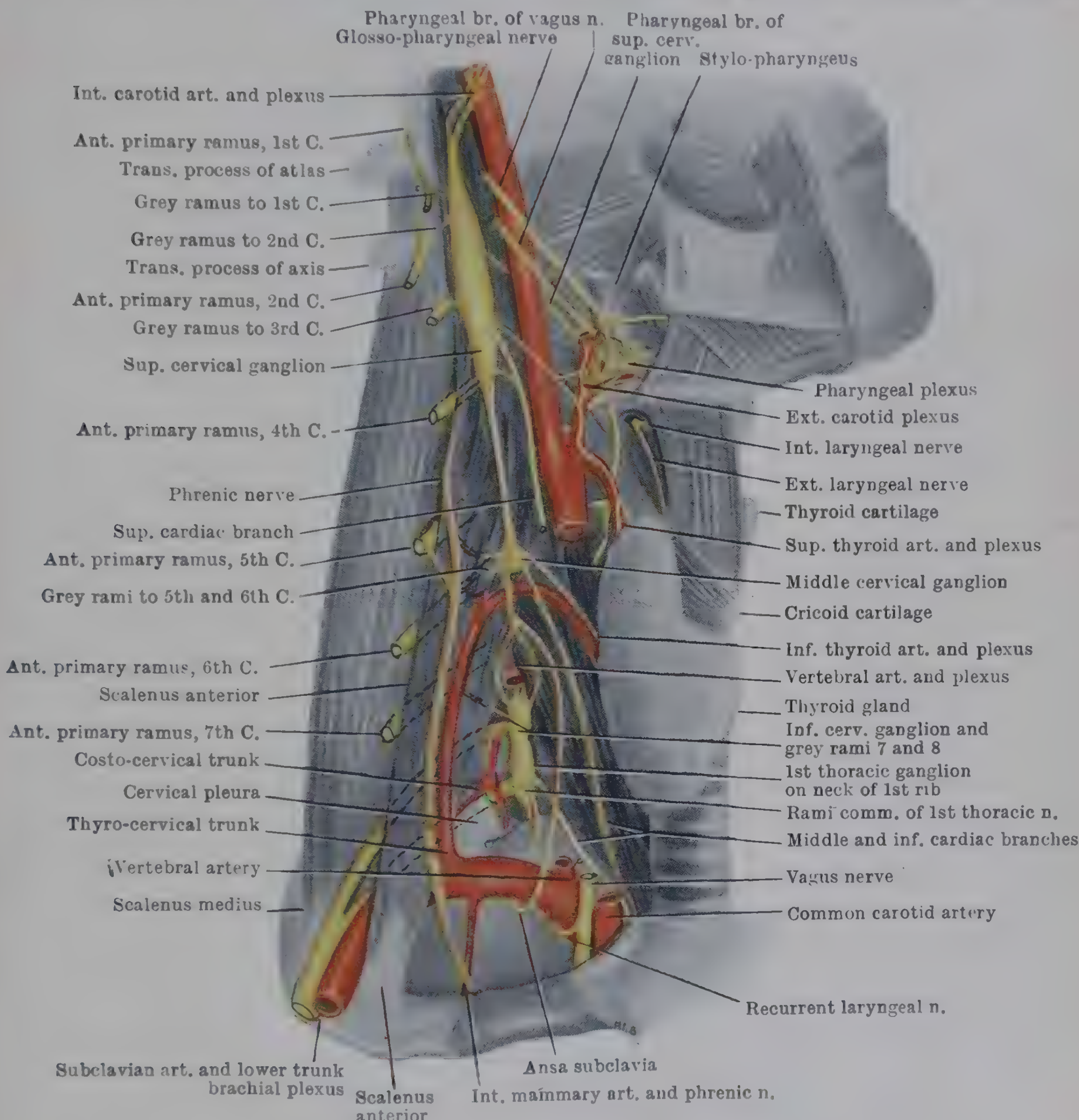

Fig. 964.—Distribution of Branches of Sympathetic Trunk and Ganglia in the Neck.

the following **cranial nerves**: to the inferior ganglion of the glosso-pharyngeal nerve, to both vagal ganglia, and to the hypoglossal nerve. The *inferior ganglion* commonly gives a branch to the recurrent laryngeal branch of the vagus.

(*b*) **Accompanying Blood-Vessels.**—(1) The *superior ganglion* gives branches to the external carotid artery, and these constitute an **external carotid plexus**, which extends along that vessel and its branches. Offshoots from it pass also to the carotid body. Other perivascular fibres, accompanying various branches of the artery, reach **glands** in the field of distribution of the artery, *e.g.*, salivary glands. Wilson (1936) found that the fibres supplying the sweat glands of the face arose from the external carotid plexus but soon joined the branches of the fifth nerve with which they were then distributed. (2) The *superior ganglion* sends upwards several branches with the internal carotid artery. They accompany the artery into the carotid canal as the **internal carotid plexus**, which sends offshoots to supply the vessel

and its branches as well as fibres to join certain cranial nerves. Occasional ganglion-cells are present in the internal carotid plexus. The distribution of the plexus, apart from the arterial branches, may be summarized as follows:—

(i) At one or other level, branches join the following **cranial nerves**: third, fourth, fifth, and sixth.

(ii) Fibres run to the vessels of the **hypophysis cerebri**.

(iii) The **deep petrosal nerve** joins the greater superficial petrosal branch of the seventh in the foramen lacerum to constitute the nerve of pterygoid canal.

(iv) **Carotico-tympanic nerves**, usually two, enter the middle ear.

(v) Some fibres constitute the **sympathetic root of the ciliary ganglion**, and pass through the ganglion to reach the eye.

It will be seen that the field of distribution of these internal carotid branches is wide and varied. They are predominantly postganglionic fibres, though some are presumably afferent; most of them are doubtless *vasomotor* in function; but some are concerned in the innervation of the *dilator muscle of the pupil* (Fig. 958) and of plain muscle in the orbit (Ingalls, 1923). Destruction or interruption of the sympathetic pathway to the eye and orbit leads to Horner's syndrome (see p. 1481).

(3) From the *middle ganglion*, or adjacent trunk, branches accompany the inferior thyroid artery to the **thyroid gland**.

(4) From the *inferior ganglion* several branches of considerable size accompany the vertebral artery and are distributed to it and its branches in the neck and within the cranium. Some fibres of the **vertebral plexus** join the fourth, fifth, and sixth cervical nerves—thus constituting an additional supply of post-ganglionic fibres to these nerves over and above those supplied by the grey rami communicantes.

(5) The *inferior ganglion*, or more commonly the *ansa subclavia*, sends branches to the **subclavian artery**. These are distributed to the vessel and its branches as vasomotor (and sensory) fibres. The fibres which accompany the subclavian artery probably do not extend farther than the axilla; thereafter, the arteries of the upper limb are innervated by sympathetic fibres which are derived from adjacent peripheral nerves.

(*c*) **Direct Visceral Branches.**—(1) A **pharyngeal branch** from the superior ganglion passes medial to the carotid sheath to join branches of the glosso-pharyngeal and vagus nerves in the formation of the **pharyngeal plexus**.

(2) **Cardiac branches**: each cervical sympathetic ganglion gives a cardiac branch which descends to the thorax. From the *superior ganglion*, the cardiac branch descends as a fine nerve behind the great vessels. The right nerve enters the thorax in front of or behind the subclavian artery and joins the deep cardiac plexus. The left nerve enters the thorax between the left common carotid and subclavian arteries, runs across the left side of the aortic arch and joins the superficial cardiac plexus. The cardiac branches of the *middle* and *inferior ganglia* are commonly associated with each other and with the cardiac branch of the superior ganglion in their course; they are distributed to the deep cardiac plexus.

Cardiac branches from the vagus, and from its laryngeal branches, are commonly intermingled with the above sympathetic branches in the thoracic part of their course.

With the possible exception of the cardiac branch of the superior ganglion, which is regarded as efferent, the above visceral branches are mixed nerves: some fibres are splanchnic afferents; others are preganglionic efferent fibres which meet their postganglionic neurons in the plexuses; and some fibres are post-ganglionic. The plexuses and their distribution will be discussed later (p. 1137).

II. Branches from Thoracic Part of Trunk

(*a*) **Accompanying Nerves.**—**Grey rami communicantes** arise from all the thoracic ganglia or from the interganglionic cords. They tend to be irregular; from any ganglion there may be several rami and these may distribute themselves to adjacent anterior primary rami of several levels so that one anterior primary ramus may receive fibres from more than one sympathetic ganglion. All anterior

primary rami receive grey rami communicantes. Not uncommonly white and grey rami associated with a particular nerve are intermingled. The postganglionic

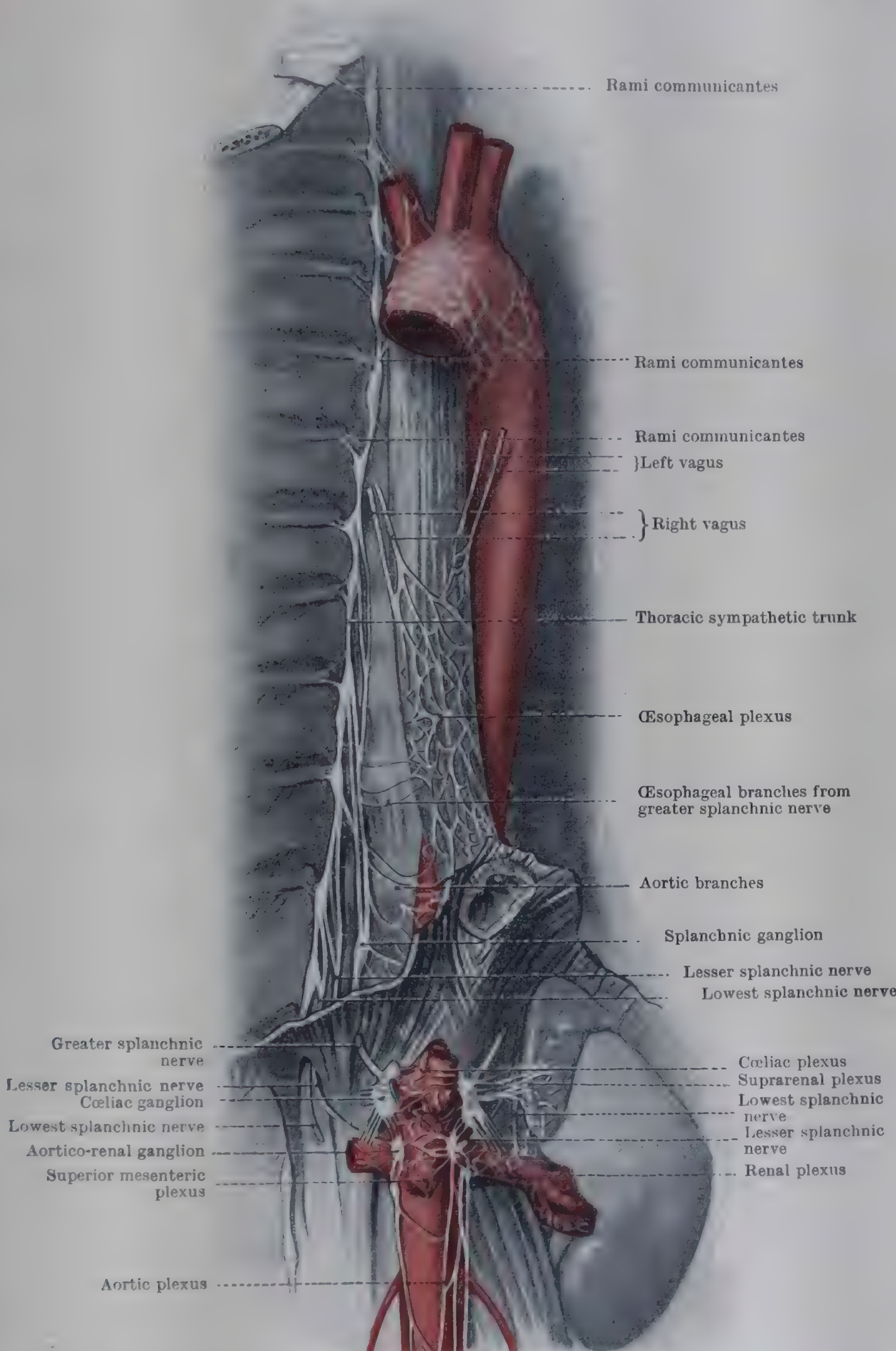

FIG. 965.—SYMPATHETIC TRUNK AND PARASYMPATHETIC FIBRES FROM THE VAGI IN THE THORAX AND UPPER ABDOMEN.

fibres are distributed with the thoracic spinal nerves as their vasomotor, pilomotor, and sudomotor components. By this means the first, and commonly also the second, thoracic ganglia contribute rami to the **brachial plexus** through the first thoracic nerve. The fibres from the second thoracic ganglion may run directly to the first thoracic nerve or they may reach that nerve by way of the communi-

cating branch between the second and first thoracic nerves (Kuntz, 1927). Such fibres are of importance in operations devised to deprive the upper limb of its sympathetic supply. Some fibres from the grey rami, or from ganglia direct, accompany the meningeal branch of the spinal nerve to the fibro-osseous coverings of the spinal cord. All the fibres mentioned above are postganglionic.

Splanchnic afferent fibres may be present in the grey rami: they pass to the spinal cord *via* the posterior nerve-roots.

(*b*) **Accompanying Blood-Vessels.**—Fine branches from the upper five thoracic ganglia are distributed to the aorta and are disposed around it as an aortic plexus (Fig. 965). They are postganglionic fibres.

(*c*) **Direct Visceral Branches.**—The thoracic visceral branches are in two main groups—those from the upper part of the thoracic trunk and those from the lower part.

(1) **Pulmonary and Cardiac Branches.**—Several branches arise in the vicinity of the second, third, and fourth thoracic ganglia and join the posterior pulmonary plexus; they communicate with the cardiac plexuses also.

(2) **Splanchnic Nerves.**—On each side three branches arise from the lower ganglia and proceed to the abdomen: they are the **greater**, the **lesser**, and the **lowest splanchnic nerves.** Each consists of nerve-fibres and scattered ganglion-cells. The fibres may be of several categories: they may be medullated *splanchnic afferent* fibres proceeding centrally towards the posterior nerve-roots and spinal cord; or *splanchnic efferent*—either non-medullated postganglionic fibres from ganglia of the sympathetic trunk or from ganglion-cells situated here and there along the course of the splanchnic nerves, or, finally, preganglionic fibres (generally medullated) which have passed without synaptic interruption through the trunk and are proceeding to meet their postganglionic neurons either in the splanchnic nerves or in the abdominal plexuses. The splanchnic nerves are therefore to be regarded as attenuated portions of a gangliated plexus which becomes, as we shall see later, much more obviously plexiform in the abdomen.

The **greater splanchnic nerve** arises from the trunk between the fifth and the ninth or tenth ganglia. By the union of several strands a nerve of considerable size is formed which descends, medial to the trunk, over the bodies of the vertebræ to pierce the crus of the diaphragm and join, in the abdomen, the upper end of the cœliac ganglion. In the thorax a dissectable enlargement (*splanchnic ganglion*) may be found on the greater splanchnic nerve about the level of the eleventh thoracic vertebra. It represents, as explained above, nothing more than an aggregation of ganglion-cells along the course of the nerve. From the thoracic part of the greater splanchnic nerve fine branches leave to be distributed to the œsophagus and thoracic aorta (Fig. 965).

The **lesser splanchnic nerve** arises in the region of the ninth and tenth ganglia and passes downwards on the vertebral bodies, medial to the trunk, to pierce the diaphragm close to the greater splanchnic nerve. It also ends in the cœliac ganglion.

The **lowest splanchnic nerve** arises from the last thoracic ganglion, or it may be from the lesser splanchnic nerve. It pierces the diaphragm to end in the renal plexus. It may not be present as a separate nerve.

The details of the plexuses in which the above splanchnic nerves end are dealt with later (p. 1140).

III. Branches from Lumbar Part of Trunk

(*a*) **Accompanying Nerves.**—**Grey rami communicantes** pass from the sympathetic trunk to the anterior primary rami of the lumbar nerves in an irregular manner. One ramus may divide to join adjacent spinal nerves; or one spinal nerve may receive several rami from different levels of the lumbar trunk. The rami have a characteristically long course in the lumbar region owing to the separation of the trunk from the spinal nerves by the psoas muscle: at times rami may pierce the muscle.

Splanchnic afferent fibres may accompany the efferent fibres of the grey rami.

(*b*) **Accompanying Blood-Vessels.**—Small vascular branches join the lumbar arteries near their origins and proceed along them to the aorta where they form a delicate plexus around the aorta; this plexus is continuous above with the thoracic aortic plexus and below with the plexus around the median sacral artery and the plexuses of the common iliac and the external and internal iliac arteries. It is reinforced by twigs from the last lumbar ganglion.

(*c*) **Direct Visceral Branches.**—Visceral branches emerge from the four lumbar ganglia (Fig. 967). Those from the upper two ganglia of each side are not uncommonly combined in a single trunk in front of the aorta about the level of origin of the inferior mesenteric artery, along which some fibres proceed, forming the **inferior mesenteric plexus**. The nerves then continue downwards to the interval between the common iliac vessels where they receive the branches from the third and fourth ganglia. The branch from the third passes between the common iliac artery and vein and that from the fourth behind both. The resulting structure formed by the confluence of all four nerves of both sides forms a loose-meshed plexus—**hypogastric plexus**—situated in front of the fifth lumbar body and between the common iliac arteries. It is continued down to the **pelvic plexuses** through which it will reach its distribution to pelvic structures (p. 1143). It will be noted that these visceral branches of the lumbar ganglia are predominantly pelvic in distribution, just as the major groups of cervical and thoracic visceral branches are directed to regions below the level of their origin from the sympathetic trunk.

The pelvic plexus is described later (p. 1143).

The fibres comprising these visceral branches are varied—*splanchnic afferent* (medullated) and both preganglionic and postganglionic *splanchnic efferent*. Ganglion-cells are found diffusely distributed along their course as in the case of the thoracic splanchnic nerves.

IV. Branches of Pelvic Part of Trunk

(*a*) **Accompanying Nerves.**—Irregularly arranged branches arise from the ganglia and are distributed to all sacral anterior primary rami and the coccygeal nerve. These are the **grey rami communicantes**, whose distribution is comparable with that of grey rami of other regions. Some fibres pass in a recurrent course towards the sacral canal, where they are distributed to the fibro-osseous structures.

(*b*) **Accompanying Blood-Vessels.**—Some fine branches are distributed to the median sacral artery and its branches.

(*c*) **Direct Visceral Branches.**—The visceral branches of the sacral ganglia are fine and not numerous. Usually two or three in number, they arise from the second and third ganglia and proceed to the pelvic plexus, in which their identity, so far as gross dissection is concerned, is lost.

Other direct visceral branches from sacral ganglia to the rectum and the ureter have been described; they would appear to be inconstant.

SYMPATHETIC PLEXUSES

Frequent reference has already been made to various plexuses in which sympathetic nerves end; it remains now to classify these and deal in greater detail with certain of them.

Some of them have been seen to be associated with the cervical sympathetic branches to certain vessels, *e.g.*, the internal carotid plexus, external carotid plexus, inferior thyroid plexus, vertebral and subclavian plexuses, and also the pharyngeal plexus. These **perivascular plexuses** are to be regarded merely as the mode of distribution of the nerves concerned for they are not rich in ganglion-cells and must be regarded as composed predominantly of *postganglionic efferent* fibres with an admixture of *splanchnic afferent*. They are doubtless vasomotor to the vessels concerned and their branches; but to a large extent they merely use the vessel as a path along which they may run to their field of distribution as sudomotor or pilomotor or vasomotor fibres.

Such perivascular plexuses are found also in connexion with the aorta in the

thorax and abdomen and extending along the proximal parts of many of its branches. Vessels in the limbs and peripheral vessels generally, however, receive their vasomotor supply from the postganglionic fibres which pass to the periphery in the spinal nerves, *i.e.*, from fibres which we have seen as components of grey rami communicantes. Perivascular plexuses are therefore associated with most blood-vessels and individual descriptions are not required.

The plexuses which remain to be discussed are known commonly as the **prevertebral** (or collateral) **plexuses**; they are concerned chiefly in the supply of thoracic, abdominal, and pelvic viscera and the associated blood-vessels. All are diffuse structures composed of fibres — pre- and post-ganglionic — and ganglionic cells. At times the fibres predominate; again cells may be so aggregated as to form dissectable ganglia which have been given precise names, but it is of fundamental importance to recognize that these prevertebral plexuses, together with their incoming and outgoing branches, are all gangliated plexuses and that ganglion-cells are scattered with varying degrees of density along the course of branches as well as in the plexus. Further, it will be noted in the description of each plexus that *both sympathetic and parasympathetic fibres are present;* in this way the plexuses form a common meeting-ground for the two different sets of fibres concerned with the supply of a particular organ or group of organs.

Thoracic Plexuses

Pulmonary Plexuses.—These are very largely parasympathetic plexuses—deriving most of their fibres from the vagus nerves—and they have been described already in connexion with that nerve (p. 1041). They are arranged behind and in front of the root of the lung; and the plexuses of the two sides communicate with one another as well as with the cardiac plexuses. The sympathetic contribution comes from the trunk at the level of the second, third, and fourth ganglia and is distributed primarily to the posterior pulmonary plexus. From the pulmonary plexuses branches are distributed to the lung, its blood-vessels, and the pulmonary pleura (Larsell, 1922).

Œsophageal Plexus.—Like the foregoing, this is, in the main, a parasympathetic plexus, and as such has been described on p. 1042. It is only necessary to state here that it receives small sympathetic contributions in the lower part of the thorax from the greater splanchnic nerve (Fig. 965).

Thoracic Aortic Plexus.—The thoracic aorta receives branches directly from the upper five thoracic ganglia of the sympathetic trunk and indirectly from the lower ganglia through the greater splanchnic nerve (p. 1141). These branches, with parasympathetic afferent fibres from the vagus nerves (pp. 1042, 1125), form a continuous fine plexus around the aorta.

Cardiac Plexus.—As the various sympathetic and vagal cardiac branches approach the heart they meet to produce a large, gangliated cardiac plexus, from which branches are distributed to the heart and also to the pulmonary plexuses. The cardiac plexus is large and diffuse and lies around the great vessels at the base of the heart. It is customary to divide the whole cardiac plexus into a superficial plexus and a deep plexus on the basis of topographical relationships.

The **superficial cardiac plexus** lies in the concavity of the aortic arch above the pericardium and in front of the ligamentum arteriosum. It commonly presents a dissectable ganglion—the *cardiac ganglion* (Wrisberg). Two nerves join this plexus: the superior cervical cardiac branch of the sympathetic and the inferior cervical cardiac branch of the vagus (parasympathetic), both of the left side. This plexus, besides communicating with the deep cardiac plexus, sends branches to the left anterior pulmonary plexus and branches of distribution to the heart, which course along the pulmonary trunk to join the right coronary plexus.

The **deep cardiac plexus** is larger and is placed between the aortic arch and the front of the trachea near its bifurcation (Fig. 966). It has communications with the superficial plexus and the pulmonary plexuses. It receives numerous branches: all the cervical cardiac branches of the sympathetic except the superior cardiac nerve of the left side, and all the cardiac vagal branches except the left

inferior cervical cardiac branch. From this plexus branches pass as noted above to the pulmonary plexuses; and the cardiac branches of distribution reach the heart by coursing along the great vessels, some along the aorta and pulmonary trunk and others along the great veins to the posterior surface of the atria.

Developmentally, the heart receives nerves at each end: an arterial supply

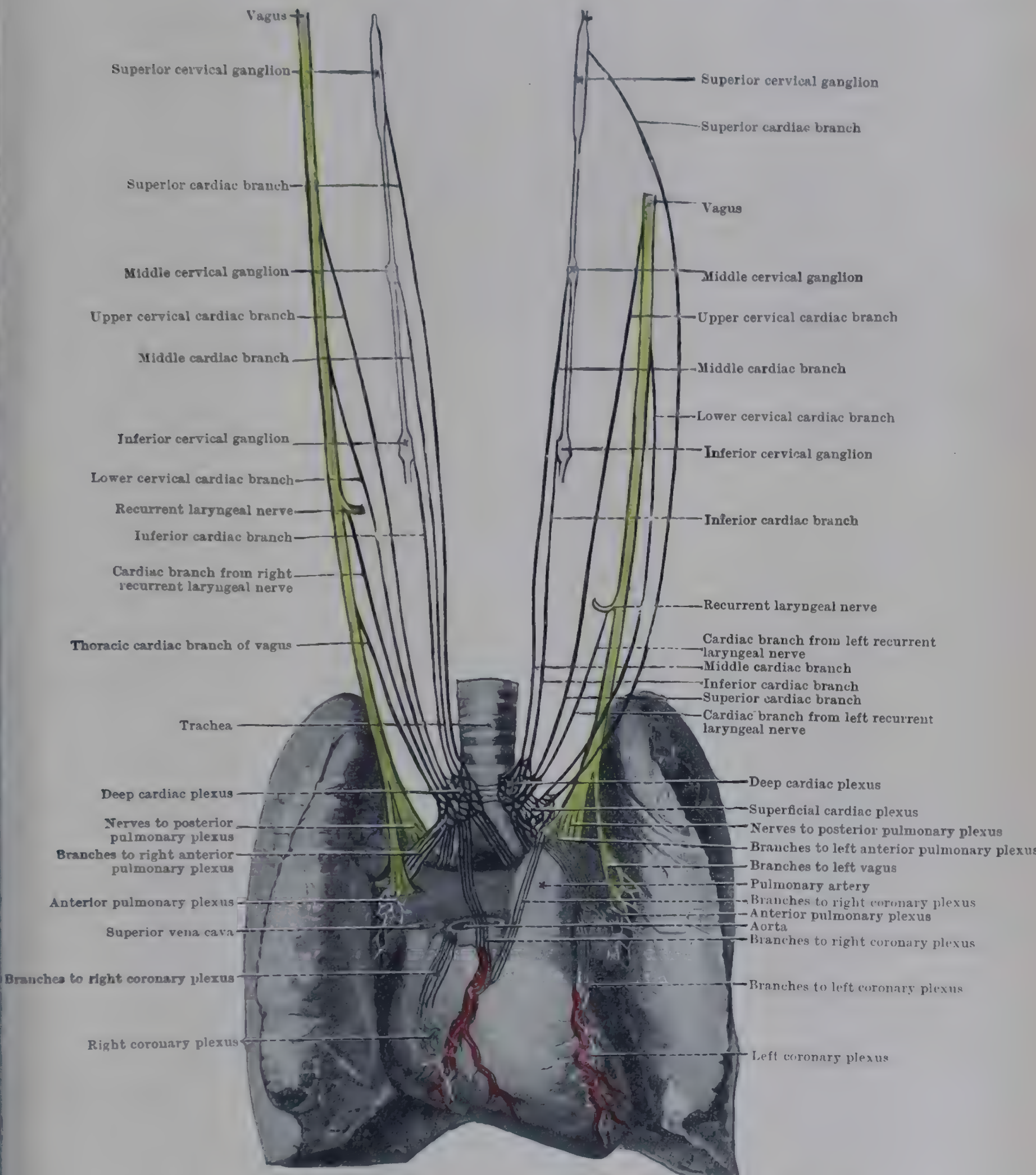

FIG. 966.—CARDIAC BRANCHES OF AUTONOMIC SYSTEM AND THE PULMONARY PLEXUSES.

which reaches it through the arterial mesocardium and is composed of the upper cardiac nerves, both vagal and sympathetic; and a venous supply which reaches it through the venous mesocardium and is composed of the lower cardiac branches of vagus and sympathetic. With approximation of the arterial and venous ends of the heart-tube in development, the two sets of nerves become more closely associated and communications are established between them. Separate arterial and venous cardiac plexuses cannot be isolated as such in the fully developed heart: *i.e.*, the superficial and deep plexuses of descriptive anatomy are not developmentally distinct; but it is possible, and certainly desirable, to consider them from the point of view of their embryonic origin (His, 1891; Perman,

1924). The superficial plexus and in large part the deep plexus are related to the arterial end of the heart, whilst the remaining elements of the deep plexus as well as the gangliated plexus on the back of the right atrium constitute the venous part.

The cardiac plexuses are mixed in that both vagal and sympathetic fibres contribute to their formation; the sympathetic fibres are predominantly post-ganglionic, while the vagal fibres are preganglionic, and the ganglion-cells situated in the plexuses and in the heart-wall therefore belong to the vagal system. In the heart, ganglion-cells are found most abundantly in relation to the atria, though not exclusively so; this accords with the view that the atria have a richer parasympathetic supply and the ventricles a richer sympathetic (Woollard, 1926).

The supply to the coronary vessels is rich—**coronary plexuses**—and both sympathetic and parasympathetic fibres innervate them; the larger branches of the coronary vessels are mainly innervated by the sympathetic, but their smaller branches by the vagus. Vaso-constriction of these vessels is probably controlled by vagal fibres and vaso-dilation by sympathetic fibres.

The conducting system of the heart is richly innervated, especially the sinu-atrial node and the atrio-ventricular node and bundle (Fig. 1066, p. 1236. Nerve-fibres proceed into the heart-wall along extensions of the conducting system, but Stotler & McMahon (1947) consider, apart from the supply of the conducting system, that the nerves within the heart-wall are vascular or, in the case of the subendocardial plexus, sensory.

Abdomino-Pelvic Plexuses

In this group there are several great accumulations of both sympathetic and parasympathetic nerves and ganglia which serve to distribute nerves to the abdomino-pelvic viscera and blood-vessels. Three great plexuses are included—the **cœliac**, the **hypogastric**, and the **pelvic**; and ramifications from each of these extend usually along blood-vessels to the various viscera—such ramifications being as a rule designated according to the vessels they accompany. The above plexuses and their extensions are all to be regarded as gangliated plexuses wherein at times cells may predominate and be aggregated into macroscopically identifiable "ganglia"; frequently, however, cells are dispersed here and there amongst bundles of fibres with no obvious ganglia. Vagal or sacral parasympathetic fibres and the sympathetic fibres once having entered a plexus can no longer be identified as such.

The branches which contribute to these plexuses come from the thoracic, lumbar, and pelvic parts of the sympathetic trunk: in general the abdominal plexuses are derived from the thoracic part and the pelvic plexus from the lumbar part; sacral sympathetic contributions to the pelvic plexus are relatively few. There are also parasympathetic fibres—some from above, through the vagal branches which enter the abdomen with the œsophagus, and some from below, in the pelvic region, through the pelvic splanchnic nerves. The cœliac plexus is placed high in the abdomen, the pelvic plexus in the pelvic cavity, while the hypogastric plexus in some measure links these together.

Cœliac Plexus.—This is the largest of the prevertebral plexuses and lies on the posterior abdominal wall in relation to the aorta about the level of the first lumbar vertebra. Three large vessels arise here and have considerable importance in the morphology of the plexuses, viz., the cœliac artery, the superior mesenteric artery, and the renal artery.

The plexus is formed by a closely interwoven network of nerves interspersed with minute ganglia. Certain macroscopic, dissectable ganglia are fairly regularly found and merit individual description. The *cœliac ganglia*, generally of irregular shape, are found with some constancy flanking the aorta at the level of origin of the cœliac artery. Each lies on the corresponding crus of the diaphragm; the left is behind the peritoneum of the lesser sac above the pancreas, while the right ganglion is in part covered by the pancreas and above this is overlapped by the inferior vena cava. The *aortico-renal ganglia* lie below the cœliac ganglia at the level of origin of the renal arteries, behind which they are commonly partly

insinuated. The aortico-renal ganglion may be fused with the cœliac ganglion and even when separate it is closely linked to it by nerve-strands.

The *superior mesenteric ganglia* lie on the aorta on each side of the origin of the superior mesenteric artery. Not uncommonly they form several smaller

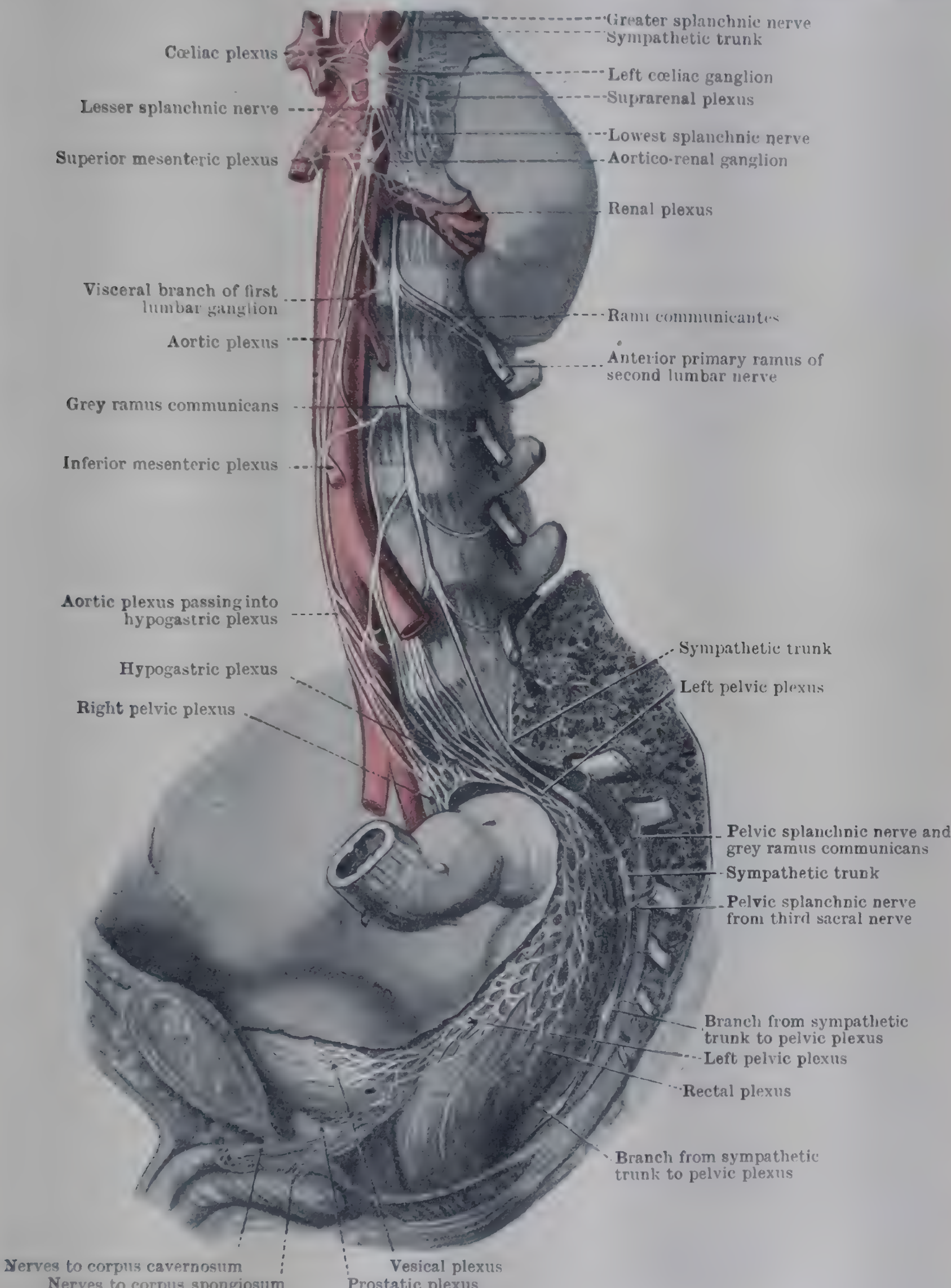

Fig. 967.—Plexuses of Autonomic System in Abdomen and Pelvis.

ganglia around the artery. All the ganglia above described are linked together within the general plexus and the plexuses and ganglia of the two sides intercommunicate freely in front of the aorta.

Afferent Branches of Cœliac Plexus.—The **sympathetic branches** are the splanchnic nerves from the thoracic part of the trunk. The **greater splanchnic nerve** enters the abdomen through the crus of the diaphragm and very soon joins the upper pole of the cœliac ganglion, where most of its fibres appear to end; but

some run directly to the suprarenal gland and a few extend beyond the cœliac ganglion to reach the aortico-renal ganglion. The **lesser splanchnic nerve** enters the abdomen lateral to the greater and gives branches to all three named ganglia of the cœliac plexus. The **lowest splanchnic nerve**, when it exists, joins the aortico-renal ganglion or adjacent plexus. The **vagal branches** are given off by the posterior gastric nerve very soon after it has entered the abdomen. They are distributed through the cœliac and superior mesenteric ganglia. Other vagal branches go direct to the stomach and liver without participation in the cœliac plexus (see p. 1041).

Efferent Branches of Cœliac Plexus.—The efferent branches of the cœliac plexus and its contained ganglia are numerous and not devoid of variation so far as their gross pattern is concerned. They are all, however, to be regarded as extensions of the plexus—*i.e.*, intermingled fibres and ganglion-cells, and, amongst the fibres, there are both pre- and post-ganglionic efferent neurons as well as splanchnic afferent neurons. A great many of the branches accompany blood-vessels and are commonly named after the vessels concerned: such nerves have a double significance, viz., they are in part vasomotor to the vessels they accompany, and they contain also the fibres destined for the supply of viscera within the field of distribution of the vessel. Both parasympathetic and sympathetic fibres run together to the viscera. The vasomotor nerves are presumably of sympathetic origin. It will be sufficient to indicate very briefly the various branches or extensions of the cœliac plexus.

(*a*) Extensions of the plexus accompany the branches of the cœliac artery itself:—the **left gastric plexus** supplies branches to the œsophagus and stomach; the **hepatic plexus** supplies branches to the liver, gall-bladder, stomach, duodenum, and pancreas; and the **splenic plexus** sends offsets to the spleen, pancreas, and stomach.

(*b*) The **phrenic plexus** accompanies the phrenic artery and is distributed to the diaphragm, suprarenal plexus, inferior vena cava, and the œsophagus. It joins the phrenic nerve, with which some of its fibres are distributed; on the right side, at its junction with the phrenic nerve, there may be a *phrenic ganglion*.

(*c*) The **suprarenal plexus** is large and derived widely from the cœliac plexus as well as directly from the splanchnic nerves. The fibres are to be regarded in this case as *preganglionic* sympathetic neurons which are for distribution to the medulla of the suprarenal gland: the medullary cells of the suprarenal are, developmentally considered, equivalent to postganglionic neurons (Elliott, 1913; Young, 1939; MacFarland & Davenport, 1941).

(*d*) The **renal plexus** is derived from the aortico-renal ganglion in the main, from the lesser and lowest splanchnic nerves and from the abdominal aortic plexus (Mitchell, 1935 *a*). It extends along the renal vessels to the hilum of the kidney. Communication is established between renal and suprarenal plexuses.

(*e*) The **testicular** and **ovarian plexuses** are offshoots of the cœliac plexus in the region of the aortico-renal ganglion. The community of origin of the renal and gonadal plexuses recalls their developmental association. Each accompanies its corresponding testicular or ovarian vessels; the testicular plexus supplies the spermatic cord, epididymis, and testis, while the ovarian plexus supplies the ovary, broad ligament, and uterine tube and ends in communication with the uterine plexus (derived from the pelvic plexus).

(*f*) The **superior mesenteric plexus** is at its commencement closely associated with the cœliac plexus and derives its fibres from that plexus generally as well as from the obvious ganglia embedded in it. It accompanies the superior mesenteric artery and its various branches and so reaches the gut between the layers of the mesentery. In this manner both parasympathetic and sympathetic nerves reach the small intestine, cæcum, and appendix, and the ascending and transverse portions of the colon. In the gut-wall, the parasympathetic fibres are relayed through the terminal (myenteric and submucous) plexuses.

(*g*) The **abdominal aortic plexus** is formed by an extension of the cœliac plexus downwards in front of the aorta as several strands towards the origin of the inferior mesenteric artery; it must be regarded in the main as the counterpart of

the superior mesenteric plexus destined for more distal parts of the intestine. The nerve strands running downwards from the cœliac plexus in front of the aorta are reinforced near the origin of the inferior mesenteric artery by visceral branches of the upper two lumbar ganglia (Fig. 968). The plexus is distributed in two parts—the first forms the perivascular plexus which accompanies the inferior mesenteric artery and the second is the extension which descends to join the hypogastric plexus.

(*h*) The **inferior mesenteric plexus** is composed of sympathetic contributions from the aortic plexus and the upper two lumbar ganglia as well as certain components that ascend from the sacral parasympathetic (Fig. 968). The latter are said (Telford & Stopford, 1934) to ascend alongside or incorporated in the hypogastric plexus and to reach the inferior mesenteric plexus a short distance below the origin of the artery. Thereafter they are distributed in company with the sympathetic components of the plexus. Offshoots accompany all the branches of the artery and are distributed to the descending colon, pelvic colon, and upper part of rectum. The plexus so formed around the inferior mesenteric artery and its branches is a gangliated plexus: numerous microscopic aggregations of nerve-cells are disposed throughout the plexus but no inferior mesenteric ganglion as such is present in Man.

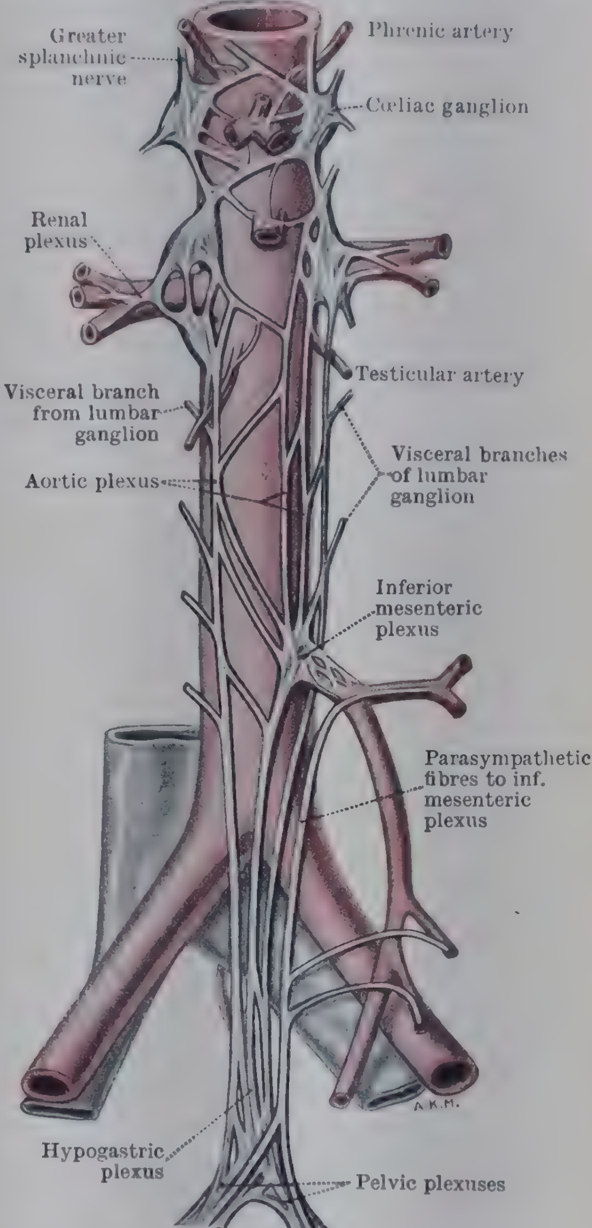

Fig. 968.—The Aortic and Hypogastric Plexuses.

Hypogastric Plexus.—This plexus has two main components. (*a*) From the aortic plexus there is a downward continuation over the aortic bifurcation in the form of several strands of fibres (Fig. 968). (*b*) Visceral branches from the lumbar ganglia contribute largely to its formation: from the upper two ganglia branches join the aortic plexus near the origin of the inferior mesenteric artery and run down with it to join the hypogastric plexus; and from the lower two lumbar ganglia visceral branches run more directly to the plexus. There is thus formed a plexiform mass of fibres and interposed ganglion-cells which occupies the interval between the common iliac arteries in front of the body of the fifth lumbar vertebra. The visceral branches contain both afferent and efferent fibres.

The commonly employed surgical name, "presacral nerve", is misleading, since the structure is not a nerve in the generally accepted sense nor is it presacral in position. Although generally plexiform, it may be condensed into a few strands, but in all cases it is composed of intermingled nerve-fibres and ganglion-cells and is thus a typical gangliated plexus. It represents the continuation downwards of the abdominal plexuses towards the pelvic region.

Pelvic Plexus.—There are two pelvic plexuses, right and left, embedded in the areolar tissue which occupies the interval between the viscera and the lateral pelvic wall. The whole mass is irregularly disposed and consists of a network of fibres with interposed nerve-cells. It is closely associated with the blood-vessels

of the region. In the male, the pelvic plexus flanks the rectum and adjacent parts of the bladder and seminal vesicle. In the female, its posterior extremity, lying alongside the rectum, contributes to the formation of the utero-sacral folds; it then extends forwards beside the vagina. Entering each pelvic plexus are three sets of fibres. (1) The corresponding half of the **hypogastric plexus,** which descends to reach the postero-superior part of the pelvic plexus. This is essentially a *sympathetic* contribution and contributes largely to the bulk of the pelvic plexus. The other contributions are derived from (2) the **second and third sacral ganglia of the sympathetic trunk**—a relatively minor group of fibres, and (3) the **pelvic splanchnic nerves** (*sacral parasympathetic*) from second and third or third and fourth sacral nerves.

From the plexus, branches—or rather extensions—proceed to various organs which occupy the pelvis and the perineum. Some **recurrent branches**—parasympathetic—ascend from the plexus *via* the hypogastric plexus to reach the *inferior mesenteric plexus,* of which they form a part and through which they are distributed with its sympathetic elements (Telford & Stopford, 1934; Mitchell, 1935 *b*).

Extensions from the main pelvic plexus, carrying both sympathetic and parasympathetic elements, are distributed as follows:—

(*a*) The **rectal plexus** accompanies vessels to the wall of the rectum and anal canal. This is joined by a continuation of the inferior mesenteric plexus on the wall of the gut. In addition, some few direct rectal branches are given off from the sacral sympathetic ganglia. All the various nerves intercommunicate in a plexus on the wall of the gut.

(*b*) The **vesical plexus** proceeds forwards from the anterior part of the pelvic plexus, invests the ureter in its terminal part, and disposes itself around the wall of the bladder. It supplies branches to the bladder, the terminal part of the ureter, the seminal vesicle, and the vas deferens. The last extend as far as the epididymis.

(*c*) The **prostatic plexus** is of considerable size and extends from the antero-inferior part of the pelvic plexus. Besides supplying the prostate, branches are given to the prostatic and membranous parts of the urethra and to the seminal vesicle.

(*d*) The **uterine plexus** passes upwards into the broad ligament with the uterine artery. The lower branches are distributed to the cervix of the uterus, while longer branches ascend to the body, the fundus, and the uterine tube.

(*e*) The **vaginal plexus** is formed mainly from the visceral branches of the sacral nerves which enter the pelvic plexus. It supplies (parasympathetic) the walls of the vagina and the urethra. The uterine and vaginal plexus together correspond to the prostatic plexus.

(*f*) The **cavernous plexus.** In the male, extensions from the prostatic plexus reach the erectile tissues of the penis, and in the female similar nerves proceed to the clitoris from the vaginal plexus. It is suggested that the pudendal nerve also carries autonomic fibres, both sympathetic and parasympathetic, to the penis or the clitoris.

Innervation of Bladder and Rectum

It will be realized that three sets of fibres are involved in the innervation of pelvic structures:—(1) The **pudendal nerve,** *i.e.*, a somatic nerve with both afferent and efferent fibres. The efferent fibres supply the striated sphincter of the urethra and the external anal sphincter. The afferent fibres are concerned in the innervation of the mucosa of the anal canal and probably the prostatic part of the urethra. (2) **Sympathetic nerves** derived from the lower part of the thoraco-lumbar outflow. They reach pelvic viscera either along the inferior mesenteric plexus or by way of the hypogastric plexus and the pelvic plexus. (3) **Parasympathetic fibres** leave the spinal cord in the second and third or the third and fourth sacral nerves and then, as the pelvic splanchnic nerves, they are distributed to the pelvic plexus.

The sympathetic and parasympathetic nerves are both afferent and efferent.

The *afferent fibres* appear to be distributed mainly to the muscular coats of the bladder

and rectum. Impulses leading to pain caused by overstretching of the muscular walls probably travel by the sympathetic fibres, but the more important proprioceptive afferent impulses normally aroused by the stretching of the walls during the filling of the viscus travel in the sacral parasympathetic fibres. These proprioceptive impulses are of great importance since they initiate the stretch-reflex so important in the onset of defæcation and micturition.

The *parasympathetic efferent fibres* are concerned in contraction of the expulsive musculature and inhibition of the non-striated sphincters of the bladder and rectum. The *sympathetic efferent fibres* have the opposite effect.

Of the two parts of the autonomic system, the parasympathetic is to be regarded as the more important on both afferent and efferent sides of the reflex arcs involved in normal micturition and defæcation.

In seminal ejaculation, the sympathetic control would appear to be of greater importance since it brings about the contraction of the seminal vesicles and ejaculatory ducts, and also leads to inhibition of the detrusor muscle of the bladder and to contraction of the non-striated sphincter of the urethra. In this way micturition is inhibited during ejaculation and the reflux of seminal fluid into the bladder avoided.

INNERVATION OF BLOOD-VESSELS

In the description of the autonomic plexuses given in the previous pages frequent reference has been made to **perivascular plexuses**. All blood-vessels are accompanied by nerve-fibres, both medullated and non-medullated, some of which are afferent and others motor. Ganglion cells are not encountered in these plexuses. The motor or vaso-constrictor fibres are in general of sympathetic origin, although in certain regions vaso-dilator fibres exist and are of parasympathetic origin, *e.g.*, in the chorda tympani branch of the seventh cranial nerve and in the sacral parasympathetic fibres to the erectile-tissue of the external genitalia. It is more than likely, however, that in the vast majority of blood-vessels the state of constriction or dilatation reflects variations in constrictor (sympathetic) tone rather than a double innervation by sympathetic and parasympathetic fibres.

The *vessels of the limbs* have a double source of **vasomotor fibres**: some extend into the proximal part of the limb as a perivascular plexus derived directly from the sympathetic trunk; this is the *proximal supply*, and does not extend far along the main artery of the limb. It is replaced by the *distal supply*, derived from the peripheral nerves of the limb; these fibres are given off from the peripheral nerves at various levels to the arteries of the limb. It is evident that the latter group of fibres are those which have been contributed to the spinal nerves from the sympathetic trunk via the grey rami communicantes. The vessels of the abdomen and pelvis, however, are innervated only by perivascular plexuses which extend along them from the sympathetic trunk directly.

All vessels are not equally supplied with vasomotor nerves: it would appear that cutaneous vessels generally and those in the distal parts of the limbs (Pick & Sheehan, 1946) are particularly well supplied with sympathetic fibres; further, certain special regions in the vascular bed, *e.g.*, arterio-venous anastomoses (Fig. 1072, p. 1246), have a richer vasomotor innervation than others.

Vasosensory fibres are widely distributed; they are found intermingled with the vasomotor fibres; but whereas the vasomotor are most often non-medullated the vasosensory fibres are usually medullated. The impulses which they convey do not as a rule arouse any conscious state; it must be presumed, however, that they have a rôle in vascular reflexes. The sensory mechanism associated with blood-vessels is highly specialized in certain regions and much attention has been paid recently to these special localized vasosensory zones. Around the carotid sinus, in the aortic arch and also in the heart-wall and the adjacent parts of the great veins. there are areas which respond to pressure changes in the lumen. The nerve-endings in each case are to be regarded as specialized *vasosensory receptors*; the afferent fibres concerned run in the ninth nerve (carotid sinus) and the vagus (heart and aorta), *q.v.*

Associated with the above zones are certain nests of epithelioid cells (Campenhout, 1946). Adjacent to the carotid sinus lies the carotid body which receives an abundant blood-supply from the adjacent artery and is richly innervated particularly by the ninth nerve (see p. 808). Experimental evidence suggests that it functions as a *chemo-receptor*, its cells being responsive to variations in the chemical constitution of the blood. Other discrete collections of cells (*aortic glomera*) are to be found adjacent to the heart and great vessels, but their function has not been ascertained. Certain of them, however, from their histological resemblance to the carotid body and from their vascular and nervous (vagal) connexions would appear, on anatomical grounds, to subserve a comparable function.

DEVELOPMENT OF AUTONOMIC NERVOUS SYSTEM

It was noted earlier (p. 1117) that certain cells of the neural crest—the **sympathoblasts**—provide the neuronal basis of the peripheral sympathetic system. These cells, retaining their nervous potentialities, migrate to the sympathetic trunk and to various sympathetic plexuses. Comparable cells are found in association with the neural crest of the head-region of the embryo, and they take part in like manner in the formation of the cranial parasympathetic ganglia and plexuses. It is more than likely, however, that the neural crest is not the sole producer of sympathoblasts; evidence accumulates to suggest that many cells migrate along the anterior nerve-roots from the cord to take part in the formation of sympathetic ganglia (Raven, 1937), and Keuning (1944) has brought forward evidence for the differentiation of ganglion cells in the gut wall from mesodermal tissues.

In the **spinal region** sympathoblasts detach themselves from the ventral border of the primitive spinal ganglion and migrate outwards along the paths of the developing posterior roots of the spinal nerves. Meanwhile, other cells have wandered out from the neural tube along the anterior roots to join the cells of neural-crest origin. These two sets of cells intermingle and thenceforward it is impossible to distinguish between them, nor is it possible to say what part each plays in the subsequent development of the sympathetic system. Leaving the spinal nerves, these wandering cells migrate to the neighbourhood of the aorta where, by rapid proliferation, they form compact masses which fuse from segment to segment and produce a continuous longitudinal gangliated cord—the **sympathetic trunk**. Primarily the ganglia are segmentally arranged and placed closely together. With growth of the embryo and with the development of nerve-fibres, the ganglia become separated by interganglionic cords. Pick & Sheehan (1946) suggest that the primordial ganglia consist of rostral and caudal portions and that the definitive ganglia of the sympathetic trunk are compounded of fusions of adjacent rostral and caudal portions. This would account for the multiplicity of rami which may be associated with one ganglion; and variations in the process of fusion would lead to the commonly observed fluctuations in the total number of ganglia.

Other cells leave the region of the sympathetic trunk and migrate farther afield to form **gangliated plexuses** closer to the viscera to be supplied, *e.g.*, the cœliac plexus. These cells have the same origin as those which form the ganglia of the trunk. The cells of such plexuses are, however, not derived only from spinal sources, for many of them are the result of migrations of cells along the vagus nerve (parasympathetic) and along the pelvic parasympathetic nerves. In the terminal plexuses in the wall of the gut and other viscera the cells are of parasympathetic origin.

In the meantime connexions are established between the spinal cord and the migrated sympathetic cells. From nerve-cells in the grey matter of the cord (the future intermedio-lateral cell-column) processes grow out along the anterior nerve-roots into the anterior primary rami and from here they pass as **white rami communicantes** to reach the sympathetic trunk, where they undergo synapse with sympathetic neurons; or others may pass through the trunk to activate cells in more peripherally placed ganglia.

Receptor neurons of the spinal ganglia also send peripheral processes through the white rami communicantes to be distributed to the regions innervated by the sympathetic system. These fibres (splanchnic afferents) have no synaptic relationship with the cells of such sympathetic ganglia as they may traverse.

The cells of the various ganglia send out processes (postganglionic fibres) which may travel in a variety of directions. Many such processes from the ganglia of the sympathetic trunk take a recurrent course, as **grey rami communicantes**, to join a spinal nerve and travel in it to reach peripheral structures such as sweat-glands and blood-vessels. Others pass as direct visceral branches to various organs; these visceral branches frequently run through plexuses and many of them reach their destination by accompanying blood-vessels as perivascular nerves.

In the **head-region** the autonomic (parasympathetic) ganglia are not segmentally arranged, but their neurons are derived in a manner comparable with that of sympathoblasts in the spinal region. They also have arisen from the neural crest in the head-region, and here too it would appear that other types of cells, unassociated with the neural crest, may contribute to the formation of the ganglia. The cells, however derived, migrate outwards along the pathway of growth of one or other of the cranial nerves. The extensive distribution of the vagus nerve leads to a very distant migration of the cells which have arisen developmentally in association with it; the cardiac and pulmonary plexuses and the various abdominal plexuses, including the terminal plexuses in the gut-wall, are to be regarded in greater or less degree as vagal plexuses, and the cells within them as elements migrated from the neural crest or from the wall of the neural tube along the pathway of vagal growth. (Keuning, 1944, has however suggested a possible local mesodermal source for the neurons in the plexuses of the gut-wall.) The ganglia which remain in the head-region are all composed of cells which have had their developmental origin mainly in the trigeminal ganglion, though the third, the seventh, and the ninth nerves have all played some part in providing cells for these ganglia (Cowgill & Windle, 1942).

The **ciliary ganglion** derives its cells mainly from the trigeminal ganglion by way of the ophthalmic nerve but also from cells which have migrated outwards along the oculomotor nerve. This ganglion receives its preganglionic innervation from cells which lie in the mid-brain and whose processes grow outwards in the oculomotor nerve.

The **sphenopalatine ganglion** is composed of cells which have migrated from the trigeminal ganglion along the maxillary nerve and also of cells which have travelled peripherally along the

facial nerve and its greater superficial petrosal branch. Its preganglionic connexions with the brain-stem run in the seventh nerve.

The **otic ganglion** arises from cells which migrate along the lesser superficial petrosal nerve from the part of the neural crest associated with the ninth nerve. Cells from the trigeminal ganglion also contribute by migration along the mandibular nerve. The otic ganglion receives its preganglionic innervation by way of the ninth nerve.

The **submandibular ganglion** and smaller ganglionic masses in its neighbourhood are composed of cells which have migrated peripherally along the mandibular nerve and along the facial nerve (chorda tympani). It is innervated by preganglionic fibres which have travelled outwards in the seventh nerve.

The various conflicting views regarding the development of the autonomic nervous system have been reviewed by Campenhout (1930) and Yntema & Hammond (1947).

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THE SKIN AND THE SENSORY ORGANS

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The **sensory organs** in general constitute the apparatus by which Man and other animals are made acquainted with their surroundings. Sensory stimuli may be received by highly developed sense-organs localized in particular parts of the body, for example, the eye and the internal ear, or by end-organs distributed widely over the surface and in the deeper parts of the body. As the skin, in addition to its other functions, is one of the principal sense-organs in virtue of the numerous nerve-endings and special end-organs that it contains, it is included in this Section.

Every sense-organ consists of (*a*) a peripheral or receptive portion, where impulses are generated in response to external stimuli, (*b*) an intermediate or conducting portion, along which the impulses are conveyed, and (*c*) a central or perceptive portion, where the impulses are collected and transformed into sensations. The conducting and perceptive portions of the various sense-organs have been described in the Sections on the Nervous System; their peripheral or receptive portions form the subject-matter of this Section, and are grouped under two headings. (1) Those associated with the *general sensations* of touch, pressure, pain, and temperature. (2) Those associated with the *special senses* of sight, hearing, smell and taste; the internal ear contains, in addition to the organ of hearing, a special organ associated with the function of equilibration. Special nerve-endings occur also in relation to muscle-fibres and tendons and are of importance in the orientation and equilibration of the body.

THE SKIN

The **skin** covers the body, and it is continuous at the orifices on its surface with the mucous lining of the alimentary canal and other passages. It contains the peripheral terminations of many of the sensory nerves, and it serves as a protection to the deeper tissues. It plays an important part in regulating the body temperature, and, by means of its sweat-glands and sebaceous glands, it acts as an excretory organ. Its superficial layers are modified in certain situations to form the hairs and nails.

The skin is very elastic, and its colour, determined partly by its own pigment and partly by that of the blood, is deeper on exposed parts and in the regions of the external genital organs, axillæ, and mammary areolæ, than elsewhere. The pigmentation of the skin is due mainly to the accumulation of granules of *melanin* in the basal-cell layer of the epidermis, but four other pigments have been identified in the human skin: *melanoid*, diffused throughout the epidermis; *carotene*, in the horny zone and in the fat of the corium and subcutaneous tissue; *reduced hæmoglobin* and *oxy-hæmoglobin* in the vessels of the corium and subcutaneous tissues. Females have whiter skin than males, with less melanin and more blood-pigment and carotene (Edwards & Duntley, 1939). The darker colour of the skin of the negro is due to a wider distribution of melanin and melanoid throughout the layers of the epidermis. Mankind is divided into three groups on the basis of skin colour:

Melanoderms, or black-skinned; Xanthoderms, or yellow-skinned; and Leukoderms, or white-skinned.

On the surface of the skin there are the openings of the hair-follicles and of the ducts of the sebaceous glands and sweat-glands. The palmar surface of the hand and the plantar surface of the foot show numerous permanent *ridges*, which, particularly in the case of those of the terminal phalanges of the digits of the hand, may be employed for purposes of identification by means of finger-prints, since they are always characteristic in the details of their arrangement for every individual. Where subcutaneous muscles exist the skin can be thrown into wrinkles by their contraction. Over the greater part of the body it is freely movable; but it is bound down to the underlying tissues on the scalp and lateral surfaces of the auricles, the palms and soles, and at the flexure-lines of joints. In the digits special **skin-ligaments** occur which prevent lateral bulging of the skin at the joints during flexion.

Fig. 969.—Schematic Vertical Section of Skin.

Structure.—The skin is composed of a deep layer called the corium or *derma*, and a superficial layer called the epidermis (Figs. 969-971).

The **corium** or *true skin* is derived from the embryonic mesoderm, and consists essentially of a felted interlacement of white and elastic fibres. Its superficial part is thrown into numerous folds, the **papillæ of the corium**, which project into corresponding recesses in the overlying epidermis and constitute its **papillary layer**. The deeper part is known as the **reticular layer**, on account of the network-like arrangement of its connective tissue fibres. The deeper layer passes, as a rule, without any line of demarcation into the layer of subcutaneous fatty tissue, but in some parts it rests upon striated or plain muscle-fibres.

The papillæ of the corium are usually developed more in the hand and foot, where the ridges of the epidermis, referred to above, are found, and usually two or more papillæ project towards the under surface of each ridge. The papillæ contain vascular loops and, in many cases, certain special sensory nerve-endings. The fibres of the corium are arranged all over the body in definite lines. These often produce characteristic creases, for example on the dorsum of the hand, and are of particular interest because, in penetrating wounds by a round instrument, invariably a linear slit results, its direction being determined by the tension of the fibres of the corium (Wood Jones, 1941).

The **epidermis** or *scarf-skin* is derived from the embryonic ectoderm and covers the corium. Its thickness varies in different parts of the body and ranges from 0·3 mm. to 1 mm. or more; it is thickest on the palms of the hands and soles of the feet, and thinnest on the eyelids and penis. It is non-vascular and may be divided into the following layers or strata, when traced from the surface inwards: the stratum corneum, stratum lucidum, stratum granulosum, and stratum germinativum. The **s. germinativum** lies next to the corium, and is so named because it is from

this layer that the more superficial layers are continually being derived. It is often called, after its discoverer, the *Malpighian layer* (Malpighi, 1628-1694). The cells in the superficial part of this layer are joined together by protoplasmic bridges so that they form in reality a continuous sheet of cells, *i.e.*, a syncytium. These bridges appear as spines or prickles on the individual cells and so this layer is sometimes known as the *s. spinosum*, or *prickle-cell layer*. The deepest part of the s. germinativum is known as the *basal-cell layer*; its cells are rather elongated or columnar in shape, but they become more flattened in the superficial part of the stratum. The s. granulosum is a layer two or three cells thick; as its name implies, the cells contain granules, which may be associated with the elaboration of the keratin that is characteristic of the s. corneum. There is a gradual change in the character of the cells of the epidermis as they are traced towards the surface. They lose their nuclei and their cell-boundaries, and this is apparent in the next layer, the s. lucidum, which receives its name on account of its clear appearance and seemingly acellular nature. The s. corneum, is the most superficial layer, and is composed of degenerating cells which have acquired a horny or keratinous character, and which are continually being shed to be replaced by cells migrating towards the surface from the deeper layers. S. corneum, s. lucidum and s. granulosum together constitute the *horny zone* of the epidermis, and the s. germinativum is the *germinative zone*.

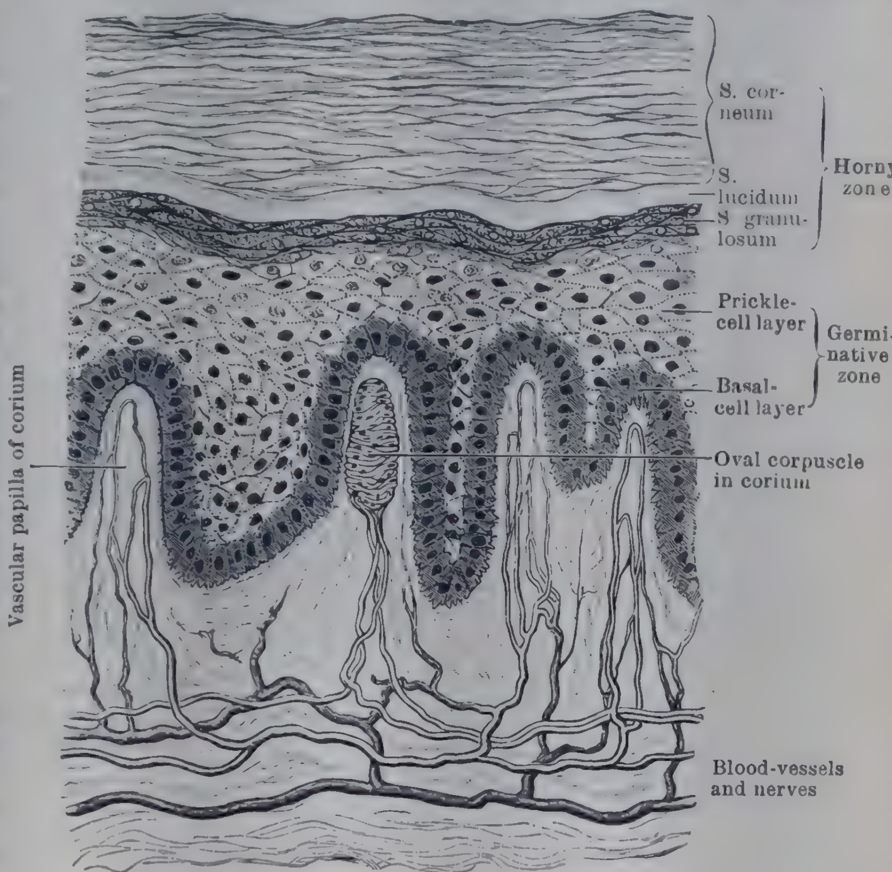


Fig. 970.—Vertical Section of Epidermis and Papillæ of Corium.

Vessels and Nerves.—In the subcutaneous tissue the **arteries** form a plexus from which branches extend into the corium, where they supply the hair-follicles and glands, and form a second plexus under the papillæ, to which small loops are given. The **veins** and the **lymph-vessels** begin in the papillæ, and, after forming subpapillary plexuses, open into their respective subcutaneous vessels. In the pads of the fingers and toes, and in some other parts of the body, complicated arterio-venous anastomoses occur in the deeper parts of the corium (Boyd, 1939; see also Lewis, 1927).

Since the skin is the main receptor of external stimuli of various kinds, it is plentifully supplied with nerves. These constitute the cutaneous distribution of the peripheral nerves, and many different modes of termination of the nerve-fibres are found, associated with the different stimuli to which they respond. These various nerve-endings are described and illustrated on pp. 1158-1160 and in Figs. 971, 975-977.

Appendages of the Skin

The appendages of the skin are the nails, the hairs, the sebaceous glands, and the sweat-glands.

Nails.—The **nails** (Figs. 972, 973) are epidermal structures, and represent the hoofs and claws of the lower animals. They are a special modification of the superficial layers of the epidermis, particularly of the s. lucidum. As can be seen in a longitudinal section (Fig. 973), it is as if the skin had been deeply invaginated and then greatly cornified. Thus, the various strata of the skin can all be recognized, modified to a greater or less degree. The visible part of the nail is its **body**; the hidden part, from which growth of the nail occurs, is the **root**. It is covered by a fold of skin called the *eponychium* which at its free edge is composed of s. corneum only, and constitutes the *cuticle*, which is removed in manicuring the hands. The nail rests on the **nail-bed**, and the most distal part of this is called the *hyponychium*.

The sides of the nail are buried, but less deeply than the root, by **nail-walls.** Dermal papillæ are found in the nail-bed, as on the palmar surface of the digits, and they are arranged in longitudinal rows that give rise to the striations seen on the body of the nail. Extending for some distance beyond the eponychium there is a white semilunar area of the nail called the **lunula**. Its development varies considerably in different persons and in the various digits.

Hair.—**Hairs** are developed more or less over the whole surface of the body with the exception of the palm and the sole, the terminal phalanges of the digits, the red part of the lips, the glans and prepuce of the penis, and the inner surface of the

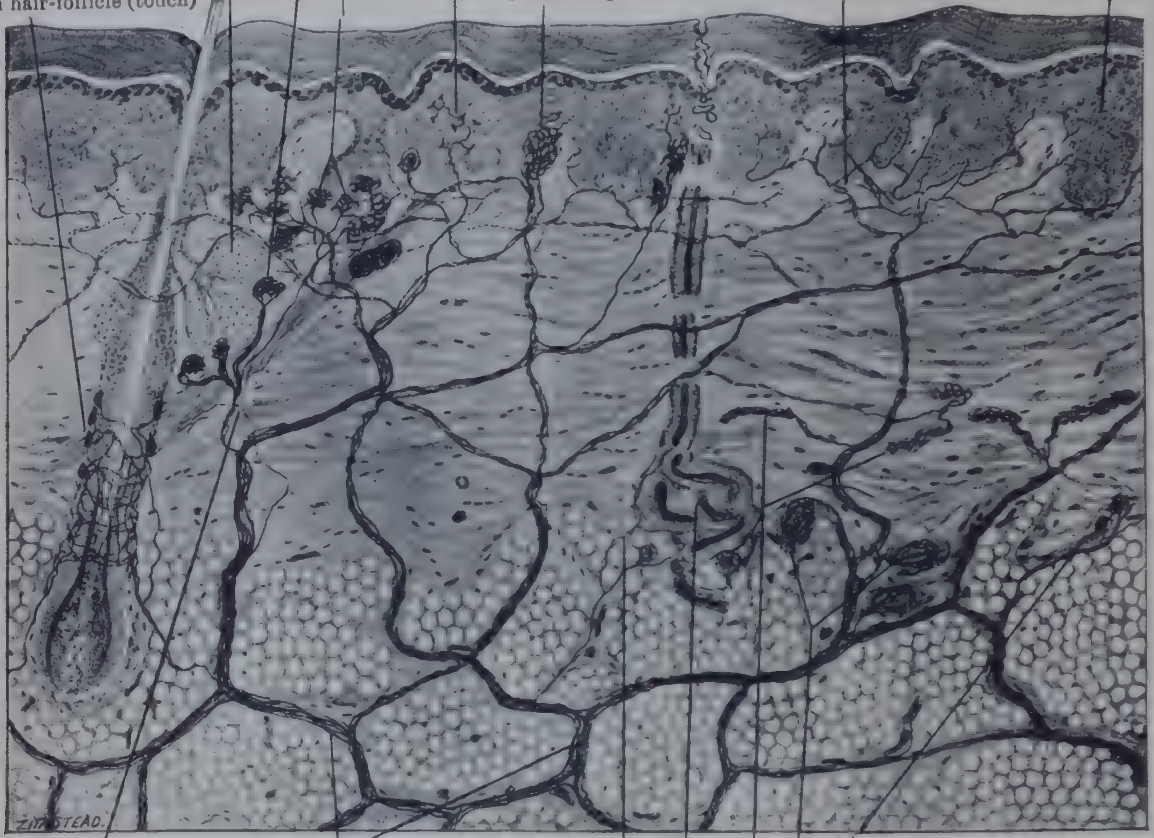


Fig. 971.—Composite Diagram showing the Innervation of the Human Skin. (Woollard, Weddell, & Harpman, 1940.)

labia majora. Over most of the body the hairs are rudimentary, giving an appearance of hairlessness, though in reality their number is greater in certain areas than in supposedly hairy animals such as the chimpanzee and the gorilla. The distribution and 'lie' of the hairs follows a definite arrangement, giving rise to the so-called *hair-tracts* (Kidd, 1903; Wood Jones, 1941; Le Gros Clark, 1945). There is also a sexual differentiation in the distribution of the hairs. As is well known, they show much greater development on the face of men than of women, and in the pubic region their distribution is more restricted in the female than in the male (Dupertuis, Atkinson & Elftman, 1945). The character of the hair is employed in classifying the races of Man; thus straight hair is characteristic of Mongolians, wavy of Europeans, and frizzly or woolly of Negroes.

The **root of the hair** is embedded in a depression of the skin termed the **hair-follicle** (Fig. 969); the *shaft* is the free portion of the hair, and consists from without inwards of cuticle, cortex, and medulla. The *cuticle* is formed of a layer of imbricated scales which overlap one another from below upwards. The *cortex* consists of longitudinally arranged fibres made up of elongated, closely applied, fusiform cells which contain pigment and sometimes air-spaces—the latter especially in white hairs. The *medulla*, absent from the fine hairs of the body generally and from the hairs of young children, forms a central core which appears black by transmitted

light and white by reflected light; it is composed of polyhedral nucleated cells which contain pigment, fat-granules, and air-spaces.

The **hair-follicle** is an oblique invagination of the epidermis and corium, and in curly hair it is twisted; the ducts of the sebaceous glands open into the hair-follicles just deep to the papillary layer of the corium. The portion of the follicle derived from the corium consists of a sheath of fibrous tissue arranged as an external longitudinal layer and internal circular layer, the latter being lined with a hyaline layer directly continuous with the basement-membrane

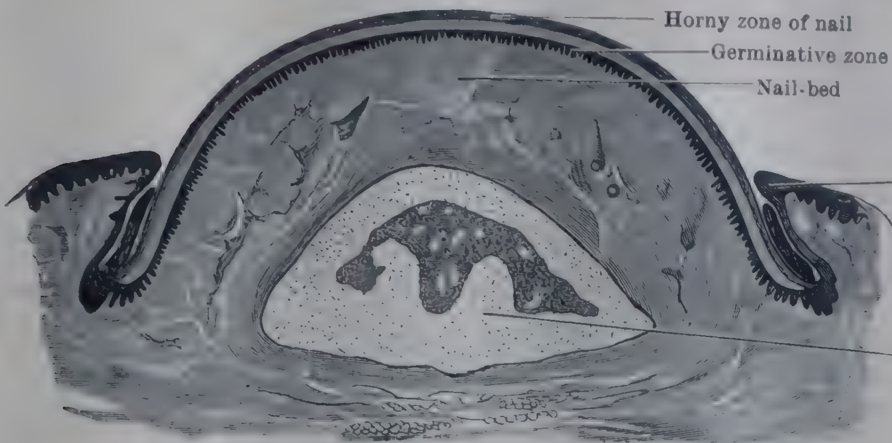


Fig. 972.—Transverse Section of Nail.

of the corium. The parts of the follicle derived from the epidermis are named the **inner** and **outer root-sheaths**. Below the orifices of the ducts of the sebaceous glands the outer root-sheath is formed only by the germinative zone of the epidermis, while above these orifices all the epidermal layers contribute to it. The outer root-sheath is clearly continuous with the germinative layer of the epidermis; it is the thickest component of the wall of the follicle, but becomes gradually thinner towards the hair-root. The inner root-sheath surrounds the cuticle of the hair, and comprises from without inwards:—(*a*) *Henle's layer*—a layer of nucleated cubical cells. (*b*) *Huxley's layer*—one or two layers of polyhedral nucleated cells. (*c*) A delicate *cuticle* composed of a layer of flattened imbricated cells, with atrophied nuclei. The bottom of the hair-follicle is moulded over the summit of a vascular **papilla**, derived from the corium and capped by the **bulb of the hair** or expanded part of the hair-root. The cells of the bulb are continuous round its edge with those of the outer root-sheath, and an upward growth from the bulb gives rise to the hair itself. The vessels form capillary loops in the papilla of the hair, and send twigs into the outer layer of its fibrous sheath; the inner and outer root-sheaths

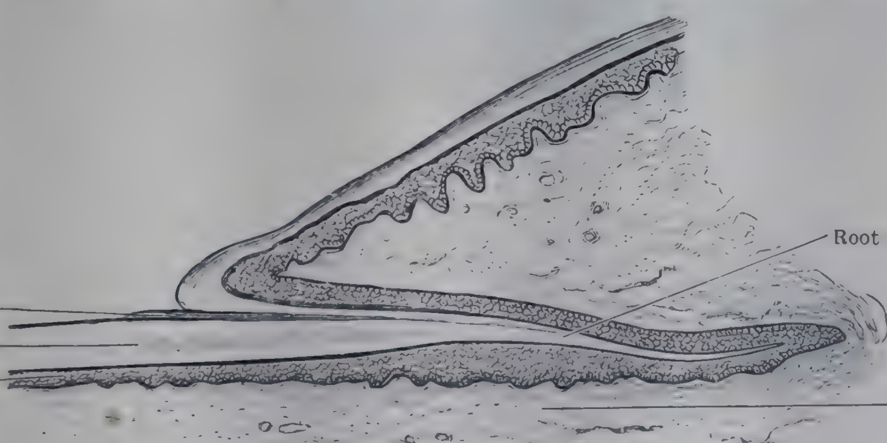


Fig. 973.—Longitudinal Section through Root of Nail.

and the hair itself are non-vascular. The nerves end in longitudinal and annular fibrils below the level of the sebaceous glands and outside the hyaline layer of the follicle.

Sebaceous Glands.—These glands exist wherever there are hairs, and their ducts open into the superficial parts of the hair-follicles (Fig. 969); the number of glands associated with each follicle varies from one to four. On the labia majora and minora, glans penis and mammary areolæ they open on the surface independently of hair-follicles, and in the areolæ they undergo great enlargement during pregnancy. The deep end of each gland expands into a cluster of oval or flask-shaped **alveoli** which are surrounded by a basement-membrane, and are filled with polyhedral cells containing oil-droplets. By the breaking down of the internal cells, their oily contents are liberated as the *sebum cutaneum* and discharged into the hair-follicle;

they are thus examples of *holocrine glands*, in which the secreting cells disintegrate. The glands are then restored by a proliferation of the deeper cells. The size of the glands bears no proportion to that of the hairs, the glands being very large in the minute hair-follicles of the fœtus and new-born child, and also in the follicles of the rudimentary hairs of the nose and certain parts of the face.

Bundles of plain muscular fibres are associated with the hair-follicles, and are named the **arrectores pilorum muscles.** Attached to the deep part of the hair-follicle, and forming with it an acute angle, they pass outwards close to the sebaceous glands, and end in the papillary layer of the corium. They are situated on the side towards which the hair slopes, so that, on contraction, they diminish the obliquity of the hair-follicle and make the hair more erect, and, at the same

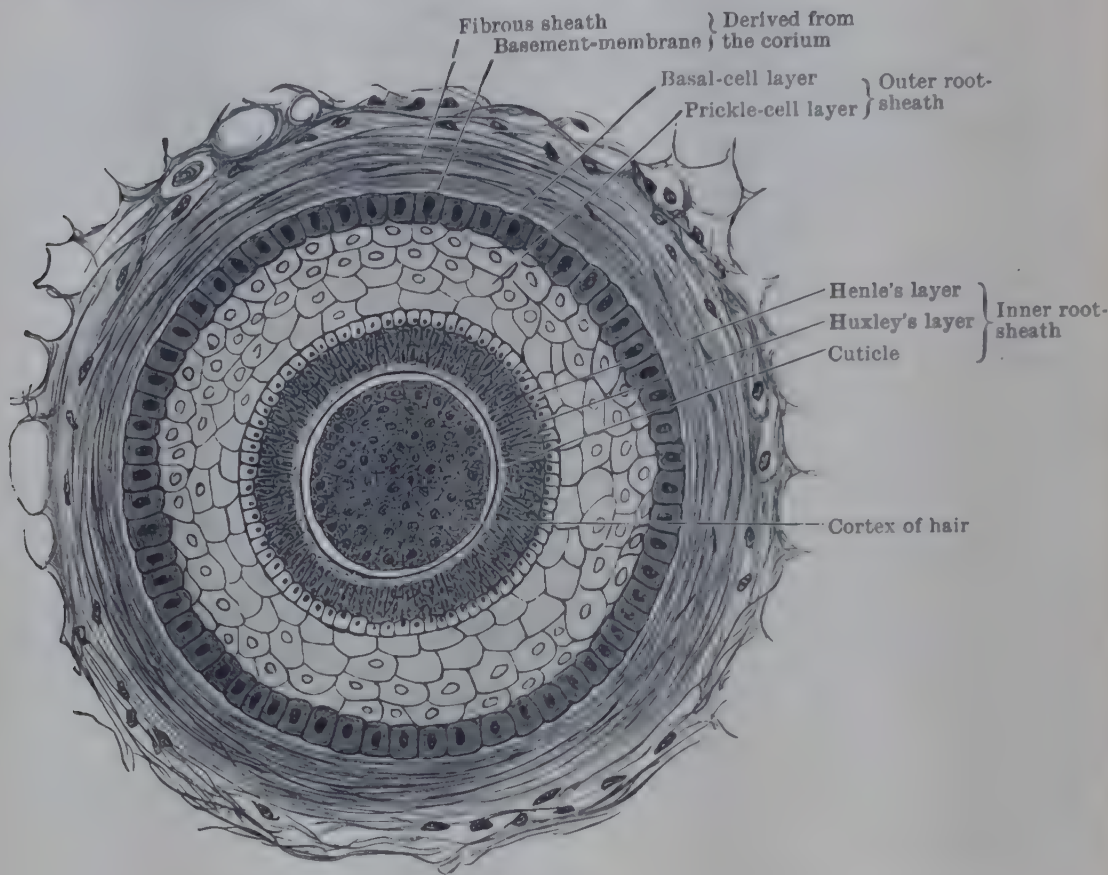


FIG. 974.—TRANSVERSE SECTION OF HAIR-FOLLICLE AND HAIR (semi-diagrammatic).

time, compress the sebaceous glands and expel their contents. The condition of "goose-skin" is caused by the contraction of these slender muscles.

Sweat-Glands.—The sweat-glands are found in the skin of nearly every part of the body; they are relatively few in number on the back of the trunk, but are very plentiful on the palms and soles, where they open on the summits of the skin-ridges and can easily be seen in the living body. Each consists of an elongated tube; the deeper portion of the tube forms its secretory part, and is coiled in the subcutaneous tissue or in the deep part of the corium to form an oval or spherical structure termed the **body** of the gland (Fig. 969). The superficial part of the tube, or **duct**, extends through the corium and epidermis, and opens on the surface by a funnel-shaped orifice called the **sweat-pore**; where the epidermis is thick the duct is spirally coiled.

The bodies of the glands, as a rule, vary in diameter from 0·1 mm. to 0·5 mm., but in the axilla they measure from 1 mm. to 4 mm. Each is surrounded by a capillary network and by a capsule of fibrous tissue inside which there is a homogeneous basement-membrane. The lumen of the tube is lined with cubical epithelial cells, between the deep ends of which and the basement-membrane there is a layer of cells with their long axis parallel to that of the tube; these are considered to be muscle-fibres and to assist in the expulsion of the secretion of the glands. The excretory ducts are devoid of the layer of muscle-fibres, and consist of a basement-membrane lined with two or three layers of polyhedral cells which are covered, next the lumen of the duct, with a thin cuticle.

The **ciliary glands**, at the margins of the eyelids, and the **ceruminous glands** of the external auditory meatus, are modified sweat-glands. The ciliary glands are, however, not coiled; the cell-protoplasm of the ceruminous glands contains yellowish pigment, and their ducts, in the fœtus, open into hair-follicles.

Development of Skin and its Appendages

Skin.—The corium is developed from the mesoderm, the cells of which, immediately underlying the ectoderm, have, by the first month of intra-uterine life, become aggregated together and flattened parallel to the surface of the embryo. By the third month they form two layers, the superficial of which becomes the corium, and the deeper the subcutaneous tissue; the papillæ of the corium make their appearance in the fourth month. The epidermis, nails, hairs, sweat-glands, and sebaceous glands are of ectodermal origin.

The epidermis at first consists of a single layer of cells, but by the end of the second month two layers are present—a superficial layer of flattened cells, and a deeper layer of cubical cells. By the third month three strata are seen, of which the two deeper layers come to form the future germinative zone, while the superficial layer is called the *epitrichium*, since it lies superficial to the emerging hairs, by which it is pushed off to help in the formation of the greasy covering of the child at birth, called the *vernix caseosa*. Cells arise from the germinative zone and become pushed nearer and nearer to the surface, where they undergo gradual cornification and so form the various layers of the horny zone. (See Hanson, 1947.)

Nails.—When seen in section, particularly a longitudinal one (Fig. 973), it is clear that the nail is a modification of the epidermis, and most of the layers of the epidermis can be recognized in the structure of the nail; the only layers unrepresented are the epitrichium and the s. granulosum.

The nail begins to develop about the third month as a thickening of the superficial layers of the epidermis under the epitrichium on the dorsal surface of the terminal phalanx of the digit. This thickening is soon overgrown proximally and at the sides by folds of the whole thickness of the epidermis—the proximal and lateral **nail-folds**. In the nail-thickening, keratinization of the s. lucidum of the epidermis gives rise to the horny zone of the nail; the s. granulosum is unrepresented; and the s. germinativum remains relatively unaltered at the root of the nail. In the nail-folds the epitrichium soon disappears, and the s. corneum persists as the *eponychium*.

The nails grow in length, or are renewed in case of removal, by a proliferation of the cells of the germinative zone, which ultimately become cornified, just as they do in the case of the skin. The growing area of the nail underlies the lunula and is sometimes spoken of as the *nail-matrix*. It has been shown (Le Gros Clark & Buxton, 1938; Gilchrist & Buxton, 1939) that in the hand nail-growth is at the rate of about 3 mm. a month; it is most rapid in the third digit and slowest in the fifth. It is more rapid in boys than in girls, and also in nail-biters; and it is less rapid in poorly nourished than in well nourished children.

Hair.—The hair-rudiments appear about the third month of intra-uterine life as solid downgrowths of the s. germinativum of the epidermis which pass obliquely into the subjacent corium. The deep end of each downgrowth of cells expands to form the hair-bulb, and this becomes moulded round a papilla derived from the corium; the cells immediately overlying the papilla are those from which the future hair will be derived, and therefore are known as the *germinal matrix* of the hair. Growth of the germinal matrix towards the surface gives rise to the hair and its inner root-sheath. The outer root-sheath is derived from the peripheral cells of the original invagination. The surrounding corium is condensed to form the fibrous sheath of the hair-follicle, the hyaline layer of which is continuous with the basement-membrane covering the corium. The hair gradually elongates, and, reaching the neck of the follicle, its extremity lies at first under the epitrichium, but becomes free by pushing this off about the fifth month of intra-uterine life. The first crop of hairs is called the *down*, and is well developed by the seventh month; it consists of very delicate hairs, some of which are shed before birth and the remainder shortly after—the last to drop out being those of the eyelashes and scalp—and are replaced by stronger hairs. Shedding and renewal of the hairs take place during life; prior to the shedding of a hair active growth and proliferation of the cells of the hair-bulb cease, and the papilla becomes atrophied, while the hair-root, gradually approaching the surface, at last drops out. New hairs arise from epidermic buds which extend downwards from the follicle, and their development is identical with that of the original hairs.

It has been shown (Trotter, 1924) that hair-follicles have periods of growth and of quiescence, of about equal duration. While there are differences in rate of growth in different parts of the body and at different age periods, the average rate of growth is about 1·5 mm. to 2 mm. per week.

Sebaceous Glands.—These appear about the fifth month of intra-uterine life as solid outgrowths from the sides of the hair-follicles, and consist of epidermal offshoots continued from the cells of the outer root-sheath. Their deep ends become enlarged and lobulated to form the secreting part of the gland, and the narrow neck which connects this with the follicle forms its duct. The sebaceous secretion helps in the formation of the *vernix caseosa*.

Sweat-Glands.—These, like the hairs, arise as solid downgrowths of the s. germinativum. They descend, however, perpendicularly, instead of obliquely, and are of a yellowish colour; they appear on the palms and soles early in the fourth month of intra-uterine life, but much later over the hairy parts of the body. The downgrowths extend through the corium, and, on

reaching the subcutaneous tissue, become coiled to form the body or secreting part of the gland. The ducts of the glands do not open on the surface until the seventh month.

ORGANS OF GENERAL SENSATIONS

Under this heading will be described the terminations of those sensory nerves which are widely distributed throughout the body and are associated with "muscle-sense" and the senses of touch, pressure, heat, cold, and pain. Those nerves may end (*a*) as fine ramifications of the naked axons lying *free* amongst the tissues, or (*b*) in *special end-organs* where the terminations of the axons are surrounded by capsules of fibrous tissue.

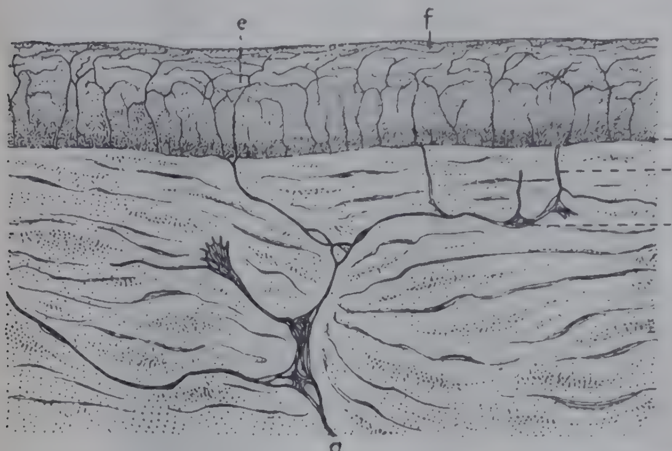


FIG. 975.—TRANSVERSE SECTION OF CORNEA STAINED WITH CHLORIDE OF GOLD (Ranvier).

a, *b*, Primary plexus in substantia propria of cornea ; *c*, branch passing to sub-epithelial plexus, *d* ; *e*, intra-epithelial plexus ; *f*, terminations of fibrils.

The following account is based largely on the work of Woollard, Weddell, and Harpman (1940) on the innervation of the skin (Fig. 971), and on subsequent papers by Weddell (1941 *a*, *b*); see also Le Gros Clark (1947).

FREE NERVE-ENDINGS

Free nerve-endings are found in the s. granulosum and in the s. germinativum of the epidermis, in the cornea, the teeth, the tympanic membrane, the walls of the blood-vessels, tendons, periosteum, and mucous membranes; and they constitute the peripheral pain end-organs.

Both medullated and non-medullated nerve-fibres may terminate in this way, the medullated fibres gradually losing their sheaths as they approach their termination. Usually two sets of plexuses—sub-epithelial and intra-epithelial—occur, from which the free nerve-endings are derived. Free nerve-endings occur also around the sweat-glands, in the papillæ and root-sheaths of the hair-follicles, and in serous membranes.

SPECIAL END-ORGANS

The special end-organs vary in size and form, but in all of them the termination of the nerve-fibre is enclosed in a capsule of varying thickness. The following are the different types of special nerve-endings: bulbous corpuscles, lamellated corpuscles, oval corpuscles, and the special sensory nerve-endings in muscle known as neuro-muscular spindles and neuro-tendinous spindles.

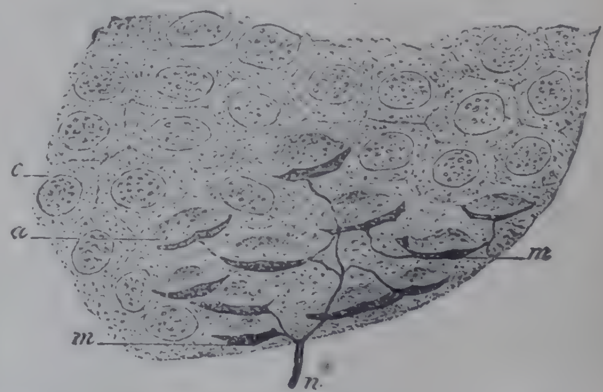


FIG. 976.—ENDING OF NERVE IN TACTILE DISCS OF THE PIG'S SNOUT (Ranvier). (From Quain's *Anatomy*.)

n, Medullated fibre ; *m*, terminal discs or menisci ; *c*, ordinary cell of epidermis ; *a*, modified cell to which a tactile disc is applied.

Bulbous Corpuscles.—These are minute cylindrical or oval bodies, first described by Krause. Each consists of a thin capsule derived from the perineurium of the nerve and enclosing a core of homogeneous or nucleated semifluid substance. As the nerve-fibre pierces the capsule it loses its medullary sheath and is continued into the core, where it may pursue a rather tortuous course, but more frequently divides into minute varicose fibrils which form an intricate plexus. Bulbous corpuscles occur in the conjunctiva, the lips and tongue, in the synovial membrane of certain joints, along the course of some of the larger nerve-trunks, and in the skin generally; in the skin of the glans of the penis and of the clitoris they may attain a considerable size and have thicker capsules than elsewhere.

The bulbous corpuscles have been shown to be associated with the sensation of cold, and they have been found to occur in multiple groups beneath each "cold spot" in the skin of the forearm

about 1 mm. from the surface; each is carried on a separate nerve-fibre, and the fibres approach the "spot" from different directions (Weddell, 1941 *b*). Rather similar endings, known as *Golgi-Mazzoni bodies*, occur in the skin and are associated with the sense of pressure (Fig. 971).

Lamellated Corpuscles.—These were described by Pacini, and consist of a fibrous-tissue capsule, composed of a number of concentric layers, arranged "like the coats of an onion" (Schafer) round a central core of more or less clear protoplasm. The deeper layers of the capsule are closely applied to each other, but those towards the circumference of the corpuscle are here and there separated by narrow lymph-spaces. Each corpuscle is of an oval shape, and its capsule is pierced at one end by a medullated nerve-fibre which loses its sheath on reaching the core of the corpuscle; the naked axon then passes to the other end of the core, where it terminates in one or more enlargements in which the neuro-fibrillæ form a dense network. Lamellated corpuscles occur in the deeper parts of the body in general; in the deeper layers of the skin of the hands and feet, in the loose areolar tissue of the posterior abdominal wall, in the subcutaneous tissue near joints, and along the course of certain nerves. They subserve the sense of pressure (Fig. 971).

Oval Corpuscles.—These corpuscles, which were described by Wagner and Meissner, are specially concerned with tactile impressions. They are oval in shape and are pierced at one end by a medullated nerve-fibre which then loses its sheath; the axons, which are frequently varicose, take a spiral or convoluted course towards the other end of the core, where they terminate in slight enlargements. Running with the medullated nerve-fibres there are several fibres which have lost their sheaths at some distance from the corpuscle; they pierce the capsule and break up into a very complicated network of horizontal branches. Oval corpuscles are most numerous in the papillæ of the corium of the palm of the hand and of the sole of the foot, and of the tips of the fingers and toes. It has been shown (Weddell, 1941 *b*) that in the pad of the fourth finger oval corpuscles are arranged in groups, there being an average of ten groups per square millimetre with two or three corpuscles in each group. The number of groups, but not the number of corpuscles in each group, becomes reduced towards the dorsum of the finger.

Also associated with the sense of touch there are certain disc-like nerve-endings, first described by Merkel (Fig. 971). As might be suspected from their function, they are particularly well developed in the pig's snout (Fig. 976).

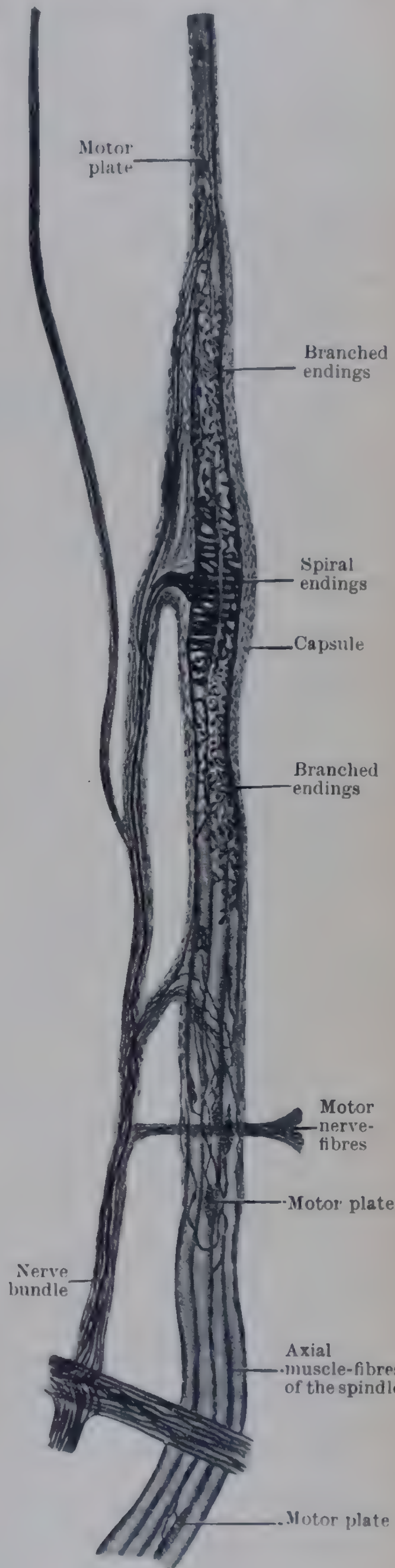


Fig. 978.—Neuro-Muscular Spindle of a Cat showing Nerve-Endings. (Maximow and Bloom, *Text-Book of Histology*. After Ruffini.)

Fig. 977.—Three Types of Special End-Organs.
A, Bulbous corpuscle; B, Lamellated corpuscle; and C, Oval corpuscle. (After Ranvier.)

There also occur in the fingers rather different corpuscles, which were described by Ruffini. They are oval or fusiform and are found in the subcutaneous tissue of the fingers, where the axons break up into a close-meshed network which lies between the smaller fasciculi of fibrous

tissue or partly encircles them. They are associated with the sense of warmth and some of them with the sense of pressure (Fig. 971).

Neuro-Muscular and Neuro-Tendinous Spindles.—These special sensory nerve-endings occur in nearly all the voluntary muscles and are associated with contractile tension or stretching of the muscle. As the names imply, they are spindle-shaped structures composed partly of nervous elements and partly of muscular or tendinous elements; the neuro-tendinous spindles are always situated close to the junction of muscle-fibre and tendon. In each case there is a fibrous capsule of several layers surrounding an internal core of specialized fibres of muscle and tendon; since these fibres lie in the interior of the spindle-shaped or fusiform body, they are known as **intrafusal fibres**. In the case of the neuro-muscular spindle the intrafusal fibres display many of the characteristics of embryonic muscle; they are smaller in both length and diameter than ordinary muscle-fibres, and they contain more protoplasm; they have numerous nuclei near the middle of the spindle, and their cross striation is less distinct there. The

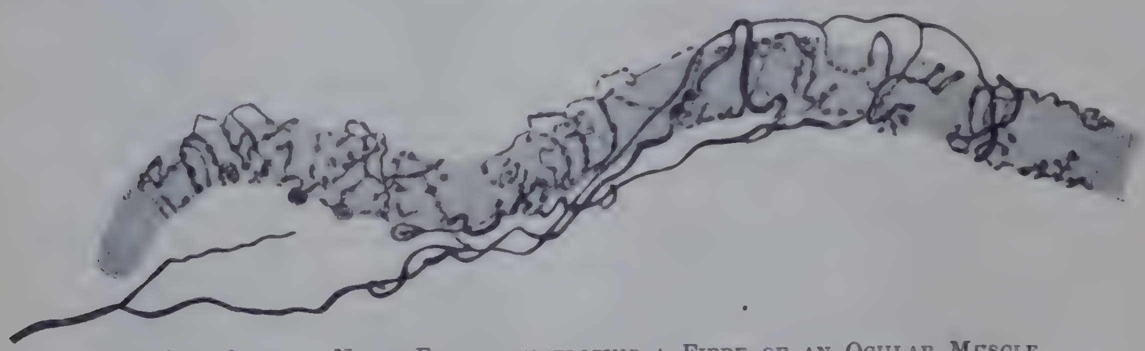


FIG. 979.—SENSORY NERVE-ENDING ENVELOPING A FIBRE OF AN OCULAR MUSCLE. (Maximow and Bloom, *Text-Book of Histology*. After Dogiel.)

intrafusal tendon-fibres also are slightly modified. In each type of spindle there is a lymph-space between the capsule and the axial core of fibres which is largest in the middle of the structure and thus gives it its spindle-shape. The nerve-fibres pierce the side of the capsule (usually near its middle) and lose their medullary sheaths as they do so; the axons then divide and surround the muscle-fibres or tendon-fibres in an annular or branching manner, or, as is more usual, in a spiral manner, forming a complicated plexus (Fig. 978).

In addition to these rather complicated modes of termination, sensory nerves may end by forming annular or spiral networks (Daniel, 1946) around non-specialized muscle-fibres, the essential difference being that, in these simpler formations, there is no capsule (Fig. 979).

Development of Nerve-Endings.—It has been shown (Jalowy, 1939) that tactile discs, oval corpuscles, and lamellated corpuscles appear in the fourth month of intra-uterine life. The tactile discs are fully developed at the seventh month, the lamellated corpuscles at the eighth month, and the oval corpuscles in the first year after birth.

ORGANS OF THE SPECIAL SENSES

ORGAN OF SIGHT

EYEBALL

The eyeball is the peripheral part of the **organ of sight**; associated with it are certain accessory structures, namely, the eyelids, the conjunctiva and the lacrimal apparatus.

The eyeball is situated in the anterior part of the orbit. It is not quite spherical, being composed of the segments of two unequal spheres, viz., a smaller anterior, corneal segment, and a larger posterior, scleral segment (Fig. 980). The anterior or corneal segment projects in front of the scleral portion, the union of the two parts being indicated, externally, by a slight groove called the **sulcus scleræ**. The central points of the anterior and posterior surfaces of the eyeball are its **anterior** and **posterior poles**; a straight line joining the two poles is termed the **optic axis**; and a line encircling the eyeball, midway between the poles, is named the **equator**. The axes of the two eyeballs are almost parallel, converging only slightly behind; but the axes of the optic nerves converge markedly behind, and, if prolonged backwards, would meet in the region of the dorsum sellæ of the sphenoid. The antero-posterior, horizontal and vertical diameters of the eyeball are nearly equal, being about one inch. Its volume is just over 8 c.cm. Females

have larger eyes, in proportion to their body weight, and in relation to the size of the orbit, than males, and the size of the eye relative to that of the orbit is much greater in the fœtus and the infant than in the adult (Schultz, 1940).

Fascial Sheath of Eyeball.—The fascial sheath is a thin fibrous coat which closely envelops the eyeball from the entrance of the optic nerve to the sclero-corneal junction; it forms a socket for the eyeball, and separates it from the other contents of the orbit. The sheath is separated from the eyeball merely by a potential space which, though it has sometimes been described as a lymph-space, is not lined with endothelium, but is traversed by a meshwork of fine areolar

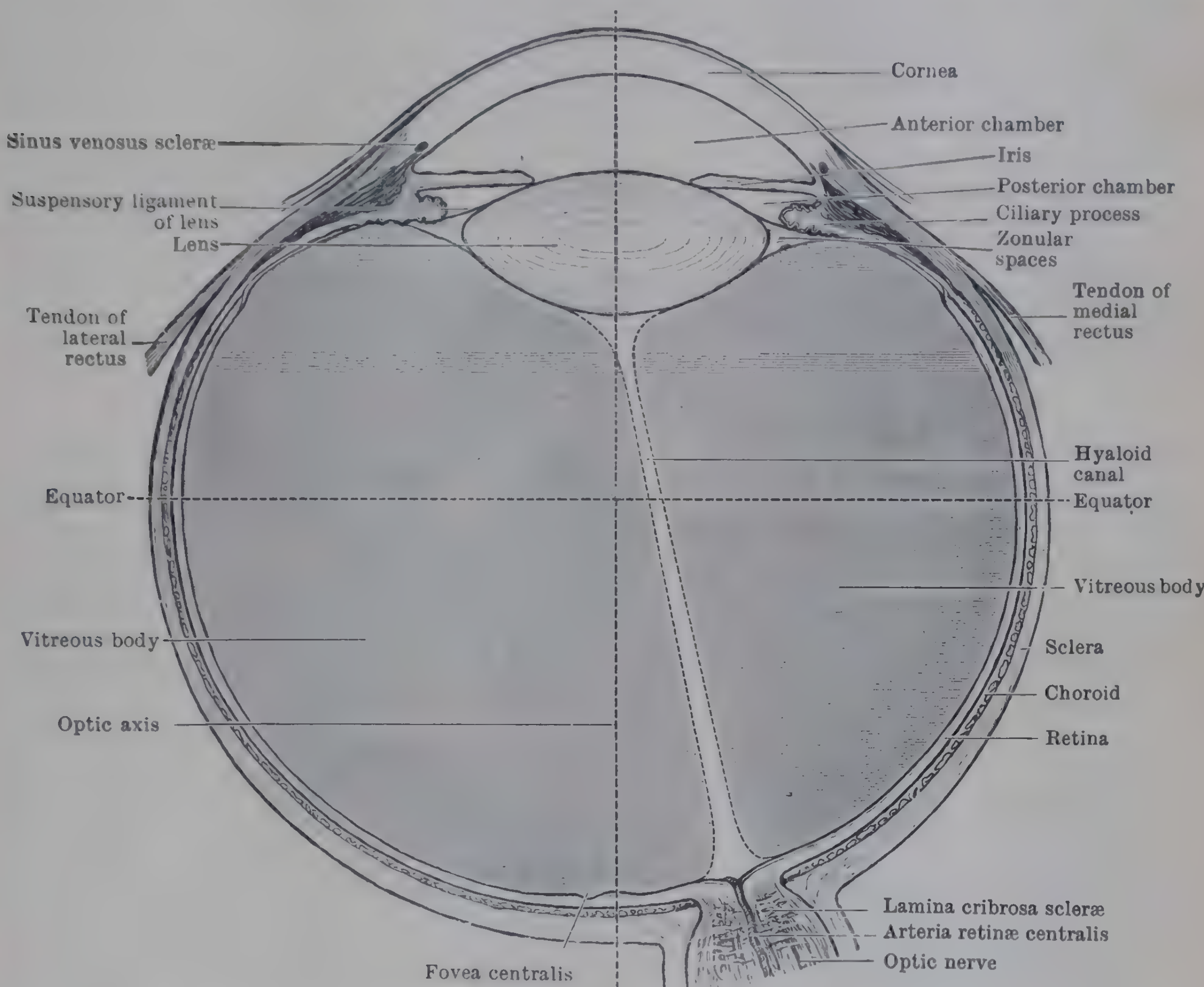


Fig. 980.—Diagram of Horizontal Section through Left Eyeball and Optic Nerve (×4).

tissue. Posteriorly, around the entrance of the optic nerve the sheath is difficult to define, for here it is pierced by the ciliary nerves and the posterior ciliary vessels; it is not continued backwards to form a sheath for the optic nerve. It is pierced near the equator by the venæ vorticosæ, and farther forwards by the orbital muscles on their way to their insertion into the sclera. The part of the sheath in front of the insertions of the recti muscles is thin; it lies between the ocular part of the conjunctiva and the sclera, and it fuses with the sclera immediately behind the sclero-corneal junction. The sheaths of the orbital muscles are thin and almost invisible posteriorly, but they become thick anteriorly and blend with the fascial sheath of the eyeball at the points where it is pierced by the muscles (Fig. 363, p. 428).

Offsets from the outer surfaces of the muscle-sheaths pass to the walls of the orbit, and, as they probably check the actions of the muscles, they are named **check ligaments**; they are developed best in association with the lateral and medial recti. The lateral part of the sheath of the lateral rectus is greatly thickened anteriorly, and forms a triangular mass of tissue which constitutes the check ligament for that muscle; it is attached to a tubercle on the orbital surface of the

zygomatic bone, and to the lateral palpebral ligament. The check ligament of the medial rectus also is triangular; it is fixed to the lacrimal bone, behind its crest, and to the lacrimal caruncle. The sheath of the superior rectus blends with that of the levator palpebræ superioris, and the sheet so formed is attached to the superior conjunctival fornix. The sheath of the inferior rectus is joined to those of the medial and lateral recti, and, as these are fixed to the medial and lateral walls of the orbit by the check ligaments, a continuous band, named the **suspensory ligament** (Lockwood, 1885), is slung from side to side beneath the eyeball like a hammock. The ends of the suspensory ligament blend not only with the check ligaments but also with the medial and lateral horns of the aponeurosis of the levator palpebræ superioris. The sheath of the superior oblique extends as far as the pulley through which the tendon passes and is attached to it. The sheath of the inferior oblique blends with that of the inferior rectus, and the united sheaths send forward one thin lamella into the lower eyelid, and another to unite with the fascial sheath of the eyeball.

The wall of the eyeball (Fig. 980) consists of three concentric coats; enclosed within it there are three transparent refracting media. The three coats are: (1) an outer, fibrous coat; (2) a middle, vascular, pigmented and partly muscular coat; (3) an inner, nervous coat. The three refracting media are named, from behind forwards, the **vitreous body**, the **lens**, and the **aqueous humour**.

FIBROUS COAT OF EYEBALL

The fibrous coat of the eyeball is divided into an opaque, posterior part named, on account of its hardness, the **sclera**, and a transparent, anterior part called the **cornea**, because it was thought to resemble a thin slice of horn.

Sclera.—The sclera is the firm, opaque, white coat of the eye. It has a blue tinge in childhood, since it is then thinner than in the adult and allows the pigment of the choroid to show through it; in old age it has a yellow hue. It is thicker at the back (1 mm.) than in front (0·6 mm.), or at the equator (0·5 mm.). At the back, 3 mm. to the nasal side of the posterior pole and slightly *above* the horizontal meridian (Traquair, 1946), the sclera is pierced by the optic nerve. The part of the sclera through which the nerve-bundles pass is called the *lamina cribrosa scleræ*; the dural sheath of the nerve blends with the sclera. Around the entrance of the optic nerve there are fifteen or twenty small apertures for the passage of the ciliary nerves and the short posterior ciliary arteries. On each side of the nerve, at a little distance from its entrance, the two long posterior ciliary arteries pierce the sclera. Near the equator there are four openings—two above and two below—for the exit of the venæ vorticosæ; and near the sulcus scleræ there are the openings for the anterior ciliary arteries. The deep surface of the sclera is intimately associated with the choroid, so that, when the two are separated, the inner surface of the sclera shows a brown colour from the pigment of the choroid which adheres to it. Nevertheless, it is customary to speak of the two coats being separated

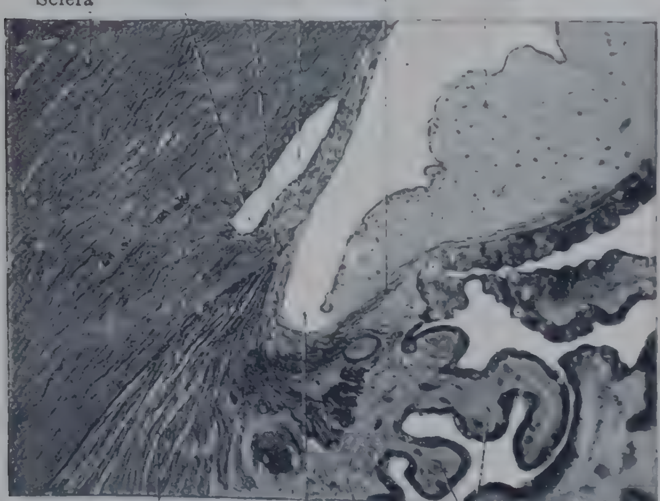


Fig. 981.—Section of Irido-Corneal Angle. (Thomson, 1912.)

from each other by the **perichoroidal space** which is traversed by the ciliary nerves and arteries just mentioned, and by a delicate meshwork of fine, pigmented areolar tissue, called the **suprachoroid lamina.** At the sclero-corneal junction the fibrous tissue of the sclera passes into that of the cornea, and in the deeper part of the junction there is a circular canal called the **sinus venosus scleræ** (Fig. 981). In a meridional section, *i.e.*, one passing through the optic axis, the sinus venosus scleræ appears as a narrow cleft distinguishable from the frequent adjacent scleral clefts by its having an endothelial lining; its outer wall is the compact tissue of the sclera and its inner wall is formed posteriorly by a projecting spur of sclera, and anteriorly by the backward prolongation of the posterior elastic lamina of the cornea, which is known as the **pectinate ligament of the iris** and is continued posteriorly into the scleral spur. The sinus communicates with the anterior ciliary veins, and, through the spaces of the irido-corneal angle, with the anterior chamber of the eye.

Structure.—The sclera consists of bundles of white fibrous tissue and some fine elastic fibres; the bundles form equatorial and meridional layers which interlace with each other. Fibroblasts are numerous between the bundles and pigmented cells occur in the inner layers.

Vessels and Nerves.—The **arteries** of the sclera are branches of the anterior and short posterior *ciliary arteries*; its **veins** open into the *venæ vorticosæ* and anterior *ciliary veins.* The **nerves** of the sclera are derived from the ciliary nerves, which, after losing their medullary sheaths, pass between the fibrous bundles.

Cornea.—The **cornea** is transparent and forms the anterior part of the outer coat. It is slightly thicker than the sclera—measuring 0·9 mm. at its centre, and 1·2 mm. at the periphery. Its anterior surface is covered with a stratified epithelium continuous with that of the conjunctiva; its posterior surface forms the anterior wall of the anterior chamber of the eye. The degree of curvature of the cornea varies in different persons, and is greater in youth than in old age; it is, as a rule, slightly greater in the vertical than in the horizontal plane, and diminishes from the centre to the circumference of the cornea; an abnormal degree of inequality of curvature is known as *astigmatism*, and gives rise to the inability to focus vertical and horizontal lines at the same point. The arc of the cornea is equal to about one-sixth of the total circumference of the eyeball.

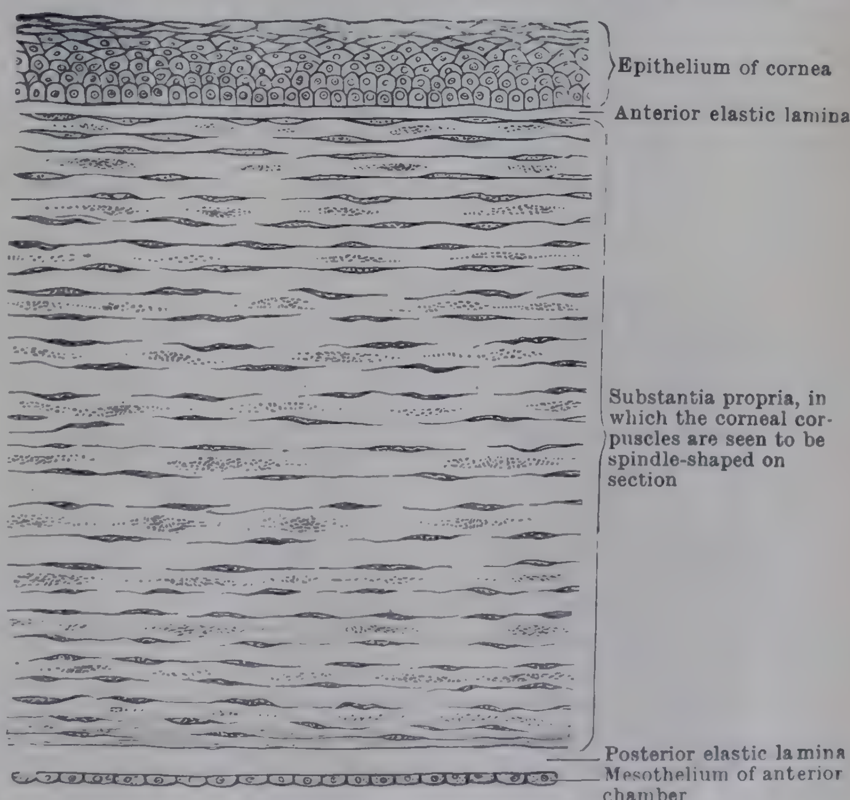


Fig. 982.—Diagrammatic Section of Cornea.

The cornea is continuous with the sclera at the **sclero-corneal junction.** The union is of such a kind that the sclera is bevelled at the expense of its inner surface and the cornea of its outer; the bevelling is most marked at the upper and lower parts of the junction, and thus the cornea, when seen from in front, is not quite circular in outline but slightly elliptical, the longer diameter being horizontal. Between the sclero-corneal junction and the front of the circumference of the iris there is a narrow recess which on section appears as an acute angle and is named **the irido-corneal angle.**

Structure.—The cornea is composed of the following strata from before backwards (Fig. 982):—

1. Epithelium of the cornea.
2. Anterior elastic lamina.
3. Substantia propria.
4. Posterior elastic lamina.
5. Mesothelium of anterior chamber.

1. The **epithelium of the cornea** is continuous with the epithelium on the free surface of the conjunctiva, and consists of six or eight strata of cells. Deepest of all is a single layer of columnar cells, the flattened bases of which rest on the anterior elastic lamina, while their opposite ends are round and contain the nuclei. Superficial to that layer there are three or four strata of polygonal cells, most of which exhibit finger-like processes which join with the corresponding processes of neighbouring cells; the most superficial layers consist of squamous cells.

2. The **anterior elastic lamina** is merely a differentiation of the anterior part of the substantia propria, from which it is separated only with difficulty; it differs from true elastic tissue in not being stained yellow by picrocarmine, and in being easily soluble in boiling water.

3. The **substantia propria** presents, in a fresh condition, a homogeneous appearance; but, with the assistance of reagents, it is seen to consist of modified fibrous tissue, with a few elastic fibres. An amorphous interstitial substance binds the fibres into bundles and cements the bundles into lamellæ which are flattened from before backwards. The fibres of any one lamella cross those of adjacent lamellæ almost at right angles.

The cells of the cornea are very irregularly stellate bodies, and are situated between the lamellæ. In fixed preparations they appear to lie in spaces which they do not completely fill

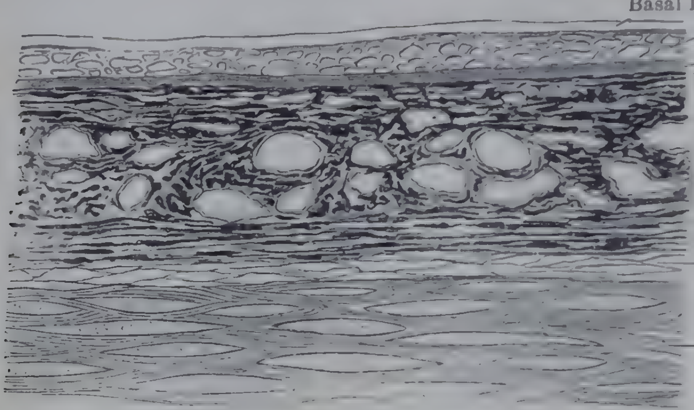


Fig. 983.—Transverse Section of Choroid and Inner Part of Sclera.

and it has been suggested that the rest of the space is occupied by lymph, that the various spaces or lacunæ communicate with each other by means of fine canaliculi, and that a path is thus established for the circulation of nutritive fluids to the cornea. The matter is not definitely settled, but it seems probable that the cells do in reality completely fill the spaces, and that the canaliculi are artificial clefts between the bundles and lamellæ and may be due to increased intra-ocular tension during life or to the action of reagents in the preparation of microscopic specimens.

After middle age a greyish opaque ring, 1·5 to 2 mm. in breadth, is frequently seen near the periphery of the cornea; it is termed the **arcus senilis**, and results from a deposit of fat in the lamellæ and in the corneal cells.

4. The **posterior elastic lamina** is a clear homogeneous membrane that covers the posterior surface of the substantia propria, to which it is less firmly attached than is the anterior elastic lamina. In the living eye, as revealed by the Gullstrand slit-lamp (Mann, 1925; Butler, 1927), it has the appearance of an olive-yellow, shining surface covered with small hexagonal dots; in old age the hexagonal pattern becomes less distinct and regular and round dark patches appear in places. At the sclero-corneal junction the posterior elastic lamina splits into bundles of fine fibres which interlace and are continued towards the circumference of the iris as the **pectinate ligament of the iris**. The spaces between the interlacing fibres are termed the **spaces of the irido-corneal angle**, and are lined with mesothelium prolonged from that of the anterior chamber of the eye. They communicate internally with the irido-corneal angle and externally with the sinus venosus scleræ, and constitute important channels through which fluid may filter from the anterior chamber into the sinus and thence into the anterior ciliary veins. When the pectinate ligament is followed backwards, most of its fibres are seen to be attached to the anterior surface of an inwardly directed rim of scleral tissue, but a few are carried past the edge of the rim, round the irido-corneal angle, and into the iris, where they are directly continuous with the fibres of the dilatator pupillæ muscle (Arthur Thomson, 1912).

5. The **mesothelium of the anterior chamber** consists of a single layer of polygonal cells; it is continued as a lining for the irido-corneal angle and is reflected on to the anterior surface of the iris.

Vessels and Nerves.—In the fœtus the cornea is traversed, almost as far as its centre, by capillaries; but in the adult it is devoid of blood-vessels, except at its margin. The capillaries of the conjunctiva and sclera pass into this marginal area where they end in loops. The rest

of the cornea is nourished by the lymph which percolates through the intercellular substance, the scleral conjunctiva being the only part of the eye in which lymph-vessels occur.

The **nerves** of the cornea are derived from the *ciliary nerves*. Around its periphery they form an annular plexus from which nerve-fibres pass into the cornea; they then lose their medullary sheaths and ramify in the substantia propria, forming the main *stroma plexus*. Fibres extend from this plexus through the anterior elastic lamina and form a *subepithelial plexus* from which fine filaments ramify between the epithelial cells as far as the superficial layers.

VASCULAR COAT OF EYEBALL

The vascular and pigmented coat of the eyeball comprises, from behind forwards, the choroid, the ciliary body, and the iris (Fig. 980).

Choroid.—The choroid is a dark-brown membrane which intervenes between the sclera and the retina. It is usually described as being loosely attached to the sclera by the suprachoroid lamina, except at the point of entrance of the optic nerve and where the blood-vessels pierce the sclera; here the connexion is much closer. After death it may easily be separated from the sclera, but microscopically the two layers are directly continuous with each other and the suprachoroid lamina is not a separate layer. The choroid extends forwards as far as the ora serrata of the retina, where it is succeeded by the ciliary body, which connects it with the circumference of the iris.

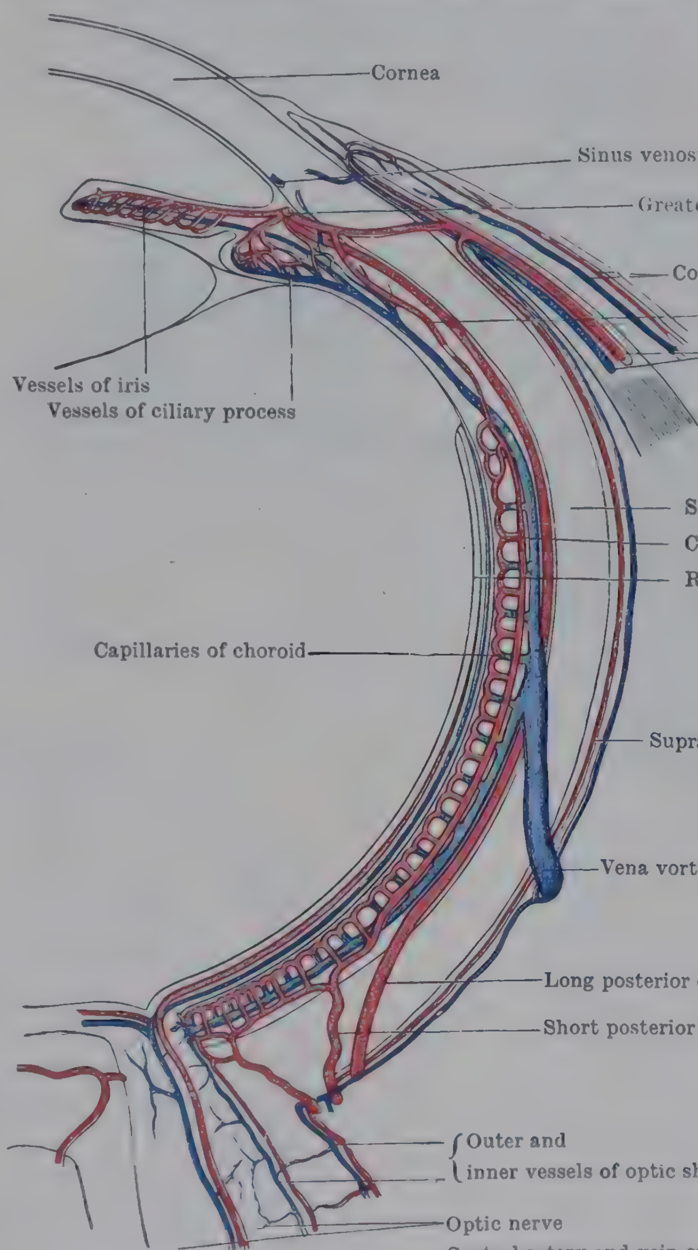


FIG. 984.—DIAGRAM OF CIRCULATION IN THE EYE. (Leber.)

Structure.—The choroid is composed, from without inwards, of three layers:—(*a*) a pigmented layer, the suprachoroid lamina; (*b*) a vascular layer, the proper tissue of the choroid; and (*c*) a glassy layer, the basal lamina (Fig. 983).

The **suprachoroid lamina** is the pigmented layer which intervenes between the sclera and the proper tissue of the choroid; it consists of a delicate network of elastic fibres, amongst which are stellate, pigmented cells and some large phagocytic cells. The pigment cells are, however, not restricted to the suprachoroid lamina, but are found both in the inner part of the sclera and among the vessels of the proper tissue of the choroid.

The **proper tissue of the choroid** consists of an outer layer—the **vascular lamina**—which contains larger blood-vessels, and an inner—the **chorio-capillary lamina**—which is composed of a close network of capillaries in a fine fibro-elastic intercellular substance. A condensation of this fibro-elastic tissue along the outer surface of the chorio-capillary lamina is called the *intermediate stratum* and serves to separate the vascular and chorio-capillary laminæ (Fig. 983).

The **basal lamina** separates the proper tissue of the choroid from the pigmented layer of

the retina, to which it is very closely adherent. It appears as a thin glassy membrane in the outer part of which very fine elastic fibres can be recognized.

Vessels.—The **arteries** of the choroid are derived from the *short posterior ciliary vessels*, which pierce the sclera around the entrance of the optic nerve and form a wide-meshed plexus in the vascular lamina. The **veins** are superficial to the arteries and converge to form whorls which open into the venæ vorticosæ.

Tapetum.—In many animals, especially the ruminants and carnivores, there is seen on the postero-lateral part of the choroid a brilliant iridescence to which the name **tapetum** is applied. Absent in Man, it may be due, as in the horse, to a thin fibrous layer between the two laminæ of the proper tissue of the choroid (tapetum fibrosum), or, as in the seal, to the presence of five or six layers of flattened iridescent cells (tapetum cellulosum) that lie immediately outside the chorio-capillary lamina.

Ciliary Body.—The ciliary body connects the choroid with the circumference of the iris (Fig. 980), and comprises three zones—(*a*) the ciliary ring, (*b*) the ciliary processes, and (*c*) the ciliary muscle.

The **ciliary ring** is a zone, about 4 mm. wide, that immediately adjoins the choroid and extends from the level of the ora serrata of the retina to the posterior

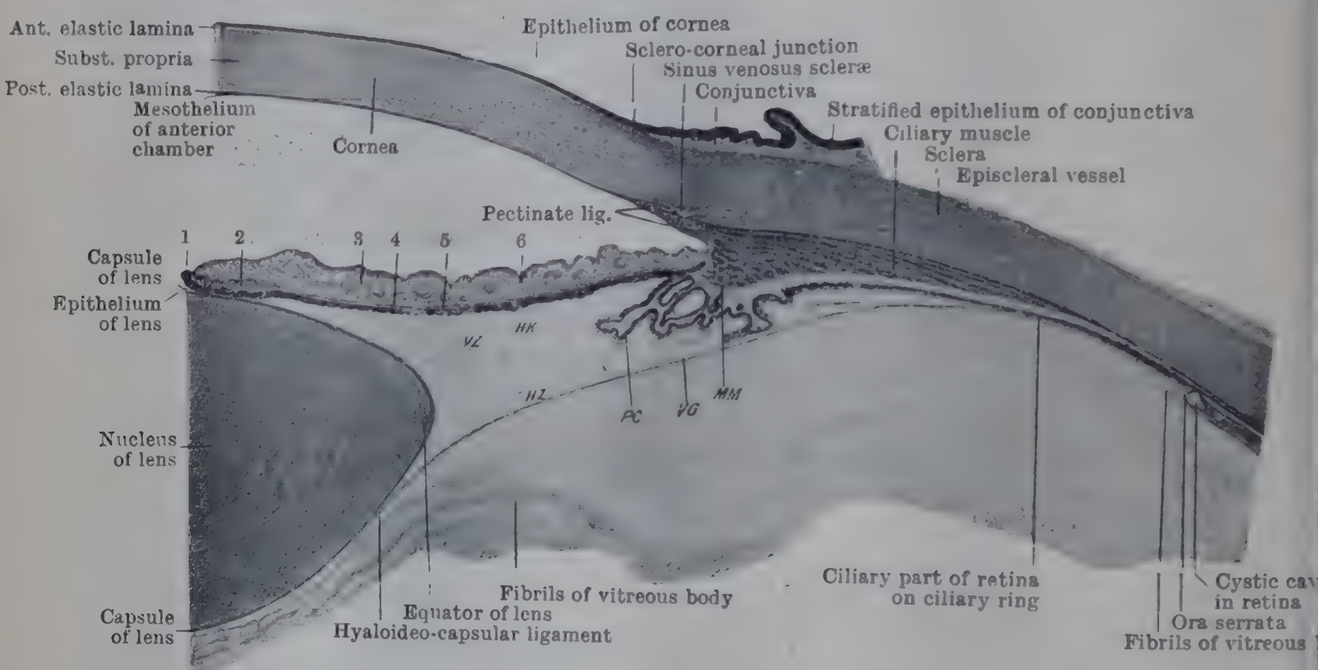


FIG. 985.—MERIDIONAL SECTION THROUGH CILIARY REGION OF HUMAN EYEBALL (×11). (Maximow and Bloom, *Text-Book of Histology*, after Schaffer.)

HK, Posterior chamber ; HZ, Posterior fibres of ciliary zonule ; MM, Circular fibres of ciliary muscle ; PC, Ciliary processes ; VG, Hyaloid membrane ; VZ, Suspensory ligament (ant. fibres of zonule).

1. Pupillary border of iris.
2. Sphincter pupillæ.
3. Iris.
4. Dilatator pupillæ.
5. Pigmented epithelium of iris.
6. Mesothelium of iris.

end of the ciliary processes; it is faintly marked on its inner surface by a series of radial ridges.

The **ciliary processes** are a series of about seventy prominent radial ridges arranged in a circle behind the periphery of the iris, against which they stand out sharply by their paler colour (Fig. 986). They have an average length of about 2 mm., and are much wrinkled ; when traced backwards they merge into the ciliary ring, and when traced forwards to the periphery of the iris their ends project freely over its deep surface and give attachment to some of the fibres of the suspensory ligament of the lens.

Structure.—The ciliary ring and processes are essentially similar in structure to the choroid, except that the suprachoroid lamina is less well developed and the chorio-capillary lamina is absent. Instead of being lined with the retina proper, the ciliary ring and processes are covered on their inner surface with two layers of epithelium which represent the original two layers of the embryonic optic cup, of which the outer is deeply pigmented. These two layers are known as the **ciliary part of the retina**. The great wrinkling of the processes causes the epithelium to

be invaginated into the substance of the processes so as to form tubular glands from which the aqueous humour may in part be derived.

The **ciliary muscle** is placed between the sclera which is superficial and the ciliary ring and processes which are deep to it. It is composed of meridional and circular fibres; the meridional fibres are attached anteriorly to the inwardly projecting spur of sclera which has been referred to (p. 1163) as giving attachment to most of the fibres of the pectinate ligament of the iris; from this point the fibres radiate backwards, to be attached to the ciliary processes and ciliary ring; the circular fibres form a small zone of muscular tissue to the medial side of the meridional fibres and behind the irido-corneal angle. The ciliary muscle, by its contraction, draws forward the ciliary ring and the ciliary processes and the lens becomes more convex, owing to the relaxation of its suspensory ligament. Considerable individual differences exist as to the degree of development of the two portions of the ciliary muscle; the meridional fibres are always more numerous than the circular fibres, which are absent or rudimentary in myopic eyes, but are well developed, as a rule, in hypermetropic eyes.

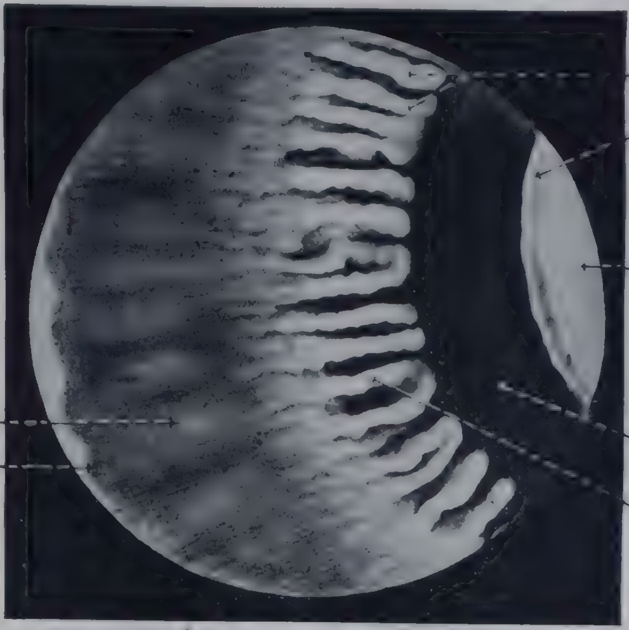


FIG. 986.—ANTERIOR PART OF EYEBALL SEEN FROM WITHIN.

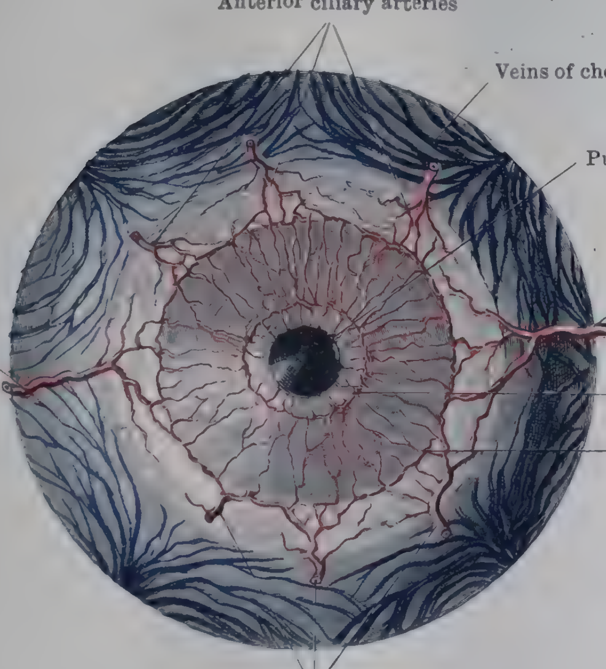


FIG. 987.—BLOOD-VESSELS OF IRIS AND ANTERIOR PART OF CHOROID VIEWED FROM THE FRONT. (Arnold.)

Iris.—The iris is a contractile diaphragm situated in front of the lens, and it presents, a little to the nasal side of its centre, an almost circular aperture — the **pupil**—which, during waking hours, is continually varying in size in order to regulate the amount of light admitted into the eyeball. The iris partially divides the space between the cornea and lens into two portions which are filled with the aqueous humour, and are named the **anterior** and **posterior chambers** of the eye. It is of almost equal thickness throughout, though it is rather thinner in the middle and thickens towards its pupillary margin; the peripheral margin is continuous with the ciliary body, and, through the pectinate ligament, with the posterior elastic lamina of the cornea: the pupillary margin rests on the front of the capsule of the lens.

The colour of the eye depends on the arrangement of the pigment in the iris; in the blue eye the pigment is limited to the posterior surface of the iris, but in the brown eye it is also scattered throughout its stroma; in the albino the pigment is absent.

The pupil is covered, during the greater part of intra-uterine life, by the **pupillary membrane.** This is a thin, highly vascular membrane, the vessels of which are derived primarily from the hyaloid artery and later from the long posterior ciliary arteries. The membrane is situated on the superficial surface of the iris, and its vessels form a series of arcades converging towards the centre of the pupil. At about the seventh month of intra-uterine life, atrophy begins in the central vessels and proceeds towards the circumference, more and more peripheral vessels becoming involved until the lesser arterial circle is reached; here the process of atrophy ceases, and this circle comes therefore to be the most central part of the vascular arcades of the iris. At birth, atrophy of the membrane is usually complete, though fragments of it may remain into adult life.

Structure.—The main mass of the iris is known as the *stroma* and is composed of delicate white and elastic fibres, mingled with pigmented cells, blood-vessels, nerves, and plain muscle-fibres.

The anterior surface of the stroma is covered with a layer of mesothelium continuous with that on the posterior surface of the cornea. Its posterior surface is covered with a double layer of epithelium continuous with that on the inner surface of the ciliary ring and processes; the epithelium of the iris differs, however, from that of the ciliary processes in that the posterior layer, as well as the anterior, is pigmented. This epithelium is the remains of the original edge of the optic cup and is thus homologous with the retina. It is from these layers that the sphincter and dilator muscles of the pupil are developed, the sphincter from the inner layer just where it turns round to become continuous with the outer layer, and the dilator from the anterior surface of the outer layer. The sphincter muscle is arranged in a circular manner round the pupil and by its contraction it reduces the size of that aperture; the dilator consists of fibres which radiate from the pupil to the periphery of the iris.

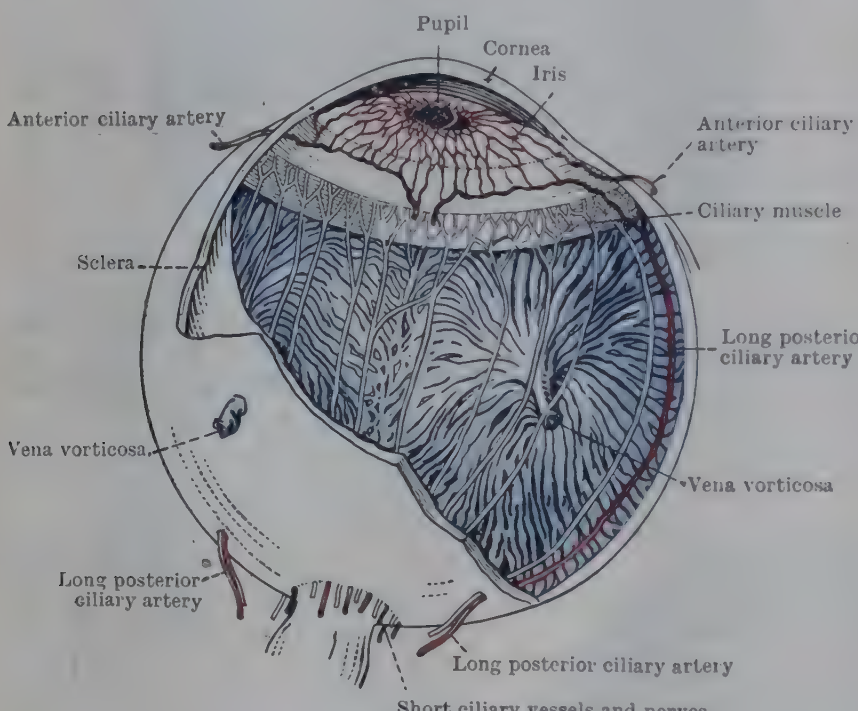


FIG. 988.—DISSECTION OF EYEBALL SHOWING VASCULAR COAT AND ARRANGEMENT OF CILIARY NERVES AND VESSELS.

Vessels and Nerves.—The **arteries** of the iris come from the *long posterior ciliary* and the *anterior ciliary* branches of the ophthalmic artery. There are two long posterior ciliary arteries, a medial and a lateral; they pierce the sclera by the sides of the optic nerve and run forwards between the sclera and the choroid as far as the periphery of the iris, where they are joined by the anterior ciliary arteries, which are usually arranged as two or three superior and two or three inferior branches; by the union of all these vessels a vascular circle is formed round the margin of the iris and is known as the *greater arterial circle* of the iris. From this circle branches pass forwards towards the pupil, round which a second circle is formed, called the *lesser arterial circle* of the iris. The **veins** of the iris proceed towards its periphery, and communicate with the veins of the ciliary processes and with the sinus venosus scleræ. The convergence of the blood-vessels towards the pupil gives a striated appearance to the anterior surface of the iris.

The **nerves** of the choroid and iris (Fig. 988) are derived from the *long* and *short ciliary* nerves. The former, two or three in number, are branches of the naso-ciliary nerve; the latter, from eight to fourteen in number, are derived from the ciliary ganglion. Piercing the sclera around the entrance of the optic nerve, the ciliary nerves run forward between the sclera and the choroid to the ciliary muscle, where they form a plexus from which fibres are distributed to the ciliary body, iris, and cornea. Ganglion-cells have been described along the course of the short ciliary nerves (Wolff, 1948). The sphincter of the pupil and the ciliary muscle are supplied by the oculomotor nerve, the dilator of the pupil by the sympathetic.

The **retina**, or nervous coat of the eyeball, is a soft, delicate membrane in which the fibres of the optic nerve are spread out. It is composed of two layers—an outer, pigmented layer, attached to the choroid; and an inner, nervous layer—the retina proper—in contact with the vitreous body. Expanding from the entrance of the optic nerve, the retina appears to end at the posterior edge of the ciliary body in a wavy border, called the **ora serrata** of the retina. But it is, in reality, only the nervous elements of the retina which come to an end at this line; the non-nervous elements, *i.e.*, the original two layers of the optic cup, are prolonged over the posterior surface of the ciliary body and iris (Fig. 985). The portion of the retina behind the ora serrata is termed the **optic part of the retina**, and its continuation over the ciliary body is called the *ciliary part of the retina*. The thickness of the retina gradually diminishes from 0·4 mm. near the entrance of the optic nerve, to 0·1 mm. at the ora serrata. It presents, just lateral to the posterior pole of the eye, a small, oval yellowish spot, called the **macula lutea**, of which the central part is depressed and named the **fovea centralis**. About 3 mm. to the nasal side and slightly above the level of the posterior pole there is a whitish disc which corresponds with the point of entrance of the optic nerve, and has a diameter of about 1·5 mm.; this is known as the *optic disc*, and its circumference is slightly raised to surround a central depression. The optic disc consists merely of nerve-fibres; it is insensitive to light, and is named the "blind spot". Around the optic disc and at the ora serrata the retina is more firmly adherent to the choroid than elsewhere.

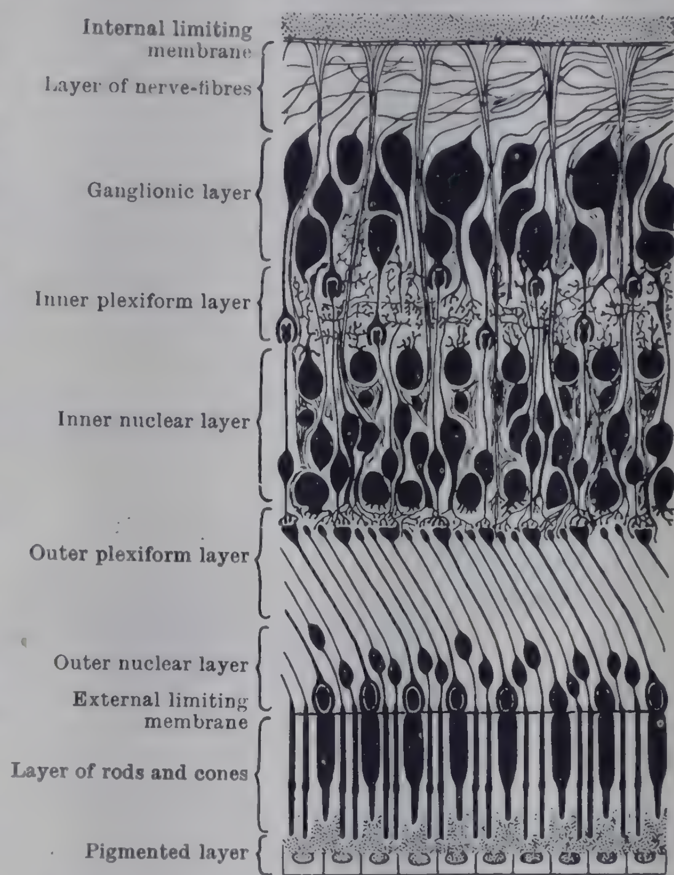


FIG. 989.—SCHEMATIC RECONSTRUCTION OF HUMAN RETINA. (After Polyak, 1941.)

The nervous layer of the retina is transparent during life, but becomes opaque and of a greyish colour soon after death. If an animal is kept in the dark before the removal of its eyeball, the retina presents a purple tinge owing to the presence of a colouring matter, named **rhodopsin** or **visual purple**, which is rapidly bleached on exposure to sunlight. The visual purple is absent from the macula lutea, and over a narrow zone, 3-4 mm. in width, near the ora serrata.

Structure (Figs. 989, 990).—The nervous elements of the retina are supported by non-nervous or **sustentacular fibres**, and are arranged in the following seven layers from within outwards, *i.e.*, from the vitreous body to the choroid :—

1. Layer of nerve-fibres.
2. Ganglionic or nerve-cell layer.
3. Inner plexiform layer.
4. Inner nuclear layer.
5. Outer plexiform layer.
6. Outer nuclear layer.
7. Layer of rods and cones.

An internal limiting membrane separates the layer of nerve-fibres from the vitreous body, and an external limiting membrane separates the layer of rods and cones from the outer nuclear layer; to the outer side of the layer of rods and cones is the pigmented layer of the retina.

1. **Layer of Nerve-Fibres.**—Most of these fibres are centripetal and are the axons of cells in the ganglionic layer; they reach the brain by means of the optic nerve, of

which they constitute the greater part. A few are centrifugal and are the axons of cells situated in the brain; they reach the retina by means of the optic nerve and ultimately ramify in the inner plexiform layer.

2. **Ganglionic or Nerve-Cell Layer.**—The cells of the ganglionic layer vary in size; they are oval or piriform in shape, and form a single layer, except near the macula lutea, where several strata are present and where the cells are smaller than towards the periphery of the retina. The axons of these nerve-cells pass into the nerve-fibre layer; the dendrites form arborizations in the inner plexiform layer with the axons of cells in the inner nuclear layer.

3. **Inner Plexiform Layer.**—This is constituted chiefly by the interlacement of the dendrites of the cells of the ganglionic layer with the axons of those of the inner nuclear layer.

4. **Inner Nuclear Layer.**—This consists of numerous cells which may be divided into (*a*) bipolar cells, (*b*) horizontal cells, and (*c*) amacrine cells. The nuclei of the sustentacular fibres also are present in this layer.

(*a*) The **bipolar cells** are by far the most numerous; they are fusiform in shape and are divided into rod-bipolars and cone-bipolars. The axons of each type arborize in

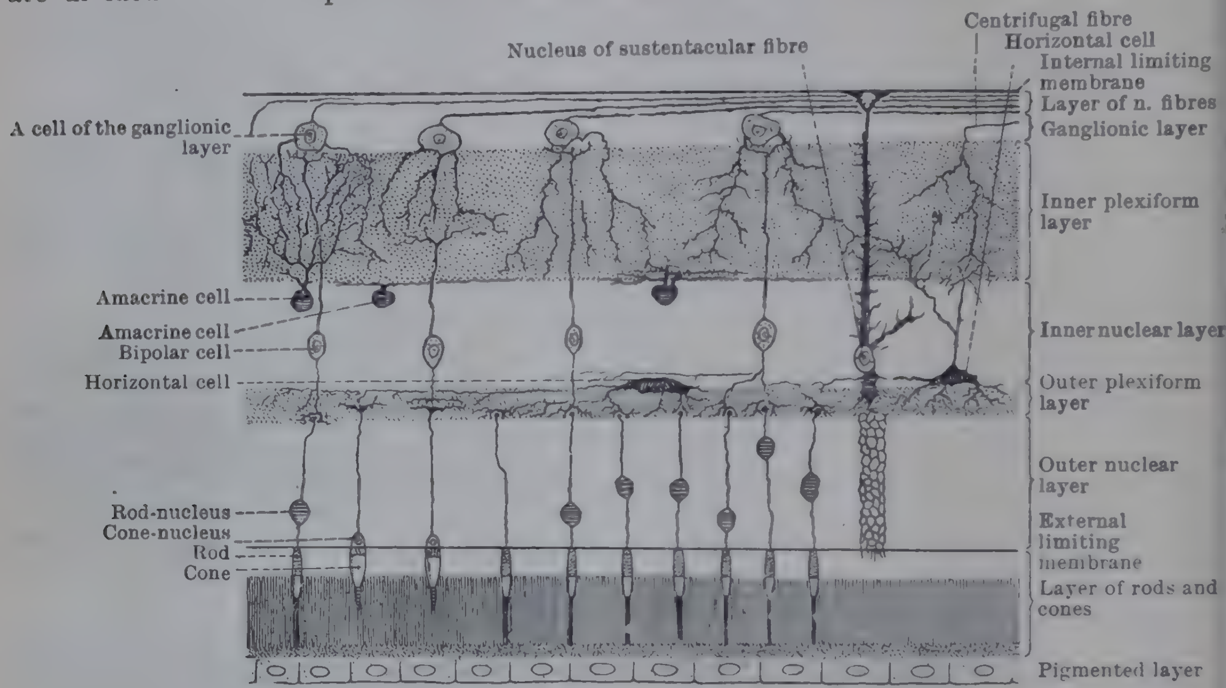


Fig. 990.—Plan of the Retinal Neurones. (After Cajal.)

the inner plexiform layer with the dendrites of the ganglion-cells; the dendrites of the rod-bipolars arborize around the ends of the rod-fibres, and those of the cone-bipolars around the ends of the cone-fibres.

(*b*) The **horizontal cells** serve to connect various rod-fibres or cone-fibres to each other. There are small and large horizontal cells: the small cells are flattened and star-like and lie on the borderline between the outer plexiform and the inner nuclear layers; they send a tuft of dendrites outwards, towards the bases of the cone-fibres; their axons are directed horizontally for a variable distance, and end around the bases of other cone-fibres. The large cells are irregular in shape and are placed to the inner side of the small cells; their processes make connexion between various rod-fibres. A third variety of horizontal cell sends short processes into the outer plexiform layer and a long process into the inner plexiform layer, where it arborizes around the end of a centrifugal fibre.

(*c*) The **amacrine cells** are so called on account of the absence of an axon. They are situated in the innermost part of the inner nuclear layer; their processes ramify in the inner plexiform layer, it may be in one stratum (stratified cells) or in several strata (diffuse cells).

5. **Outer Plexiform Layer.**—This is constituted by the interlacement of the dendrites of the bipolar and horizontal cells, just described, with the spherules of the rod-fibres and the ramifications of the foot-plates of the cone-fibres.

6. **Outer Nuclear Layer.**—This is chiefly made up of the nuclei of the rod-fibres and cone-fibres; the nuclei of the rod-fibres lie at different levels in the layer, but those of the cone-fibres are all situated close against the external limiting membrane of the retina. The rod-nuclei send a process into the outer plexiform layer where it ends in

a small rounded knob or spherule in association with the dendrites of rod-bipolar or of horizontal cells; the cone-nuclei send out processes which are similarly arranged but end in an expanded foot plate instead of in a spherule. From their opposite ends the rod-nuclei send outwards processes which pass through the external limiting membrane into the inner ends of the rods, whereas the cone-nuclei, since they are placed close alongside the external limiting membrane, become directly continuous through the membrane with the inner ends of the cones.

7. **Layer of Rods and Cones.**—The rods and cones are the special receptive endings of the **rod-cells** and **cone-cells**, each of which is thus composed of a cell-body, a nucleus, in the outer nuclear layer, an axon—the rod-fibre or cone-fibre—which ends in the outer plexiform layer and a dendrite, or receptor, the definitive rod or cone. At the fovea centralis, cones alone are present, and in this situation they are more slender and elongated than elsewhere; as one passes forwards over the retina from the macula the rods appear and gradually outnumber the cones; near the ora serrata cones are again the more numerous; over the retina as a whole the rods are nearly twenty times as many as the cones. The rods are slender, cylindrical, and of almost uniform diameter throughout their length; the cones are spindle-shaped and taper to a fine point at the outer end. Each rod and cone has an outer and an inner segment; the outer segment of a rod is slightly more slender than the inner and it contains the rhodopsin; the outer segment of a cone is far smaller than the inner and it rapidly tapers to a fine point. The inner segments of both rods and cones have an affinity for staining reagents, and each shows a homogeneous basal portion and a longitudinally striated outer part.

Pigmented Layer.—This consists of a single layer of cells which, on surface view, are hexagonal (Fig. 991), their outer flattened surfaces being firmly attached to the choroid. When seen in section the outer part of each cell shows a large oval nucleus which rests on the basal lamina of the choroid. When the eye is in the dark the pigment accumulates near the outer part of the cell, but when the eye is exposed to light the pigment streams in between the rods and cones.

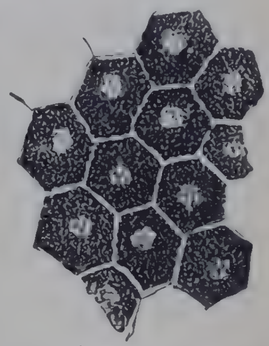


Fig. 991.—Pigmented Layer of Human Retina (viewed from the surface).

Sustentacular Fibres of Retina.—The cell-bodies of these fibres lie in the inner nuclear layer, and the fibres extend from the cell-body inwards and outwards through the whole thickness of the retina from the internal to the external limiting membrane; these two membranes are, in fact, formed by the fusion of the expanded inner and outer ends of the fibres. In the inner nuclear and inner plexiform layers the inwardly directed fibres give off numerous side-branches, and in the outer nuclear layer the outwardly directed fibres form a delicate network which lodges the rod- and cone-nuclei.

Structure of Macula Lutea and Fovea Centralis.—At the fovea centralis there are no rods; the cones are closely packed, and are narrower and more elongated in their outer segments than they are elsewhere in the retina. Since the macula lutea, and especially the fovea centralis, are the regions of distinct vision, the cones are here almost bare, and the light has to pass through only a comparatively thin layer of retinal tissue—the cone-fibres and cone-nuclei—on its way to the receptor cells. At the periphery of the macula there is a great increase in the thickness of the ganglionic layer and in that of the inner nuclear layer, but these layers rapidly come to an end as the fovea is approached. It thus happens that the cone-fibres must pass obliquely from the fovea centralis to reach the cone bipolars in the inner nuclear layer which are nearer the periphery of the macula, and the cone-nuclei and fibres thus form an obliquely directed stratum covering the cones in the region of the fovea. Furthermore, since the fovea is almost devoid of nerve-fibres, those fibres from other regions of the retina which, on their way to the disc, approach the fovea, must skirt round it and are thus found to be arranged in a series of arcs around the fovea as a centre. As the ora serrata of the retina is approached, there can be seen, in the adult, a series of cystic cavities in the plane of the ganglionic layer (Fig. 985); they cause this part of the retina to bulge in towards the vitreous body. The transition at the ora serrata from the pars optica retinæ to the pars ciliaris is a very sudden one, the thickness of the pars optica rapidly diminishing by a disappearance first of the rod and cone layer, then of the other nervous elements, so that in the pars ciliaris there is nothing left except a pigmented layer and a layer of undifferentiated columnar epithelium—in fact, the two original undifferentiated layers of the optic cup.

Vessels (Fig. 992).—The retina is supplied by the **arteria retinæ centralis**—a branch of the ophthalmic artery. It pierces the sheath of the optic nerve obliquely from below and appears at the centre of the optic disc. It then divides into an upper and a lower branch, each of which divides into a nasal branch and a temporal branch; the resulting four branches are named the *superior* and *inferior temporal arteries* and the *superior* and *inferior nasal arteries*. The temporal arteries pass laterally above and below the macula lutea, to which they give small branches;

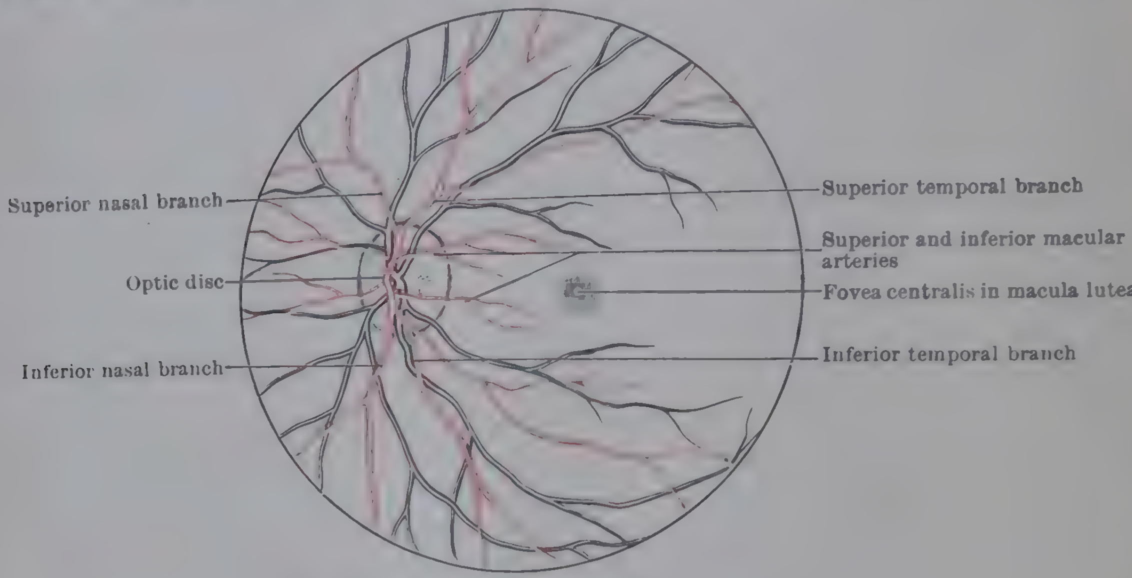


Fig. 992.—Blood-Vessels of Left Retina.

these do not, however, extend as far as the fovea centralis, which is devoid of blood-vessels. The macula receives also two small arteries (*superior* and *inferior macular*) directly from the stem of the arteria centralis. The larger vessels run in the layer of nerve-fibres; they do not anastomose with each other except through the capillary plexuses, which extend as far as the inner nuclear layer. The **veins** follow the course of the arteries; they have no muscular coats, but consist merely of a layer of endothelial cells outside which there is a perivascular lymph-sheath surrounded by delicate reticular tissue. The *central vein of the retina* joins the superior ophthalmic vein or may run direct to the cavernous sinus.

REFRACTING MEDIA

The light waves, on their way to the retina, must pass through a number of structures of different densities, *i.e.*, the cornea (already described), the aqueous humour, the lens, and the vitreous body. These constitute the **refracting media** of the eye.

Aqueous Humour and Chambers of Eye.—The **aqueous humour** is a fluid with a refractive index of 1·336, and consists of about 98 per cent of water, with 1·4 per cent of sodium chloride, and traces of albumin. It fills the **anterior** and the **posterior chambers** of the eye, which are the spaces in front of the lens, separated from each other by the iris and communicating with each other through the pupil. The anterior chamber communicates also with the spaces of the iridocorneal angle, and the posterior chamber with the zonular spaces.

Lens.—The lens lies in front of the vitreous body and behind the iris. It is a biconvex, transparent body (Fig. 980), enclosed in a thin, transparent, homogeneous *capsule*. The central points of its anterior and posterior surfaces are termed the **anterior** and **posterior poles**, and a line joining the poles is known as the **axis**; the peripheral circumference is named the **equator**. The axial measurement of the lens is 4 mm., and the transverse diameter from 9 to 10 mm. The anterior surface is in contact with the pupillary margin of the iris; the central part of that surface corresponds with the pupil; the peripheral part is separated from the iris by the aqueous humour of the posterior chamber. The posterior surface of the lens is more convex than the anterior, and occupies the hyaloid fossa of the vitreous body. The curvatures of the surfaces of the lens, especially that of the anterior surface, are constantly varying, during life, for the purpose of focusing near or distant objects on the retina.

substance of each tarsus there is a row of from 20 to 30 modified sebaceous glands named the **tarsal glands,** of which the openings have already been noticed. The lateral ends of the tarsi unite to form the *lateral palpebral ligament,* which fixes them to a small tubercle on the orbital surface of the zygomatic bone; their medial ends join to form the *medial palpebral ligament,* which is attached to the frontal process of the maxilla immediately in front of the lacrimal fossa.

The eyelids are further strengthened by a membranous sheet, named the **palpebral fascia,** which extends into them from the orbital margin, along which it is continuous with the periosteum. In the upper eyelid the fascia fuses with the superficial lamella of the aponeurosis of the levator palpebræ superioris; in the lower eyelid it is thin, and blends with the anterior surface of the inferior tarsus.

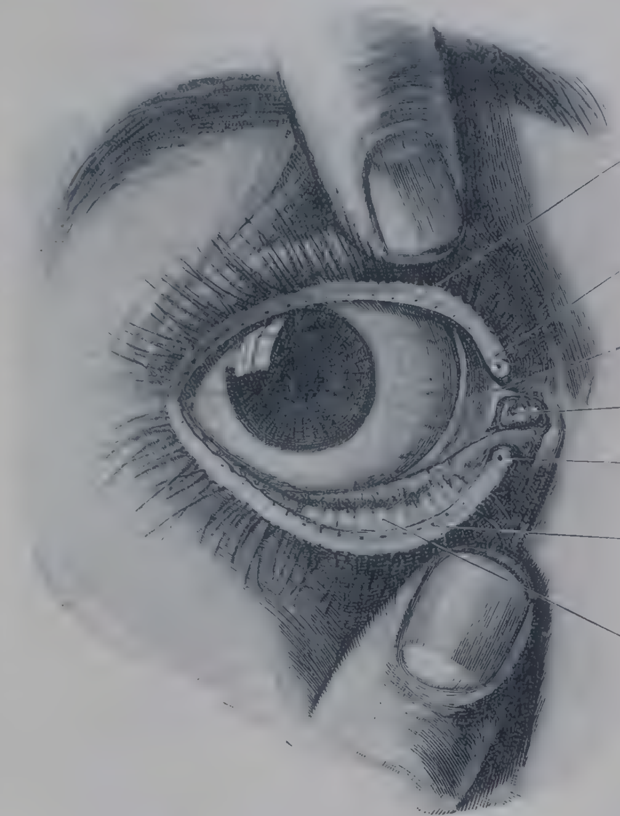


FIG. 996.—EYE WITH LIDS SLIGHTLY EVERTED TO SHOW STRUCTURES AT THE MEDIAL ANGLE.

The skin of the eyelids is thin, and is continuous, at their free margins, with the palpebral conjunctiva. The subcutaneous tissue is loose and devoid of fat, and in it are found the fibres of the orbicularis oculi muscle—a small separate slip of which occupies the margin of the lids behind the eyelashes.

Behind and between the roots of the eyelashes there are two or three rows of modified sweat-glands termed the **ciliary glands** (p. 1157).

H. Müller (1859) described a layer of plain muscle in each eyelid: in the upper lid it extends from the deep lamella of the aponeurosis of the levator palpebræ superioris to the superior tarsus; in the lower lid it arises from the fascial sheath of the inferior oblique and divides into two lamellæ, one ending in the ocular part of the conjunctiva, the other in the lower eyelid.

The **eyelashes** are short curved hairs, three or four rows deep, which project from the free margins of the eyelids. In the upper eyelid they are longer and more numerous than in the lower lid.

Conjunctiva.—The conjunctiva is the membrane which clothes the deep surfaces of the eyelids and is reflected from them on to the front of the eyeball; the lines of reflexion are known as the *superior* and *inferior* **conjunctival fornices.** The palpebral part of the conjunctiva is highly vascular, is covered with a stratified columnar epithelium and is closely adherent to the tarsi. The ocular part is thinner and is transparent, so that the sclera and cornea can be seen through it. It is covered with a stratified squamous epithelium. It covers the sclera but is not adherent to it, for the two are separated by the thinned-out fascial sheath of the eyeball; at the sclero-corneal junction the sheath comes to an end and the conjunctiva is continued forwards over the cornea, to which it is firmly adherent, and, in fact, is represented merely by the epithelium of the cornea.

Vessels and Nerves.—The chief **arteries** of the eyelids are the superior and inferior palpebral branches of the ophthalmic artery; they pierce the palpebral fascia above and below the medial palpebral ligament and turn laterally in the corresponding lid near its free margin. The upper lid receives branches from the supra-orbital and supratrochlear arteries also, and the lower lid from the facial artery. The **veins** are arranged in two sets: (*a*) *subconjunctival,* which open into the muscular tributaries of the ophthalmic veins, and (*b*) *pretarsal,* which open into the anterior facial and superficial temporal veins. The **lymph-vessels** form networks in front of and behind the tarsal plates. There are at least four main vessels in each eyelid, two coursing medially, and two laterally. Those directed medially ultimately join to form a vessel that accompanies the anterior facial vein and drains into the submandibular glands. The lateral vessels join to

form a trunk directed to the superficial parotid lymph-glands (Burch, 1939). The lymph is drained chiefly into the parotid lymph-glands, but partly, by vessels which accompany the anterior facial vein, into the submandibular lymph-glands. The **sensory nerves of the eyelids** are the supra-orbital and supratrochlear for the upper lid, and the infra-orbital for the lower lid. The region of the lateral angle is supplied by the lacrimal nerve, and that of the medial angle

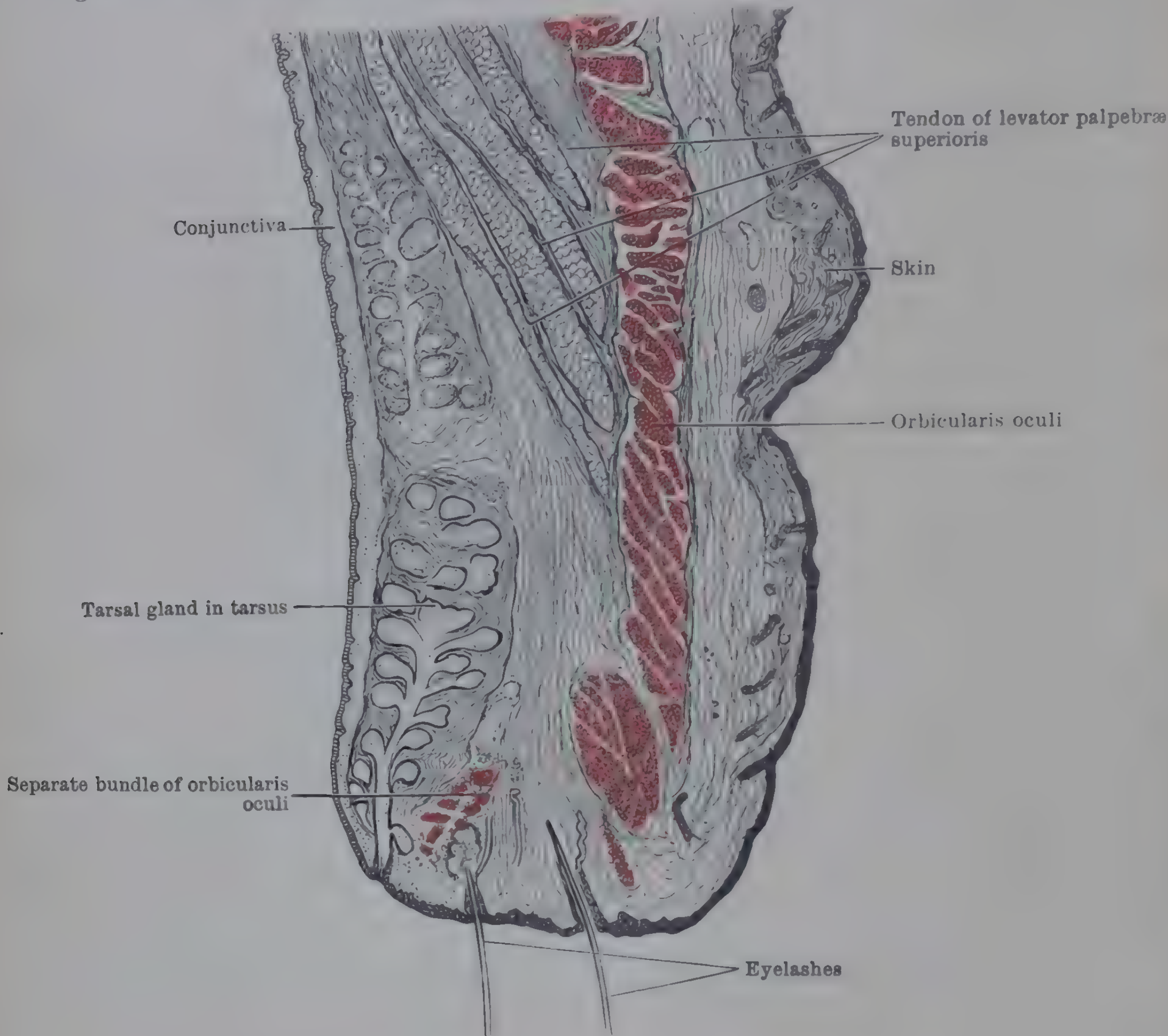


FIG. 997.—DIAGRAMMATIC SAGITTAL SECTION THROUGH UPPER EYELID.

by the infratrochlear. The levator palpebræ superioris muscle is supplied by the oculomotor nerve, and the plain muscle-fibres of the eyelids by the sympathetic.

S.N. LACRIMAL APPARATUS

The **lacrimal apparatus** consists of: (1) the lacrimal gland, which secretes the lacrimal fluid; and (2) the lacrimal canaliculi, lacrimal sac, and naso-lacrimal duct, through which the fluid is conveyed to the nasal cavity. When the secretion of lacrimal fluid is excessive, it overflows as *tears*.

The **lacrimal gland** (Fig. 999) is about the size and form of an almond, and is situated in the upper and lateral part of the orbit. It occupies the fossa on the medial surface of the zygomatic process of the frontal bone, and extends down almost as far as the lateral angle of the eye; from this point a continuation of the gland, called the **palpebral process**, projects upwards, backwards, and medially in the root of the upper eyelid and along the line of the superior conjunctival fornix. Occasionally the palpebral process projects also in a downward and medial direction beyond the lateral angle of the eye, and for a considerable distance along the root of the lower lid. It is only at its lateral end that the palpebral process is connected with the main gland, and the two are separated from each other by the expanded insertion of the levator palpebræ superioris, which, until it is turned aside, completely hides the process. The **ducts** of the gland vary in number from three to nine, and open at the upper and lateral part

of the superior fornix of the conjunctiva. In close relation with the conjunctival fornices (especially the superior fornix) there are numerous small *accessory*

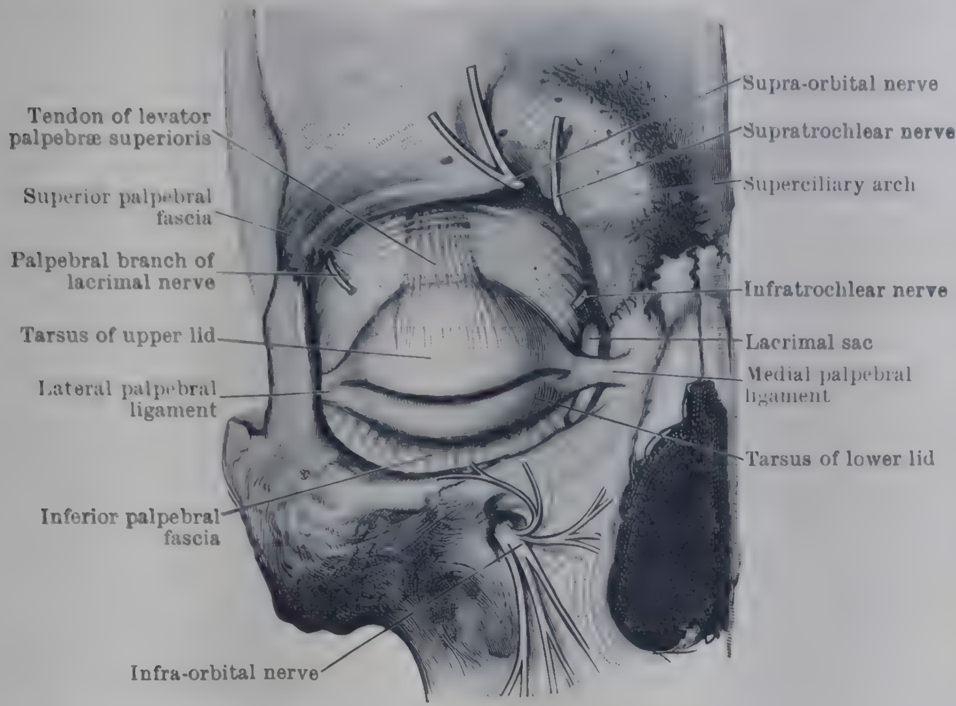


FIG. 998.—DISSECTION OF RIGHT EYELID. The orbicularis oculi has been removed.

lacrimal glands, the secretion from which may serve to moisten the conjunctiva after the extirpation of the principal gland and its process.

Structure, Vessels, and Nerves.—The structure of the lacrimal gland resembles that of the parotid gland. It is supplied by the sympathetic, lacrimal, and facial **nerves**, and by the lacrimal **artery**; its **veins** open into the ophthalmic vein.

The **lacrimal canaliculi** (Fig. 999), one in each eyelid, begin in minute orifices, termed *puncta lacrimalia*, situated on the summit of the lacrimal papillæ; each

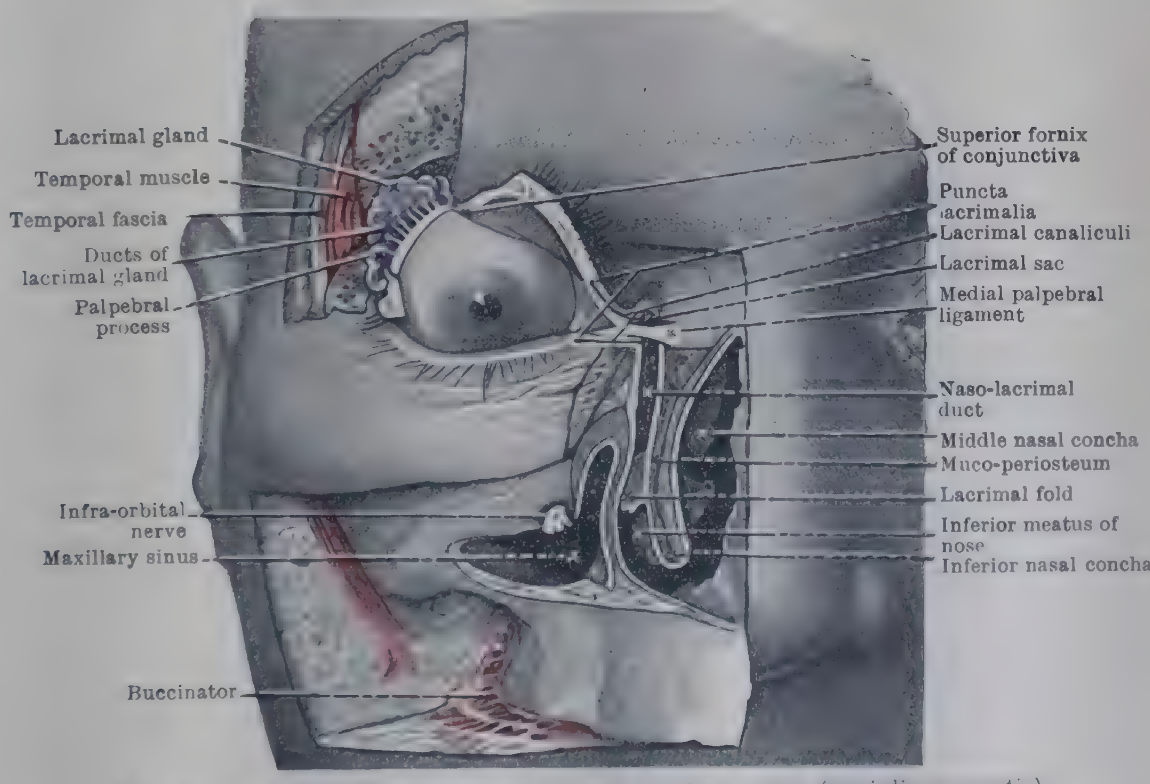


FIG. 999.—DISSECTION TO SHOW THE LACRIMAL APPARATUS (semi-diagrammatic).

canaliculus is about 10 mm. long. From the puncta lacrimalia they pass medially above and below the lacus lacrimalis; the superior at first ascends for a short distance and then inclines downwards; the inferior descends for a short distance

and then runs horizontally; where the canaliculi change their direction they are dilated into *ampullæ*. The two canaliculi open close together into the lateral and front part of the lacrimal sac, a little above its middle; sometimes they open into a pouch-like dilatation of the sac. The canaliculi are lined with stratified epithelium, and are surrounded by the lacrimal part of the orbicularis oculi muscle.

The lacrimal sac and naso-lacrimal duct together form the passage by which the lacrimal fluid is conveyed from the lacrimal canaliculi to the nasal cavity.

The **lacrimal sac** (Figs. 998, 999) is the upper, blind part of the naso-lacrimal duct, and it occupies the lacrimal fossa on the medial wall of the orbit. A sheet of fascia, continuous with the orbital periosteum, stretches from the anterior to the posterior edge of the lacrimal fossa and thus covers the lateral side of the lacrimal sac. The medial palpebral ligament and some of the fibres of the orbicularis oculi muscle lie in front of the upper half of the lacrimal sac; the lacrimal part of this muscle lies behind and to the lateral side of the sac; the lower half of the sac is below these two structures.

The **naso-lacrimal duct** (Fig. 999) is about 18 mm. long, and has a diameter of from 3 to 4 mm. Rather narrower in the middle than at its ends, it is directed downwards and slightly backwards and laterally. It opens into the inferior meatus of the nose towards its anterior end, about 30 mm. behind the nostril. The opening is very variable in form and position, and is frequently guarded by a fold of mucous membrane termed the *lacrimal fold* (Fig. 999). The duct is lined with columnar epithelium.

Vessels and Nerves.—The arteries are derived from the palpebral arteries, from the terminal branch of the facial artery, and from the infra-orbital artery. The **veins** of the naso-lacrimal duct are large, and form a well-marked plexus. The **nerves** of the lacrimal canaliculi and sac are derived from the infratrochlear nerve; the lower part of the naso-lacrimal duct receives a branch from the anterior superior dental nerve.

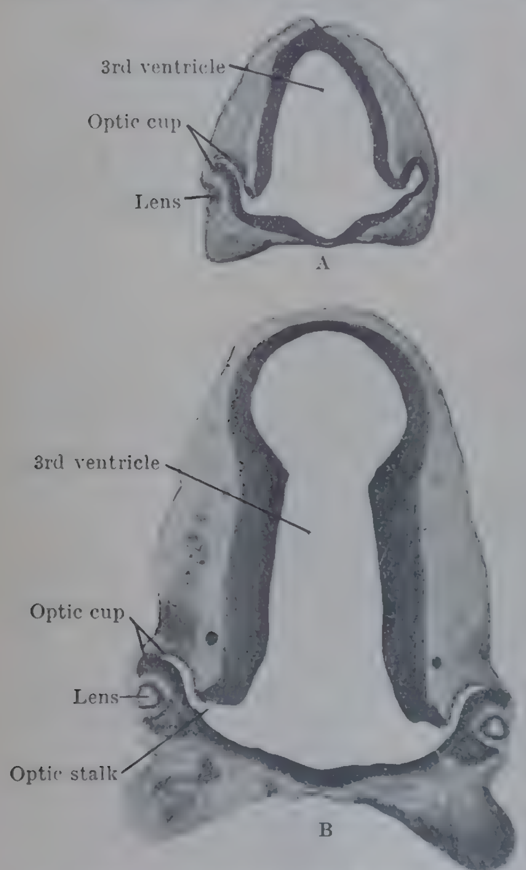


Fig. 1000.—Sections of Developing Eye of Human Embryos. ×20
A. 5 mm. B. 10 mm

Development of Eye

The *retina* and *optic nerve* are developed from a hollow outgrowth of the fore-brain termed the **optic vesicle**. The vesicle extends towards the side of the head, and its connexion with the brain is gradually elongated to form the **optic stalk**. The ectoderm towards which the optic vesicle is growing becomes thickened, invaginated, and finally cut off as a hollow island of cells named the **lens-vesicle**. The lens-vesicle indents the lateral and lower part of the optic vesicle, converting it into a cup (**optic cup**), which thus consists of two layers of cells continuous with each other at the margin of the cup. The inner layer is the thicker, and it becomes the nervous layer of the retina, while the outer forms the pigmented layer. The rim of the optic cup grows forwards in front of the equator of the lens to become the pigmented part of the iris, which is thus in reality composed of two layers, and it bounds the future pupil. The indentation that forms the optic cup extends also along the postero-inferior aspect of the optic stalk in the form of a groove termed the **choroidal fissure** (Fig. 1001). Through this fissure mesoderm passes inwards between the lens and the retina to form a part of the vitreous body, and the *arteria retinæ centralis* also becomes enclosed in it and so gains its future position in the optic nerve. This artery is prolonged forwards from the optic disc through the vitreous body, as a cone of branches, as far as the back of the lens. By the fifth or sixth month all these branches have disappeared except one—the **hyaloid artery**—which persists until the last month of intra-uterine life, when it also atrophies, leaving only the **hyaloid canal** (and its corkscrew-like anterior end adherent to the back of the lens) to indicate its position.

The *vitreous body* is developed between the optic cup and the lens, and is derived partly from ectoderm and partly from mesoderm. It consists primarily of a series of fine protoplasmic

fibres which project from the cells of the retinal layer of the cup and from the back of the lens and form a delicate reticular tissue. At first the fibres are seen in relation to the whole of the optic cup, but later they become more condensed where they form the *ciliary zonule* and the walls of the *hyaloid canal*, though they can still be seen throughout the whole of the vitreous in the adult. The mesodermal element of the vitreous body is derived from the mesoderm which enters the optic cup through the choroidal fissure.

The *lens*, at first in contact with the ectoderm from which it is derived, is soon separated from it by mesoderm, and is then a rounded vesicle with epithelial walls. The outer or superficial wall remains as a single layer of cells—the anterior epithelium of the adult lens. The cells of the inner or deep wall become elongated into lens-fibres, and at the same time they grow forward into the cavity of the lens-vesicle, which thus becomes obliterated. The elongation of the cells into lens-fibres is greatest at the centre of the lens, while near the equator the fibres are shorter, and here the gradual transition between the anterior epithelium and the lens-fibres is seen (Fig. 993). The lens becomes enveloped in a vascular tunic which receives its vessels from

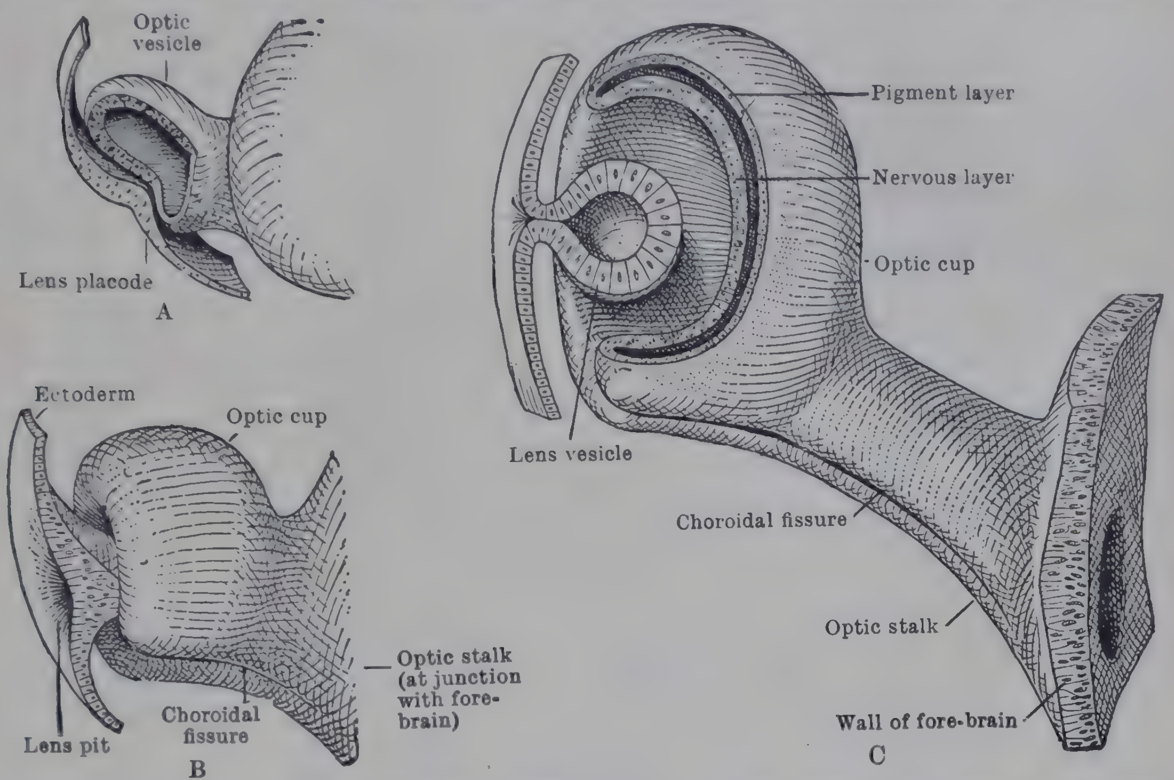


FIG. 1001.—MODELS OF DEVELOPING HUMAN EYE. ×100. (From Arey's *Developmental Anatomy*, after Ida Mann, 1928.) The lens has been sectioned, and the optic vesicle has been partly cut away in A and C.

A, 4·5 mm. embryo ; B, 5·5 mm. ; C, 7·5 mm.

the arteria retinæ centralis and from the vessels of the iris. The front part of this tunic forms the pupillary membrane which disappears before birth (p. 1168).

The optic stalk, at first hollow, becomes solid by the thickening of its walls, and, acquiring nerve-fibres, is transformed into the *optic nerve*. The further development of the retina resembles, in certain respects, that of the spinal cord.

In the first stage in the development of the retina there are present an inner marginal layer and an outer neuro-epithelial layer ; that is followed by the formation of an inner and outer neuroblastic layer owing to a migration of cells from the primitive neuro-epithelial layer to the marginal layer. The new inner neuroblastic layer ultimately gives rise to the ganglion-cells, the amacrine cells, and the cells of the sustentacular fibres, while the outer neuroblastic layer furnishes the bipolar and the horizontal cells of the inner nuclear layer, and the nuclei of the rods and cones. It will thus be seen that the inner nuclear layer of the fully formed eye, comprising amacrine, sustentacular, bipolar, and horizontal cells, is a composite structure derived in part from the inner primitive neuroblastic layer and in part from the outer layer (Mann, 1928).

The condensed mesoderm around the optic cup becomes the *sclera* and *choroid*. The mesoderm in front of the lens becomes divided by a cleft into a thick anterior layer and a thin posterior layer. The cleft becomes the *anterior chamber* of the eye ; the anterior mesodermal layer becomes the substantia propria of the *cornea* ; the posterior mesodermal layer forms the stroma of the *iris* and anterior part of the temporary vascular tunic of the lens. The deep surface of the iris is ectodermal in origin and is derived from the forward growth of the edge of the optic cup ; from this ectodermal source the muscular tissue also of the iris is derived.

The **eyelids** arise as folds above and below the cornea, each being covered on both surfaces with ectoderm. By the third month the edges of the folds meet and unite, the eyelids being only permanently opened shortly before birth ; in many animals they are not opened until after birth. The ectoderm forms the epithelium of the *conjunctiva* and the *epithelium of the cornea*. It is also invaginated at the margins of the eyelids to form the *hair-follicles* and the lining cells of the

tarsal and *ciliary glands*, and at the superior conjunctival fornix to form the lining cells of the ducts and alveoli of the *lacrimal gland*.

The **lacrimal sac** and **naso-lacrimal duct** are developed along the line of the furrow which separates the maxillary process from the lateral nasal process. The furrow is lined with ectodermal cells, and these cells, after the meeting and fusion of the lips of the furrow, proliferate and form a solid rod which is embedded in the mesoderm. By the breaking down and disintegration of its central cells, the rod becomes hollowed out to form the lacrimal sac and the naso-lacrimal duct—the lower end of the duct remaining closed until near the end of intra-uterine life. The **lacrimal canaliculi** develop as secondary buds of cells which extend sidewards from the upper end of the solid rod, and subsequently undergo canalization. The **lacrimal caruncle** is formed from a small part of the margin of the lower eyelid which is cut off by the growth of the inferior lacrimal canaliculus.

For further information, consult Ida Mann's *Development of the Human Eye* (1928).

ORGANS OF HEARING AND EQUILIBRATION

The **ear** or **auditory organ** (Fig. 1002) consists of three portions—external, middle, and internal—and it is customary to speak of these as the external, middle, and internal ear. The peripheral terminations of the cochlear and vestibular divisions of the auditory nerve are distributed within the internal ear, which contains not only the essential peripheral organ of hearing but also the peripheral organs of equilibration. The monograph of Bast & Anson (1949) gives the most recent detailed account of these organs, including their development.

EXTERNAL EAR

The **external ear** includes—(*a*) the auricle, attached to and projecting from the side of the head; and (*b*) the external auditory meatus, leading inwards from the most depressed part of the auricle to the tympanic membrane.

Auricle

The **auricle** (Fig. 1003) forms an angle of about 30° with the side of the head, though this varies considerably in different persons. Its lateral surface is irregularly concave, but has several well-marked elevations and depressions. The deepest of the depressions — the **concha** — is situated near the middle of the auricle; it is divided by a ridge, called the **crus of the helix**, into an upper and a lower portion; the lower portion is the larger and leads into the external auditory meatus. Anteriorly, the crus helicis is continuous with the **helix** or margin of the auricle, which is incurved in the greater part of its extent, and is directed at first upwards, and then backwards and downwards, to become gradually lost in the upper part of the lobule. Near the point where the helix begins to descend, a small **tubercle** is often seen. In front of the descending part of the helix there is a second elevation, called the **antihelix**, which bifurcates at its upper end into two **crura** that enclose a

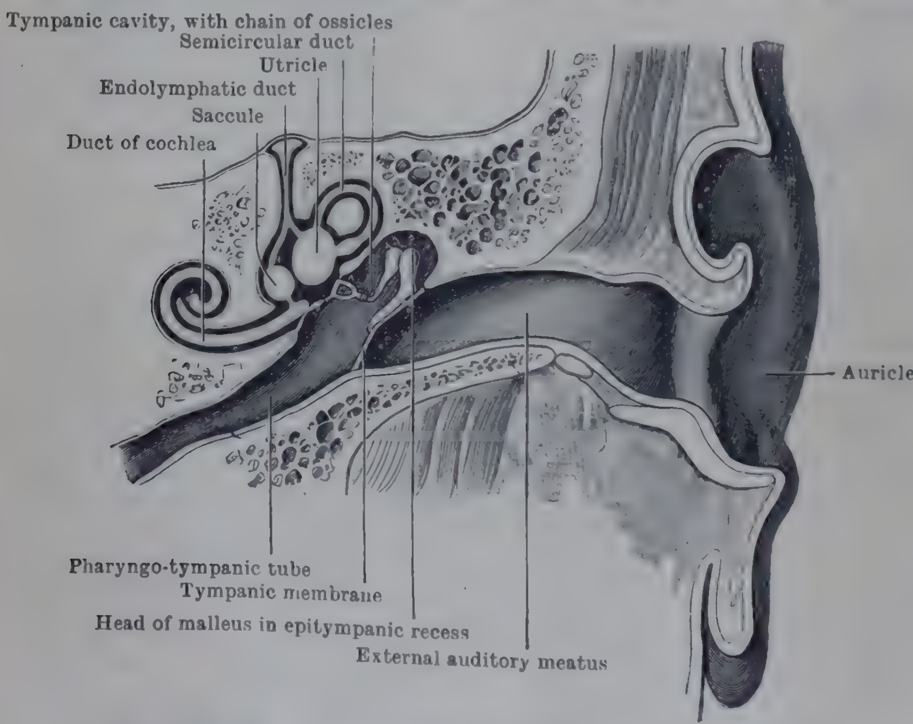


Fig. 1002.—Diagrammatic Section of Organ of Hearing.

depression called the **triangular fossa**. The elongated furrow between the helix and antihelix is named the **scaphoid fossa**. The concha is overlapped in front by a tongue-like process called the **tragus**, and below and behind by a triangular projection called the **antitragus**; the notch, directed downwards and forwards between those two processes, is named the **incisura intertragica**. The tragus is often partially divided into two small tubercles, and it is separated from the crus of the helix by the **anterior notch of the auricle**. The **lobule** is situated below the incisura intertragica, and is the most dependent part of the auricle; its shape and degree of development are subject to much variation.

The medial or cranial surface of the auricle presents elevations corresponding to the depressions on its lateral surface, *e.g.*, the **eminence of the concha**, the **eminence of the scaphoid fossa**, the **eminence of the triangular fossa**, etc.

The auricle, usually smaller and more finely modelled in women than in men, presents great variations in size and shape in different persons. In the new-born child its length is about one-third of that of the adult; in old age it increases both in length and breadth.

The **tubercle of the ear** is a triangular prominence which projects usually forwards from the helix. It is more often present in men than in women. Its significance, which was recognized by Charles Darwin, is that it probably represents the point of the ear of lower animals; it is well seen in the macaque monkey, the ear of which closely resembles that of a human fœtus of the sixth month.

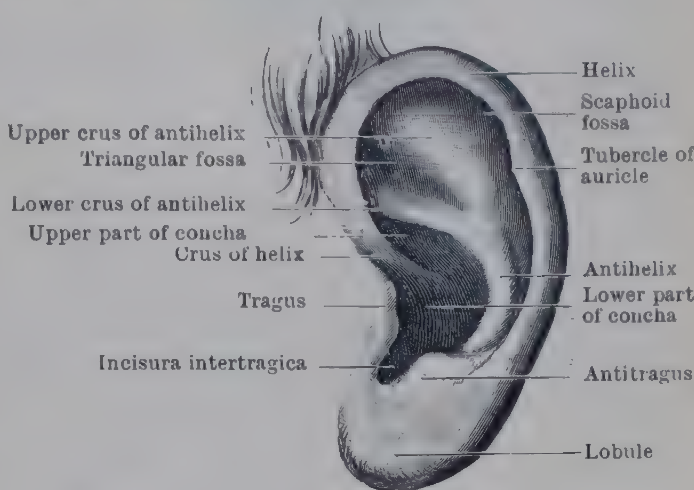


Fig. 1003.—Lateral Surface of Left Auricle.

Structure of Auricle.—The skin of the auricle is thin and smooth, and is prolonged, in the form of a tube, as a lining to the external auditory meatus. On the lateral surface of the auricle, it adheres firmly to the subjacent perichondrium. Strong hairs, named **tragi**, are often present in men on the tragus and antitragus, and also in the incisura intertragica; soft downy hairs are found over the greater part of the auricle and point towards the tubercle. Sebaceous glands, present on both surfaces of the auricle, are most numerous in the concha and triangular fossa. Sweat-glands are found on the medial surface; few or none on the lateral surface.

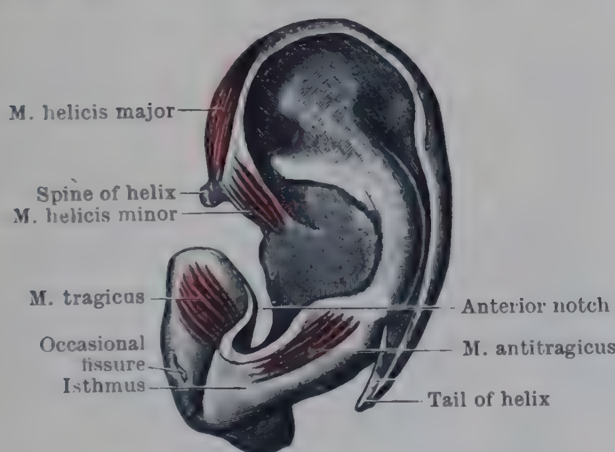


Fig. 1004.—Lateral Surface of Cartilage of Left Auricle, with Muscles.

The greater part of the auricle is supported by yellow fibro-cartilage; the cartilage is, however, absent from the lobule, which is composed of fat and fibro-areolar tissue. When laid bare, the cartilage (Figs. 1004, 1005) presents, in an exaggerated form, all the inequalities of the auricle. It is continuous medially with the cartilaginous part of the external auditory meatus through a narrow **isthmus**, 8 or 9 mm. in breadth, which corresponds laterally with the deepest part of the incisura intertragica. The most anterior part of the cartilage of the helix projects forwards as the **spine**, and the most inferior part is called the **tail** of the helix. Small clefts are found here and there in the cartilage, and one of these is shown in Fig. 1004.

Ligaments of Auricle.—The cartilage of the auricle is fixed to the temporal bone by two extrinsic ligaments—an *anterior*, stretching from the spine of the helix and the tragus to the zygomatic process, and a *posterior*, stretching from the eminence of the concha to the mastoid part of the bone. Small intrinsic ligaments pass between individual parts of the auricle.

Muscles of Auricle.—The muscles of the auricle are divisible into two groups, *extrinsic* and *intrinsic*. The extrinsic muscles connect the auricle to the skull and scalp, and are described in the Section on Myology. The intrinsic muscles are confined to the auricle and are six in number, four on its lateral surface and two on its cranial or medial surface. They are mere vestiges and have little or no action.

(*a*) *On the lateral surface* (Fig. 1004)—

1. The **helicis major** muscle passes upwards from the spine of the helix along the ascending part of the helix. 2. The **helicis minor** muscle covers the crus of the helix. 3. The **tragicus** muscle runs vertically over the greater part of the tragus. Some of its fibres may be prolonged upwards to the spine of the helix and constitute the **pyramidalis** muscle. 4. The **antitragicus** muscle covers the antitragus and runs obliquely upwards and backwards to the antihelix and tail of the helix.

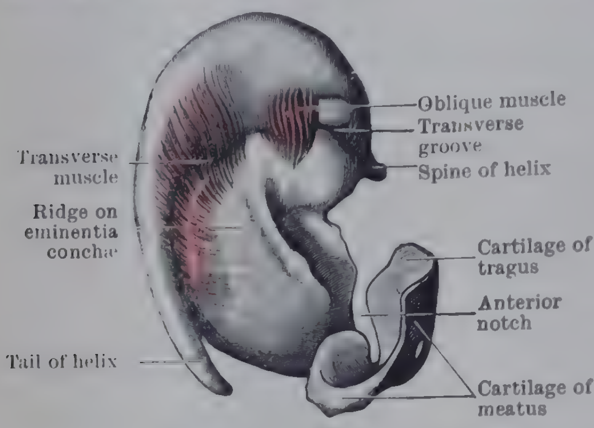


Fig. 1005.—Medial Surface of Cartilage of Left Auricle, with Muscles.

(*b*) *On the medial surface* (Fig. 1005)—

1. The **transverse muscle of the auricle** consists of scattered fibres which stretch from the eminence of the lower part of the concha to the eminence of the scaphoid fossa. 2. The **oblique muscle of the auricle** comprises a few fasciculi which run obliquely or vertically from the eminence of the triangular fossa to the eminence of the upper part of the concha.

Vessels and Nerves.—The **arteries** are derived—(*a*) from the superficial temporal artery, which sends two or three branches to the lateral surface; and (*b*) from the posterior auricular artery, which gives three or four branches to the medial surface. From the branches of the posterior auricular artery two sets of twigs pass to the lateral surface, one turning round the free margin of the helix, and the other passing through small fissures in the cartilage. The **veins** from the lateral surface open into the superficial temporal vein; those from the medial surface chiefly join the posterior auricular vein, but some communicate with the mastoid emissary vein. The **lymph-vessels** take three directions, viz.: (*a*) forwards to the parotid lymph-glands, and especially to the gland in front of the tragus; (*b*) downwards to the lymph-glands that lie alongside the external jugular vein, and to the lymph-glands under the sterno-mastoid muscle; and (*c*) backwards to the mastoid lymph-glands.

The **nerves** are motor and sensory. The muscles are supplied by the facial nerve. The skin receives its sensory nerves from—(*a*) the great auricular nerve, which supplies nearly the whole of the medial surface, and sends filaments in company with the branches of the posterior auricular artery to the lateral surface; (*b*) the auriculo-temporal nerve, which supplies the tragus and ascending part of the helix; (*c*) the lesser occipital nerve, which sends a branch to the upper part of the medial surface.

External Auditory Meatus

The **external auditory meatus** (Figs. 1002, 1006) is the passage that leads from the concha to the tympanic membrane. Its length, measured from the bottom of the concha, is 24 mm.; from the margin of the tragus it is 35 mm. On account of the obliquity of the tympanic membrane the anterior and inferior walls of the meatus are longer than the posterior and superior walls. The meatus consists of a lateral, cartilaginous part, about 8 mm. in length; and a medial, bony part about 16 mm. in length. The entire meatus makes a sinuous bend (Fig. 1002) and may be divided into three portions—lateral, intermediate, and medial; each is directed medialwards, but, in addition, the lateral part is inclined forwards and slightly upwards; the intermediate, backwards; and the medial—the longest—forwards

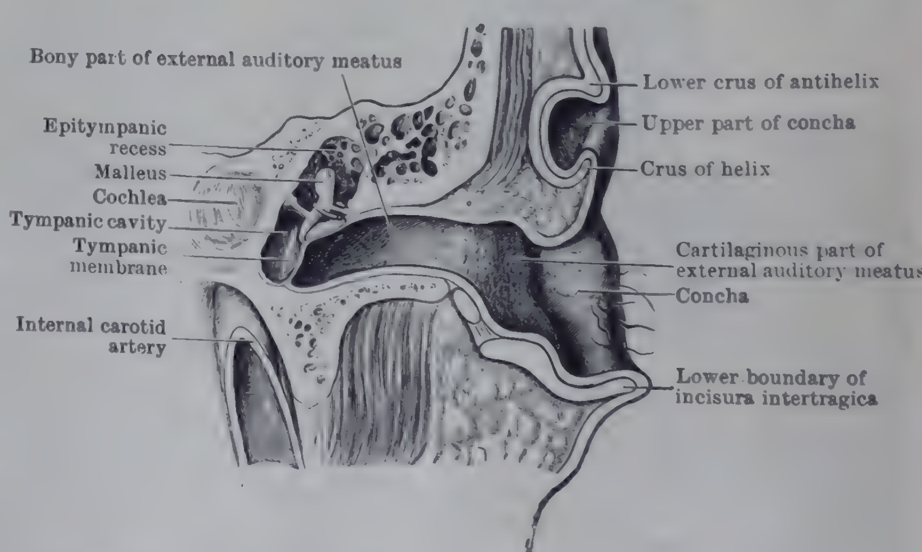


Fig. 1006.—Coronal Section of Right Ear: Anterior Half of Section, viewed from behind.

and slightly downwards. The passage is not circular in transverse section but elliptical—its greatest diameter being directed from above downwards and backwards. It is widest at its lateral end and becomes slightly narrower at the medial end of the cartilaginous part; it is expanded in the lateral portion of the bony part, and constricted near its medial end; this, the narrowest part, is named the **isthmus**, and its outer end is 20 mm. distant from the bottom of the concha. The medial end of the meatus is the most nearly circular part and is closed by the tympanic membrane.

The lumen of the cartilaginous part is influenced by the movements of the mandible, being widened when the mouth is opened. A large part of the head of the mandible lies in front of the bony part of the meatus, and a small portion lies in front of the cartilaginous part also; between this part of the meatus and the mandible there is lodged a process of the parotid gland. Posteriorly the bony portion of the meatus is related to the mastoid process.

Structure of Meatus.—The cartilage of the meatus does not form a complete tube but is folded to form a groove, opening upwards and backwards, the margins of the groove being connected with each other by fibrous tissue. The medial end of the cartilaginous part of the meatus is firmly fixed to the lateral margin of the bony part; its lateral end is continuous with the cartilage of the tragus. Two fissures exist in the anterior portion of the cartilaginous part, and are filled with fibrous tissue. In the lateral part of the meatus the cartilage forms about three-fourths of the circumference of the tube; but near the medial end it forms only a part of the anterior and lower boundaries.

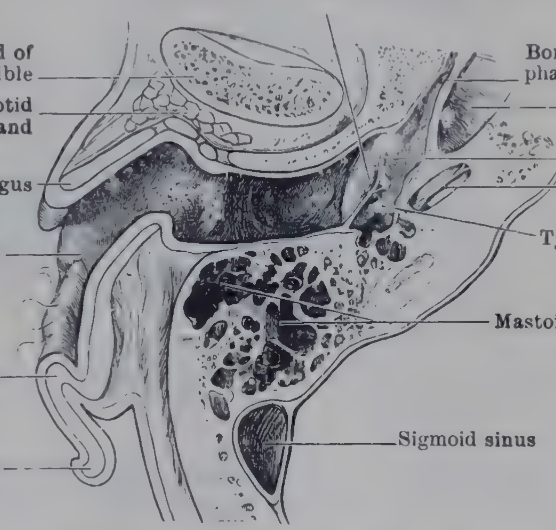


Fig. 1007.—Horizontal Section through Right Ear; Upper Half of Section, viewed from below.

The bony part is described on pp. 164, 165. In the new-born child it is represented only by an incomplete ring of bone—the **tympanic ring**—together with a small portion of the squamous part of the temporal bone, which articulates with the ring and completes it superiorly (Fig. 188, p. 224). Along the concavity of the ring there is a groove, called the **tympanic groove**, in which the circumference of the tympanic membrane is fixed. On the medial surface of the anterior part of the ring, a little below its free end, a groove, called the **malleolar sulcus**, is directed downwards and forwards. It transmits the anterior process and the anterior ligament of the malleus, the tympanic artery, and the chorda tympani nerve. A **fibrous tympanic plate** (Symington, 1885) intervenes between the tympanic ring and the cartilage of the meatus, and into that plate the bony ring extends. The bony outgrowth does not, however, proceed uniformly from the whole circumference of the ring but occurs most rapidly from its anterior and posterior parts, with the result that when the two outgrowths fuse, at about the end of the second year of life, a gap is left between them in the floor of the meatus; this gap is usually closed by the fifth year, but may persist in the adult skull.

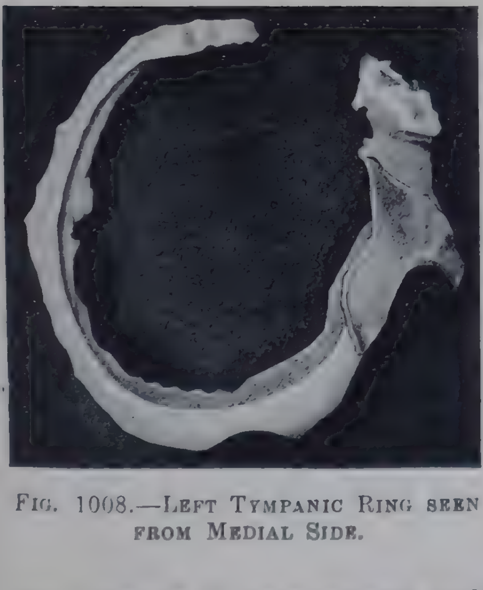


Fig. 1008.—Left Tympanic Ring seen from Medial Side.

The lumen of the meatus in the new-born child is extremely small: its lateral part is funnel-shaped; its medial part is a mere slit, bounded below by the fibrous tympanic plate and above by the tympanic membrane. Since there is no bony external auditory meatus the tympanic membrane is close to the surface, and is on the inferior rather than the lateral surface of the skull.

The meatus is lined with skin which covers also the lateral surface of the tympanic membrane. The skin is thick in the cartilaginous part, and contains fine hairs and sebaceous glands; the

glands extend for some distance along the postero-superior wall of the bony part of the meatus. In the subcutaneous tissue of the cartilaginous part there are numerous enlarged sweat-glands (p. 1157); they are named **ceruminous glands** because they secrete the ear-wax or cerumen.

Vessels and Nerves.—The **arteries** of the external auditory meatus are branches of the posterior auricular and superficial temporal arteries, and of the deep auricular artery, which distributes some minute twigs to the tympanic membrane also. The **veins** open into the maxillary and external jugular veins, and into the pterygoid venous plexus. The **lymph-vessels** end like those of the auricle. **Sensory nerves** are supplied to the meatus by the auriculo-temporal nerve and by the auricular branch of the vagus nerve.

MIDDLE EAR OR TYMPANUM

The **tympanic cavity** is a small air-chamber in the temporal bone, between the tympanic membrane and the lateral wall of the internal ear or labyrinth (Figs. 1002, 1006). It is lined with mucous membrane, and it contains a chain of ossicles—malleus, incus, and stapes—which reaches from its lateral wall to its medial wall, and transmits the vibrations of the tympanic membrane across the cavity to the internal ear. Several ligaments and two small muscles are attached to the ossicles.

The larger part of the tympanic cavity is opposite the tympanic membrane and is the true **tympanum**, but the cavity extends also above the level of the

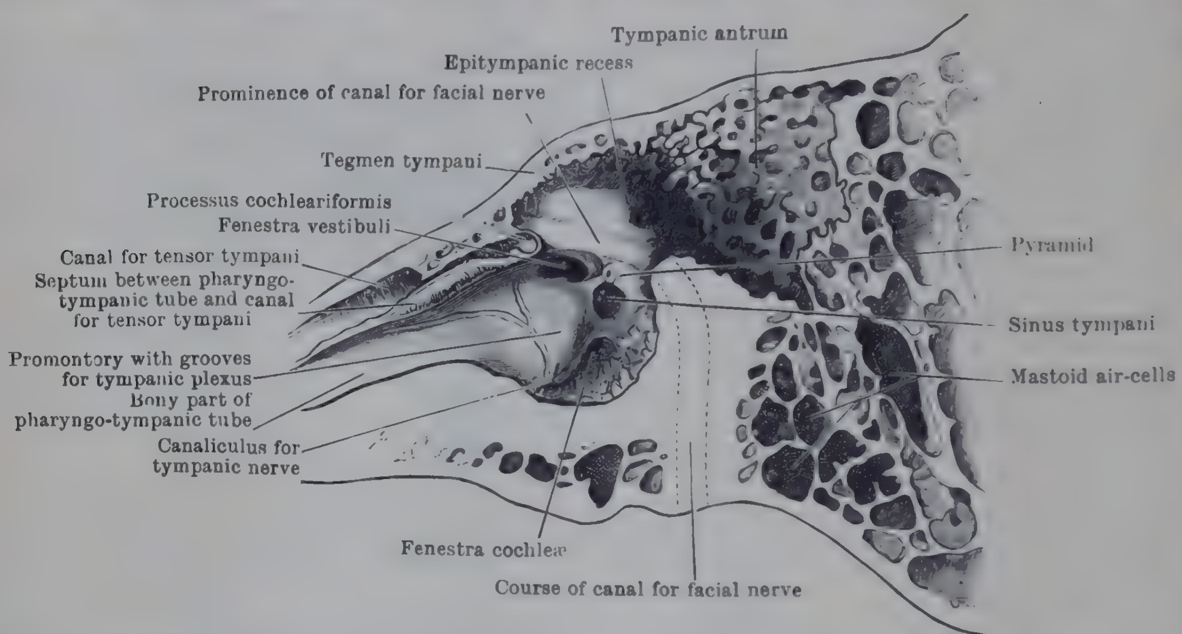


FIG. 1009.—SECTION THROUGH LEFT TEMPORAL BONE, SHOWING MEDIAL WALL OF TYMPANIC CAVITY.

membrane and this part is named the **epitympanic recess**; it contains the greater part of the incus and the upper half of the malleus. Including the recess, the vertical and antero-posterior diameters of the cavity are each about 15 mm. The distance between its lateral and medial walls is about 6 mm. in the upper part and 4 mm. in the lower, while at its central part, owing to the bulging of the two walls towards the cavity, it is only 1·5 or 2 mm.

The tympanic cavity communicates, behind, with the tympanic antrum (see p. 1187), and through that with the mastoid air-cells; in front, with the nasal part of the pharynx through the pharyngo-tympanic tube. It is enclosed by a roof, a floor, and four walls—anterior, posterior, medial, and lateral.

The **roof** of the tympanic cavity (Fig. 1009) is a thin plate of bone—the **tegmen tympani**—which forms a portion of the anterior surface of the petrous part of the temporal bone. It extends backwards to cover the tympanic antrum, and forwards to form a roof for the canal for the tensor tympani muscle. It separates the tympanic cavity and antrum from the middle cranial fossa; it may contain a few air-cells, and occasionally it is partly deficient. In the child its lateral edge corresponds with the petro-squamous suture, traces of which can generally be seen in the adult bone.

The **floor** is narrower than the roof, and consists of a thin plate of bone which separates the tympanic cavity from the jugular fossa; anteriorly, it slopes upwards

and is continuous with the posterior wall of the carotid canal (Fig. 159, p. 185). The inner orifice of the canaliculus which transmits the tympanic nerve—a branch of the glosso-pharyngeal—is placed near the junction of the floor and medial wall.

The **medial wall** of the middle ear (Fig. 1009) is also the lateral wall of the internal ear. It presents:—(1) A rounded eminence, called the **promontory**, caused by the bulging of the first coil of the cochlea; its surface is marked by small grooves which lodge the tympanic plexus of nerves. (2) An oval or kidney-shaped opening, named the **fenestra vestibuli**, situated above and behind the promontory, with its long axis directed antero-posteriorly and its concavity directed downwards. It measures 3 mm. in length and 1·5 mm. in breadth and, in the macerated bone, leads into the vestibule of the bony labyrinth, but, in the recent state, is closed by the base of the stapes surrounded by its **annular ligament**. (3) An elevation—the **prominence of the canal for the facial nerve**—situated above the fenestra vestibuli, in the epitympanic recess. (4) The **processus cochleariformis**—a thin, narrow bony shelf which extends backwards above the anterior end of the fenestra vestibuli, where it makes a sharp lateral curve and forms a pulley over which the tendon of the tensor tympani muscle plays. (5) A funnel-shaped recess, situated behind and below the promontory, and almost hidden by its overhanging edge, and which leads to an irregularly oval opening, termed the **fenestra cochleæ**; in the macerated bone the fenestra opens into the cochlea, but in the recent state is closed by the **secondary tympanic membrane**. This membrane consists of three layers: (*a*) a *lateral* layer, continuous with the mucous lining of the tympanic cavity and containing a network of capillaries; (*b*) an *intermediate* fibrous layer; (*c*) a *medial* layer, continuous with the epithelial lining of the labyrinth. (6) A small depression named the **sinus tympani**, situated behind the promontory and between the fenestra vestibuli and the fenestra cochleæ; it indicates the position of the ampullated end of the posterior semicircular canal, but of course is not caused by this.

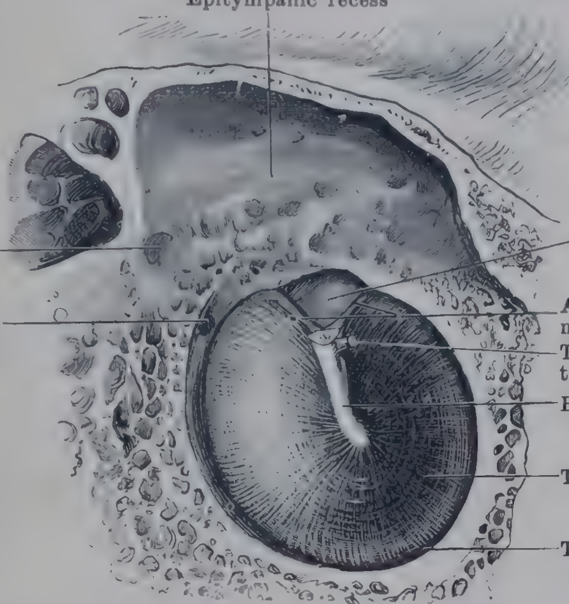


Fig. 1010.—Left Tympanic Membrane and Epitympanic Recess, viewed from Within. The head and neck of the malleus have been removed to show the flaccid part of the membrane and the malleolar folds.

The **posterior wall** of the tympanic cavity (Figs. 1009, 1010), presents, from above downwards:—(1) A round or triangular opening, called the **aditus**, which leads from the epitympanic recess into the **tympanic antrum**; (2) a depression—the **fossa for the incus**—situated in the postero-inferior part of the epitympanic recess, for the reception of the end of the short process of the incus; (3) a minute, conical, bony projection called the **pyramid**, the summit of which is perforated by the tendon of the stapedius muscle. From the interior of the pyramid a small canal passes downwards and backwards in front of the facial canal, into which it usually opens; its walls give attachment to the stapedius, and it transmits the vascular and nervous supply to that muscle. This small canal sometimes opens independently on the base of the skull, immediately in front of the stylo-mastoid foramen; (4) a small aperture—the **posterior canaliculus for the chorda tympani**—situated close to the posterior edge of the tympanic membrane nearly on a level with the upper end of the handle of the malleus.

The **anterior wall is** narrowed in its transverse diameter by the approximation

of the lateral and medial walls of the tympanic cavity, and in its vertical diameter by the descent of the tegmen tympani and the ascent of the floor (Fig. 1009). It presents the openings of two parallel canals, one above the other, separated by a thin lamella of bone, the posterior end of which is the processus cochleariformis. The two canals run forwards on the lateral side of the carotid canal and open in the angle between the squamous and the petrous parts of the temporal bone. The upper and smaller canal is the **canal for the tensor tympani**, and lies immediately below the tegmen tympani. It has a diameter of about 2 mm., and extends on to the medial wall of the tympanic cavity above the anterior part of the fenestra vestibuli. The lower and larger canal is the **bony part** of the **pharyngo-tympanic tube**, and it gradually increases in diameter from before backwards. Below the orifice of the tube the anterior part of the tympanic cavity is separated from the ascending portion of the carotid canal by a thin plate of bone in which sometimes there are gaps. The plate is perforated by the carotico-tympanic nerves as they pass from the sympathetic plexus on the carotid artery to join the tympanic plexus.

The **lateral wall** is formed almost entirely by the tympanic membrane (Fig. 1010). The tympanic groove, in which the membrane is attached, is deficient superiorly, and the gap is called the **tympanic notch**. On a level with the upper edge of the membrane, and in front of the tympanic ring, there is the medial end of the **squamo-tympanic fissure**. It transmits the tympanic branch of the maxillary artery, and lodges the anterior process and anterior ligament of the malleus. Close to the medial end of the fissure is the **anterior canaliculus for the chorda tympani**.

The **tympanic membrane** is an almost circular sheet of fibrous tissue, with a diameter of about 10 mm. It is placed very obliquely, and forms an angle of about 55° with both the lower and anterior walls of the external auditory meatus.

At its attachment to the tympanic groove the membrane is considerably thickened. This thickened portion is named the **fibro-cartilaginous ring** and is prolonged from the anterior and posterior ends of the tympanic notch to the lateral process of the malleus as two ligamentous bands which raise up ridges, called the **anterior** and **posterior malleolar folds**, on the medial surface of the membrane. The small, triangular portion of the membrane (Fig. 1010) between the malleolar folds is thin and lax, and is its **flaccid part**, whilst the main portion of the membrane is tightly stretched and is termed the **tense part**. The handle of the malleus is firmly fixed to the tympanic membrane, the central portion of which is drawn in towards the tympanic cavity. The point of greatest convexity of the membrane corresponds with the lower end of the handle of the malleus, and is named the **umbo of the tympanic membrane**.

Structure.—The tympanic membrane is composed of three layers—cuticular, fibrous, and mucous.

The **cuticular layer** is continuous with the skin of the external auditory meatus.

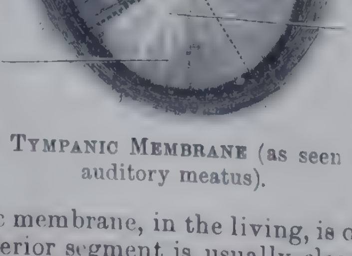


FIG. 1011.—LEFT TYMPANIC MEMBRANE (as seen from the external auditory meatus).

The **fibrous layer** is composed of radial and circular fibres. The radial fibres pass from the handle of the malleus to the fibro-cartilaginous ring; the circular fibres are numerous near the circumference of the membrane, but scattered and few in number near its centre (Fig. 1010). Both radial and circular fibres are absent from the flaccid part, which thus consists only of the cuticular and mucous layers.

The **mucous layer** is part of the mucous lining of the tympanic cavity and is thickest at the upper part of the membrane.

Otoscopic Examination of Tympanic Membrane (Fig. 1011).—The tympanic membrane, in the living, is of a "pearl-grey" colour, but may have a red or yellow tinge; the posterior segment is usually clearer than the anterior. At the antero-superior part, close to its periphery, a whitish point appears as if projecting towards the meatus; this is the lateral process of the malleus. Passing downwards and backwards from that point to the umbo

there is a ridge caused by the handle of the malleus, the lower end of which appears rounded. Two ridges, corresponding with the malleolar folds, extend from the lateral process of the malleus, one forwards and upwards, the other backwards and upwards. Behind and near the lower end of the handle of the malleus there is a rather red or yellow spot, due to the promontory of the medial wall shining through the membrane. If the membrane is very transparent, the long process of the incus may be visible behind the upper part of the handle of the malleus, reaching downwards as far as its middle. From the lower end of the handle, a bright area termed the "cone of light" radiates in a downward and forward direction.

For the purpose of precise localization of any point on the membrane, its surface is divided into quadrants by the handle of the malleus and a line continued from it to the circumference and by a line drawn at right angles to this through the lower end of the handle.

Vessels and Nerves.—The **arteries** are arranged in two sets—one on the outer surface and the other on the inner; they anastomose by means of small branches which pierce the membrane, especially near its periphery. The branches to the outer surface are derived chiefly from the deep auricular branch of the maxillary artery; those to the inner surface from its anterior tympanic branch and from the stylo-mastoid branch of the occipital artery. The **veins** from the outer surface open into the external jugular vein; those from the inner surface end partly in the venous plexus on the pharyngo-tympanic tube, and partly in the sigmoid sinus and in the veins of the dura mater. The **lymph-vessels**, like the blood-vessels, are arranged in two sets which communicate freely with each other. The lateral surface of the membrane receives its **nerves** from the auriculo-temporal nerve and from the auricular branch of the vagus nerve; the medial surface, from the tympanic branch of the glosso-pharyngeal nerve.

Tympanic Antrum and Mastoid Air-Cells

The **tympanic antrum** is an air-space situated behind the epitympanic recess. In the adult its average length is from 12 to 15 mm., its height from

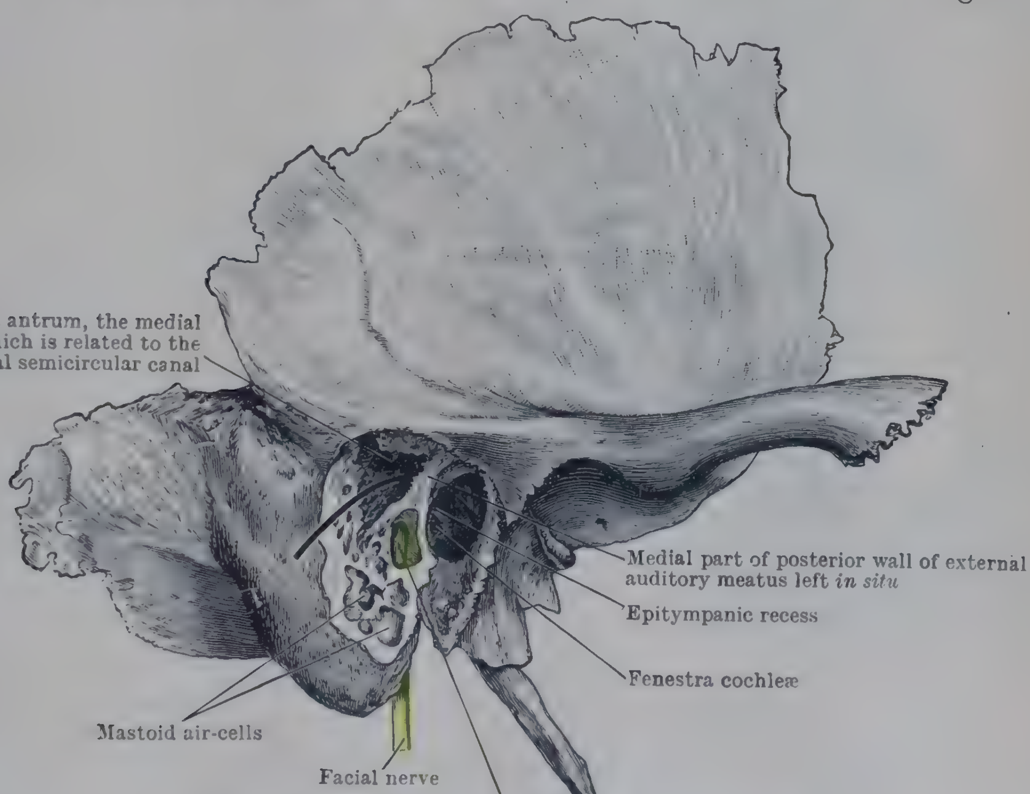


Fig. 1012.—Preparation displaying Position and Relations of Right Tympanic Antrum. The greater part of the posterior wall of the external meatus has been removed, leaving only a bridge of bone at its medial end; under this a bristle passes from the tympanic antrum to the tympanic cavity.

8 to 10 mm., and its width from 6 to 8 mm. Its roof is a backward extension of the tegmen tympani and its floor and medial wall are the mastoid and petrous parts of the temporal bone; laterally it is closed by the portion of the squamous part of the temporal bone which lies below the supramastoid crest. It communicates with the epitympanic recess through the aditus, on the medial wall of which, immediately above and behind the canal for the facial nerve, there is a smooth convexity that indicates the position of the ampullated end of the lateral semicircular canal.

At birth the lateral wall of the antrum has a thickness of only 1 or 2 mm., but it increases to about 10 mm. by the ninth year and to about 15 mm. in the adult. Coincident

with the growth of the mastoid process the mastoid air-cells are developed as downward and backward diverticula from the antrum, and present great variation in different skulls.

The **mastoid air-cells** may be large or small, numerous or few, and may involve all the mastoid part of the temporal bone or may not extend at all deeply into it; when the cells are large and numerous the compact bone around them is thin, and the inner cells are separated from the posterior cranial fossa and the sigmoid sinus only by a thin sheet of bone which sometimes is perforated. The air-cells are not always limited to the mastoid part of the temporal bone, but may extend upwards towards the squamous part, forwards into the roof of the meatus, and medially towards the temporo-occipital suture; occasionally they invade the jugular process of the occipital bone. The tympanic antrum and the mastoid air-cells are lined with thin mucous membrane continuous with that of the tympanic cavity; it is firmly adherent to the endosteum, and its free surface is covered with a layer of flattened, non-ciliated epithelium.

Pharyngo-Tympanic Tube

The **pharyngo-tympanic tube** is the passage through which air may pass from the pharynx to the tympanic cavity in order that the pressure of air on each side of the tympanic membrane may be equal. The tube is about 3·5 cm. ($1\frac{3}{8}$ inches) long and is partly bony and partly cartilaginous. The lower and medial part is cartilaginous and is twice as long as the upper and lateral bony part. From the **pharyngeal opening** the tube is directed upwards and laterally, making an angle with the horizontal plane of about 40° and with the sagittal plane an angle of about 45°; the bony part of the tube is rather more horizontal than the cartilaginous part and makes with it a wide angle —about 160°. The cartilaginous part of the tube is composed of a triangular plate of cartilage folded along its long axis so as to form a gutter, open in a downward and lateral direction. The two sides of the gutter are unequal, the medial being much the deeper. The gap between the sides of the gutter is bridged over by fibrous tissue, thus converting the gutter into a tube. The base of this triangular cartilage impinges on the wall of the pharynx and partially surrounds the *pharyngeal opening* of the tube; the apex is firmly fixed to the bony part of the tube; the amount of cartilage thus becomes gradually less as the bony part of the tube is approached. As can be easily demonstrated by a triangular piece of paper folded in the manner indicated above, it is only the medial and upper walls of the gutter that impinge on the pharyngeal wall; in that situation they give rise to a hook-like ridge, named the **tubal elevation**, from the posterior edge of which there is prolonged down the pharyngeal wall a fold of mucous membrane called the **salpingo-pharyngeal fold**; this fold overlies the salpingo-pharyngeus muscle (Fig. 504, p. 588).

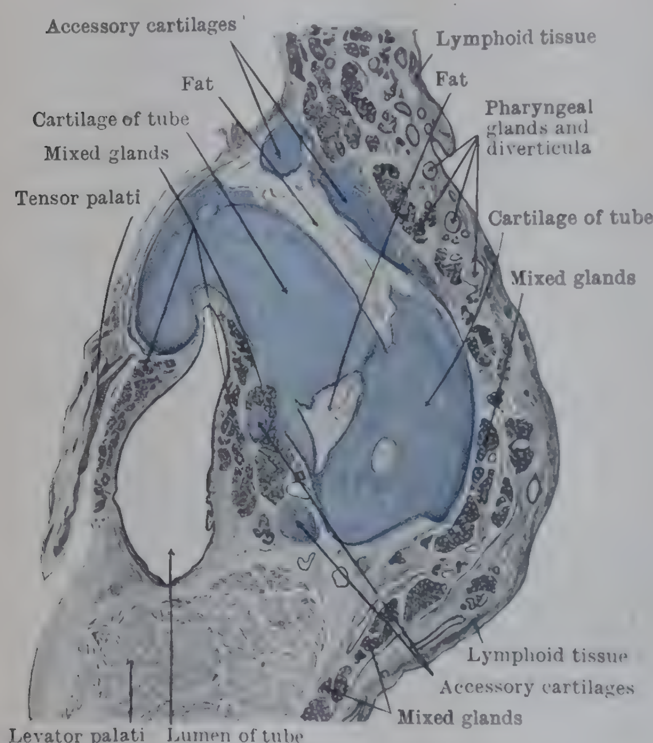


Fig. 1013.—Cross-Section through Pharyngo-Tympanic Tube near its Pharyngeal End.

The cartilaginous part of the tube is firmly fixed to the under surface of the skull in the groove between the greater wing of the sphenoid and the petrous part of the temporal bone. Close to its medial end it is supported by a small tubercle on the posterior edge of the medial pterygoid plate. The tensor palati muscle,

which receives some fibres of origin from the cartilage, lies on the lateral side of the tube and separates it from the middle meningeal artery and the mandibular division of the trigeminal nerve; the levator palati and the mucous membrane of the pharynx are on its medial side. The bony part of the tube occupies the angle between the tympanic and petrous parts of the temporal bone, and it opens into the tympanic cavity below the canal for the tensor tympani muscle; the internal carotid artery ascends across its medial side.

The tube is opened, during deglutition, by the tensor palati and salpingo-pharyngeus muscles. When the tensor contracts, the lateral wall of the tube is drawn laterally and forwards. The salpingo-pharyngeus draws the medial part of the cartilage downwards and backwards, thus increasing the angle between it and the lateral part.

Mucous Membrane.—The mucous lining of the tube is continuous behind with that of the tympanic cavity, and in front with that of the nasal part of the pharynx. In the bony part it is thin and firmly fixed to the bony wall; in the cartilaginous part it is loose and thrown into longitudinal folds. Numerous mucous glands open into the tube near its pharyngeal end, and there also there is a considerable amount of lymphoid tissue. The lymphoid tissue is continuous with that of the nasal part of the pharynx, and, like it, is especially well developed in children. The mucous membrane is lined with ciliated columnar epithelium.

Vessels and Nerves.—The **arteries** of the tube come from the ascending pharyngeal and middle meningeal arteries and from the artery of the pterygoid canal. Its **veins** drain into the pterygoid venous plexus. Its sensory **nerves** are derived from the tympanic plexus and from the pharyngeal branch of the spheno-palatine ganglion.

The tube of the child differs considerably from that of the adult; its lumen is wider, its direction more horizontal, and its bony part relatively shorter. The pharyngeal opening is below the level of the hard palate in the fœtus; at birth it is level with the palate; at the fourth year it is 3 to 4 mm. above it, and in the adult 10 mm. above it; in the child it is a narrow fissure, and the tubal elevation is less prominent.

Auditory Ossicles

The auditory ossicles, three in number, form an articulated column that connects the lateral wall of the tympanic cavity with the medial wall; they are

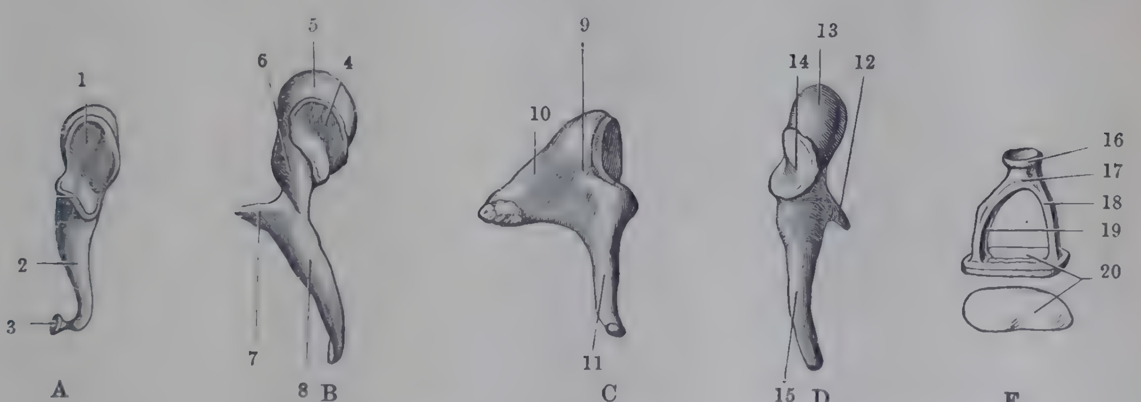


Fig. 1014.—Auditory Ossicles of Left Ear (enlarged about three times).

A, Incus, seen from the front; B, Malleus, seen from behind; C, Incus, and D, Malleus, seen from medial side; E, Stapes, seen from above and from the medial side.

1. Body of incus, with articular facet for head of malleus.
2. Long process of incus.
3. Lentiform nodule of incus.
4. Articular facet for incus.
5. Head of malleus.
6. Neck of malleus.
7. Lateral process of malleus.
8. Handle of malleus.
9. Body of incus.
10. Short process of incus.
11. Long process of incus.
12. Anterior process of malleus.
13. Head of malleus.
14. Facet for incus.
15. Handle of malleus.
16. Head of stapes.
17. Neck of stapes.
18. Anterior limb of stapes.
19. Posterior limb of stapes.
20. Base of stapes.

named the malleus, the incus, and the stapes. The malleus is attached to the medial surface of the tympanic membrane; the stapes fits against the fenestra vestibuli; and the incus is between the other two.

The **malleus** (Fig. 1014, B, D)—the largest of the three—is from 8 to 9 mm. long; it bears some resemblance to a club, or small hammer [*malleus* = a hammer], and has a head, a neck, a handle, and two processes—anterior and lateral.

The head and neck are situated in the epitympanic recess; the lateral process and the handle are fixed to the medial surface of the tympanic membrane; the anterior process is directed forwards towards the squamo-tympanic fissure, to the margin of which, in the adult, it is connected by ligamentous fibres. The **head** is smooth and convex above and in front; on its posterior surface there is a facet for articulation with the body of the incus. The facet is more or less elliptical, but is constricted near the middle; an oblique ridge, corresponding with the constriction, divides the facet into two parts—an upper and larger, directed backwards, and a lower and smaller, directed medialwards. Opposite the lower part of the constriction the inferior edge of the facet is very prominent, and is continued upwards into the oblique ridge just referred to and forms a tooth-like spur. On the back of the head, below this spur, there is an oblique crest, to which the lateral ligament of the malleus is attached. The **neck** is the slightly constricted portion immediately below the head. Its lateral surface is directed towards the flaccid part of the tympanic membrane; its medial surface is crossed by the chorda

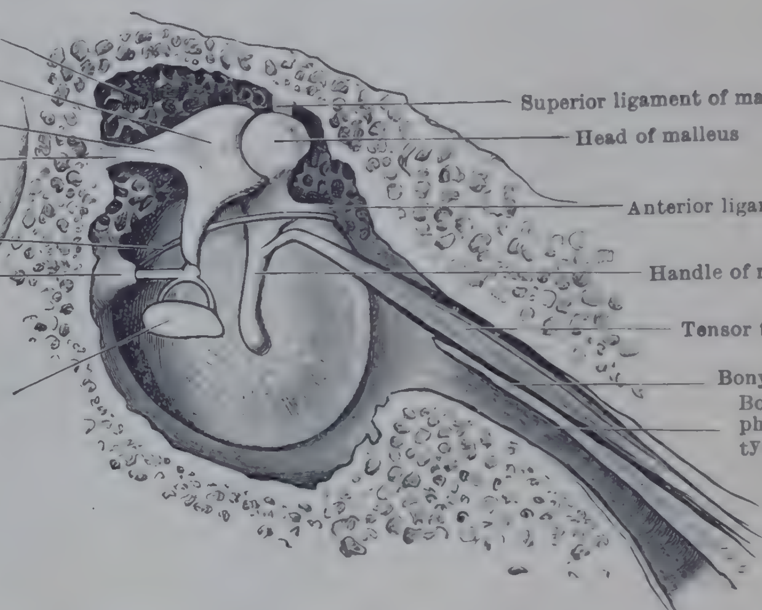


FIG. 1015.—LEFT TYMPANIC MEMBRANE AND CHAIN OF AUDITORY OSSICLES (seen from medial side).

tympani nerve. The **handle** projects downwards, backwards, and medialwards from the neck, and forms with the long axis of the head an angle of 126° to 150°; the lower end is slightly curved, the concavity being directed forwards and sidewards. The handle is fixed by its periosteum and by a layer of cartilage to the fibrous layer of the tympanic membrane. On the medial surface of the handle, near its upper end, there is a slight projection for the attachment of the tendon of the tensor tympani muscle. The **anterior process** is a slender spicule that springs from the front of the neck and is directed forwards towards the squamo-tympanic fissure. The **lateral process** is a conical eminence, and it may be looked upon as the upper end of the handle projected laterally; it is fixed to the upper part of the tympanic membrane by a layer of cartilage, and to the ends of the tympanic notch by the anterior and posterior malleolar folds.

The **incus** (Fig. 1014, A, C) is so named from its fancied likeness to an anvil. It has a body, a long process, and a short process; the processes form with each other an angle of 90° to 100°. The body and the short process are situated in the epitympanic recess. On the **body** there is a saddle-shaped surface for articulation with the head of the malleus. That surface is directed forwards, and its lower part is hollowed out for the accommodation of the spur of the malleus, and it ends below and medially in a prominent edge. The long process projects downwards into the tympanic cavity, where it lies parallel with the handle of the malleus, but slightly posterior and medial to it. Its lower end is bent medialwards and narrowed to form a short neck, on the end of which there is a

small knob of bone, called the **lentiform nodule**, for articulation with the head of the stapes. The short process is thick, pyramidal in shape, and projects horizontally backwards; its apex, covered with cartilage, is received into the fossa for the incus.

The **stapes** (Fig. 1014, E) is like a stirrup and has a head, a neck, two limbs, and a base. The **head**, directed laterally, is concave for articulation with the lentiform nodule of the incus. The **neck** is slightly constricted, and from it the two limbs spring; the tendon of the stapedius is inserted into the posterior surface of the neck. The **anterior limb** is shorter and less curved than the **posterior limb**. Diverging from each other, the limbs are directed medialwards and are attached—one near the anterior end of the base, the other near its posterior end. The **base** is oval or kidney-shaped when seen from the medial side, and it fits against the fenestra vestibuli. In the recent condition an *obturator membrane* fills the arch formed by the limbs and the base, the limbs being grooved for its reception.

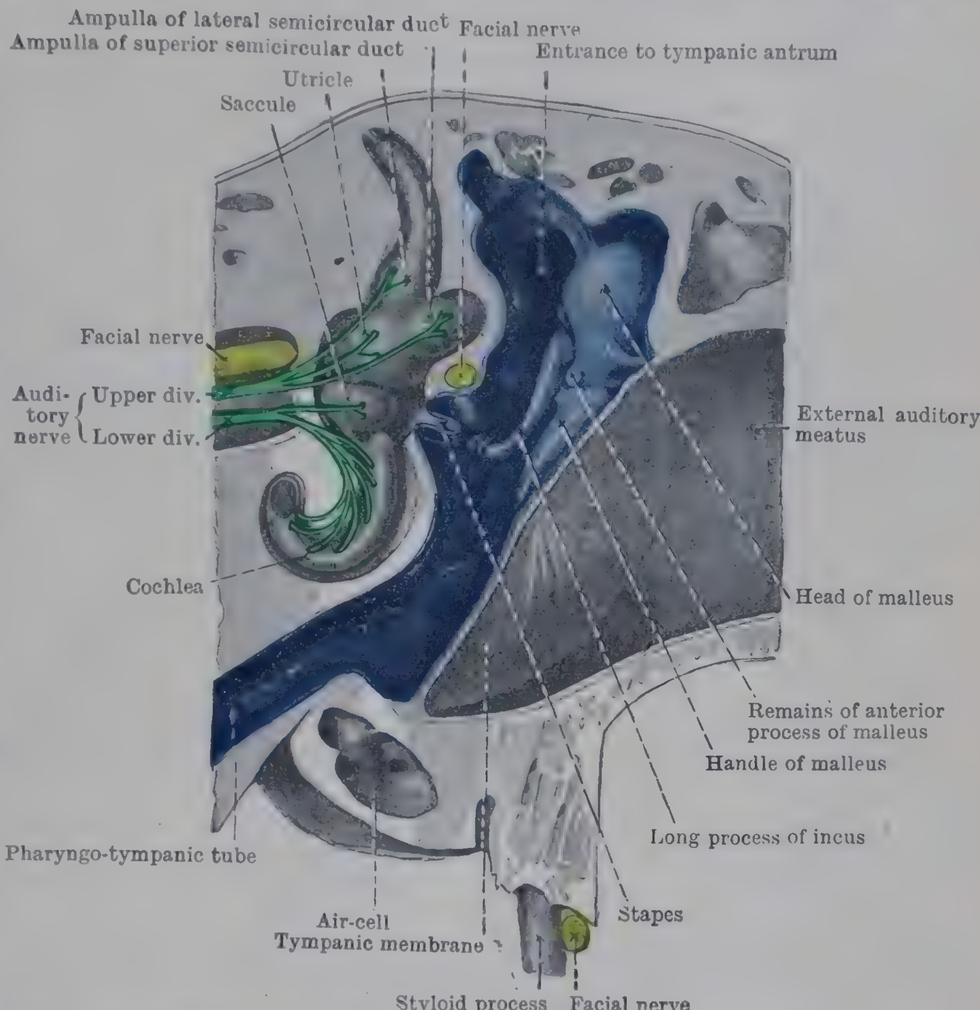


FIG. 1016.—SECTION OF LEFT TYMPANIC CAVITY AND ADJACENT PARTS VIEWED FROM THE FRONT (semi-diagrammatic).

Joints of Auditory Ossicles.—The joint between the head of the malleus and the body of the incus is synovial, and may be described as a saddle-shaped joint. It is surrounded by an articular capsule, from the inner surface of which a wedge-shaped *disc* projects into the joint-cavity and incompletely divides it. The joint between the lentiform nodule and the head of the stapes is of the nature of a ball-and-socket joint, but some observers deny the presence of a synovial cavity and regard the articulation as a syndesmosis.

Ligaments of Auditory Ossicles.—The malleus is attached to the walls of the tympanic cavity by anterior, superior, and lateral ligaments (Fig. 1015). The **anterior ligament** consists of two portions: one passes forwards from the anterior process through the squamo-tympanic fissure, to reach the spine of the sphenoid, from which it is continued to the spheno-mandibular ligament; the other extends from the anterior process to the anterior margin of the tympanic notch. The former of these two parts may contain muscle-fibres and was described by Soemmerring (1806) as the *musculus externus mallei* (Walls, 1946). The **superior ligament** stretches from the head of the malleus to the roof of the epitympanic recess. The **lateral ligament** is short and fan-shaped; its fibres radiate from the oblique crest of the malleus to the posterior edge of the tympanic notch. It is strong, and, with the anterior ligament, it forms the axis around which the

malleus rotates; and the two constitute what Helmholtz (1868) termed the "axis-ligament" of the malleus.

The posterior end of the short process of the incus is tipped with cartilage and fixed by means of a ligament to the floor of the fossa for the incus (Fig. 1015).

The medial surface and the circumference of the base of the stapes are covered with hyaline cartilage; the cartilage encircling the base is joined to the circumference of the fenestra vestibuli by a ring of elastic fibres named the **annular ligament of the base of the stapes.**

Muscles of Auditory Ossicles.—These are the tensor tympani and the stapedius.

The **tensor tympani**, the larger of the two, takes origin from the upper surface of the cartilage of the pharyngo-tympanic tube, from the adjacent part of the greater wing of the sphenoid and from the walls of the bony canal in which the muscle lies. It ends in a tendon which turns laterally round the processus cochleariformis, and passes across the tympanic cavity to be inserted into the medial edge and anterior surface of the handle of the malleus near its upper end. When the muscle contracts, it draws the handle towards the tympanic cavity, and so makes the tympanic membrane more tense. It receives its nerve-supply from the motor root of the trigeminal nerve, through the otic ganglion.

The **stapedius** arises from the walls of a canal that leads downwards from the interior of the pyramid. Its tendon emerges from the apex of the pyramid and is inserted into the posterior surface of the neck of the stapes. On contraction it draws back the head of the stapes, and so tilts the anterior part of the base towards the tympanic cavity. It is supplied by a branch of the facial nerve.

Movements of Auditory Ossicles.—The handle of the malleus follows all the movements of the tympanic membrane; and the malleus and incus move together around an axis that extends forwards through the short process of the incus and the anterior process of the malleus. When the tympanic membrane moves medialwards it carries the handle of the malleus with it; the long process of the incus, moving medialwards at the same time, forces the base of the stapes towards the labyrinth. The movement is communicated to the fluid (perilymph) in the bony labyrinth, and causes a lateral bulging of the secondary tympanic membrane, which closes the fenestra cochleæ. The movements are reversed when the tympanic membrane is relaxed, unless the lateral movement of the membrane is excessive. When that occurs, the incus does not follow the full movement of the malleus, but merely glides on that bone at the incudo-malleolar joint, and thus the forcible dragging of the base of the stapes out of the fenestra vestibuli is prevented. The spur arrangement, already described, on the head of the malleus and body of the incus, causes the incudo-malleolar joint to become locked during the medial movement of the handle of the malleus, the joint becoming unlocked during its lateral movement.

Mucous Membrane of Tympanic Cavity.—The **mucous lining** is continuous, through the pharyngo-tympanic tube, with that of the nasal part of the pharynx; it extends backwards also and lines the tympanic antrum and the mastoid air-cells. Thin and transparent, it follows closely all the irregularities of the walls of the cavity, and is reflected over the ossicles, their ligaments and muscles, and the chorda tympani; there is thus formed a number of folds that enclose pouches in which pus may collect in inflammatory conditions of the middle ear.

Vessels and Nerves of Tympanic Cavity.—The **arteries** are: (1) the anterior tympanic artery, which reaches the cavity by way of the squamo-tympanic fissure; (2) the stylo-mastoid artery, which passes through the stylo-mastoid foramen; (3) a branch from the middle meningeal artery which accompanies the greater superficial petrosal nerve. The **veins** drain into the pterygoid plexus and superior petrosal sinus. The **lymph-vessels** form a network in the mucous membrane and end mainly in the retropharyngeal and parotid lymph-glands. The **nerves** to the muscles have been referred to above. The mucous membrane receives its nerves from the tympanic plexus. The chorda tympani branch of the facial nerve passes from behind, upwards and forwards through the tympanic cavity; its course is described on p. 1032.

Early Condition of Tympanic Cavity.—During the greater part of intra-uterine life the tympanic cavity is almost completely filled with a soft, jelly-like embryonic tissue in which there is a slit-like space lined with epithelium. By the time of birth that tissue has disappeared, and at birth the cavity is filled with fluid which becomes absorbed after the entrance of air from the nasal part of the pharynx through the pharyngo-tympanic tube. All the parts of the middle and internal ear are relatively large and show little if any difference from the adult condition.

INTERNAL EAR

The **internal ear** is lodged within the petrous part of the temporal bone, and is composed of a series of delicate membranous chambers and passages—the *membranous labyrinth*—enclosed within corresponding cavities which are hollowed out of the bone and constitute the *bony labyrinth*. The component parts of the membranous labyrinth are, from before backwards, the **duct of the cochlea** (which contains the essential organ of hearing), the **saccule** and the **utricle**, and the three **semicircular ducts**; the corresponding parts of the bony labyrinth are the **cochlea**, the **vestibule**, and the three **semicircular canals**. The utricle and the saccule are both contained in the vestibule; and all the parts of the bony labyrinth are considerably larger than the corresponding parts of the membranous labyrinth.

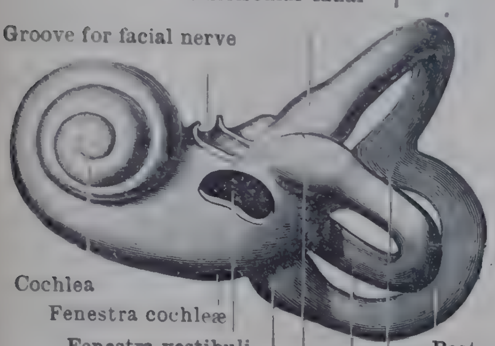


FIG. 1017.—LEFT BONY LABYRINTH (seen from lateral side).

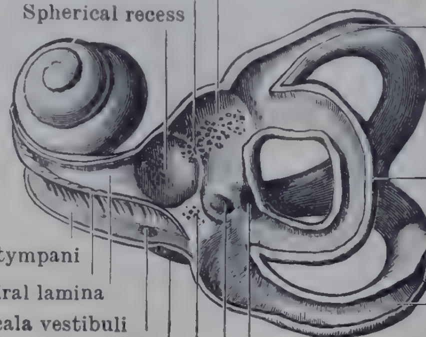


FIG. 1018.—INTERIOR OF LEFT BONY LABYRINTH (seen from below and lateral side).

For the comparative anatomy of the membranous labyrinth, with stereoscopic illustrations, consult Gray (1907-8).

BONY LABYRINTH

Vestibule.—The vestibule is the middle portion of the bony labyrinth, and communicates behind with the semicircular canals and in front with the cochlea. It is an oval cavity with its long axis directed forwards and medially, and it measures about 6 mm. antero-posteriorly, 4 or 5 mm. vertically, and about 3 mm. transversely. Its lateral wall is directed towards the tympanic cavity, and in it is the fenestra vestibuli, which is closed by the base of the stapes. Its medial wall corresponds with the bottom of the internal auditory meatus, and presents, at its antero-inferior part, a circular depression called the **spherical recess**, which lodges the saccule. In the recess there are twelve or fifteen very small foramina (**macula cribrosa media**) which transmit the filaments of the auditory nerve to the saccule. The spherical recess is limited above and behind by an oblique ridge, called the **vestibular crest**, the anterior end of which is triangular in shape and named the **pyramid of the vestibule**. Posteriorly the crest divides into two limbs that enclose a small depression called the **cochlear recess**, in which there are several minute foramina for the passage of the nerves to the vestibular end of the duct of the cochlea. Above and behind the vestibular crest, in the roof and medial wall of the vestibule, there is an oval depression, called the **elliptical recess**, which lodges the utricle. The pyramid of the vestibule and adjacent part of the elliptical recess show twenty-five or thirty very small foramina (**macula cribrosa superior**) for the passage of the nerves to the utricle and to the ampullæ of the superior and lateral semicircular ducts. Behind and below the elliptical recess there is a furrow that gradually deepens to form a canal, called the **aqueduct of the vestibule**, which

passes backwards through the petrous part of the temporal bone and opens into the posterior cranial fossa as a slit-like fissure about midway between the internal auditory meatus and the groove for the sigmoid sinus. This aqueduct is from 8 to 10 mm. long, and gives passage to the endolymphatic duct and a small vein. At the posterior part of the vestibule there are five circular openings which lead into the semicircular canals; at its anterior part there is an elliptical opening that leads from the spherical recess into the scala vestibuli of the cochlea. This opening is bounded below by a thin bony plate, called the **osseous spiral lamina**, which springs from the floor of the vestibule immediately lateral to the spherical recess and forms, in the cochlea, the bony part of the septum between the scala tympani and the scala vestibuli.

Semicircular Canals.—The three semicircular canals are situated above and behind the vestibule (Figs. 1017, 1018). They are distinguished from one another by their positions, and are named superior, posterior, and lateral. Each forms about two-thirds of a circle, one end of which is dilated and termed the **ampulla.** They are slightly compressed from side to side, and their diameter is from 1 to 1·5 mm., whilst that of the ampullæ is about 2 mm. They open into the vestibule by five apertures only, since the medial end of the superior canal joins the upper end of the posterior canal to form a common canal termed the *crus commune.*

The **superior semicircular canal**, 15 to 20 mm. long, is vertical and placed across the long axis of the petrous part of the temporal bone. Its convexity is directed upwards, and its position is indicated by the arcuate eminence. Its ampullated end is the antero-lateral end, and it opens into the vestibule immediately above the ampullated end of the lateral canal. Its opposite end joins the non-ampullated end of the posterior canal to form the **crus commune**, which is about 4 mm. long, and which opens into the upper and medial part of the vestibule. The **posterior semicircular canal**, from 18 to 22 mm. long, also is vertical. Its ampulla is placed inferiorly and opens into the lower and posterior part of the vestibule, where there are six or eight small apertures (**macula cribrosa inferior**) for the transmission of the nerves to this ampulla. Its upper end joins the crus commune. The **lateral canal**, from 12 to 15 mm. long, arches nearly horizontally. Its lateral end is ampullated and opens into the vestibule immediately above the fenestra vestibuli, close to the ampullated end of the superior canal, and causes an elevation on the medial wall of the aditus to the tympanic antrum above the canal for the facial nerve (Fig. 1016). The lateral canal of one ear is very nearly in the same plane as that of the other; the superior canal of one ear is nearly parallel to the posterior canal of the other (Crum Brown, 1874).

Cochlea.—When freed from its surroundings the **cochlea** has the form of a short cone (Fig. 1019). The central part of its **base** corresponds with the bottom of the internal auditory meatus; and its apex or **cupola**, directed laterally, is in close relation with the canal for the tensor tympani muscle, and thus the whole structure lies across the long axis of the petrous temporal bone. (In the following description the cochlea is supposed to be placed on its base.) It measures about 9 mm. across the base and about 5 mm. from base to apex, and consists of a spirally arranged tube which forms from $2\frac{1}{2}$ to $2\frac{3}{4}$ coils around a central pillar termed the **modiolus.** The length of the tube is 32 mm., and its diameter, near the base of the cochlea, is 2 mm. Its coils are distinguished by the terms basal, middle, and apical; the basal coil bulges into the tympanic cavity, giving rise to the promontory on its medial wall.

The modiolus is about 3 mm. long, and its diameter diminishes rapidly from the base to the apex; it ends about 1 mm. from the cupola. Its **base** corresponds with the **cochlear area** on the fundus of the internal auditory meatus, and exhibits (Fig. 1020): (1) the **tractus spiralis foraminosus**, which transmits the nerves to the basal and middle coils of the cochlea; and (2) a **central foramen**, which gives passage to the nerves to the apical coil. From the free edge of the osseous spiral lamina numerous small canals, for the transmission of vessels and nerves, pass to its attached edge, where they unite to form the **spiral canal** of the cochlea, which lodges the **spiral ganglion**. From the spiral canal other small canals pass down the modiolus and open by the holes along the tractus spiralis foraminosus.

The **osseous spiral lamina** is a thin, flat shelf of bone which winds round the modiolus like the thread of a screw, and, projecting about half-way into the cochlear tube, incompletely divides it into two passages—an upper, the **scala vestibuli**, and a lower, the **scala tympani**. It begins at the floor of the vestibule, near the fenestra cochleæ, and ends near the cupola of the cochlea in a sickle-shaped process, called

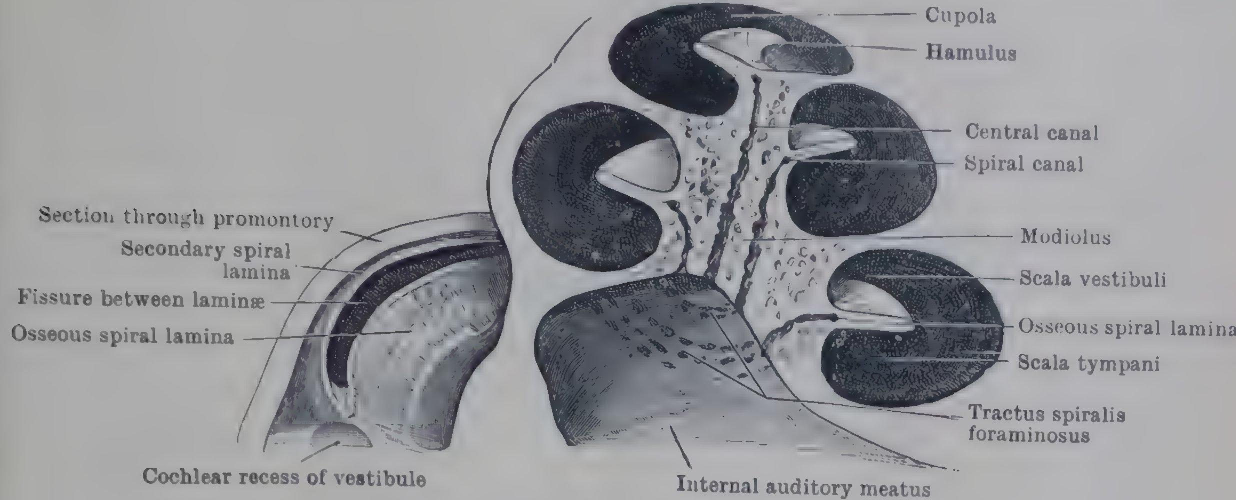


FIG. 1019.—SECTION OF BONY COCHLEA.

the **hamulus of the spiral lamina**, which helps to bound an aperture named the **helicotrema**, through which the scala tympani and scala vestibuli communicate with each other. In the basal coil the upper surface of the lamina forms almost a right angle with the modiolus, but the angle becomes more and more acute on ascending the tube. In the lower half of the basal coil a second smaller bony plate, called the **secondary spiral lamina**, projects from the outer wall of the cochlea towards the osseous spiral lamina, without, however, reaching it, so that a slit-like fissure is seen between the two laminæ, which are continuous with each other round the posterior end of the fissure. A membrane, called the **basilar lamina**, stretches from the free edge of the osseous spiral lamina to the outer wall of the cochlea, and completes the division of the cochlear tube into scala vestibuli and scala tympani; the two, however, communicate with each other through the helicotrema at the cupola of the cochlea. The **scala tympani** begins at the fenestra cochleæ, which is closed by the secondary tympanic membrane. Close to the beginning of the scala tympani and on its medial wall there is seen the inner orifice of the **aqueduct of the cochlea**; this is a canal, 10 to 12 mm. in length, which opens on the under surface of the petrous part of the temporal bone in the upper border of the jugular fossa. This aqueduct establishes a communication between the scala tympani and the subarachnoid space. The **scala vestibuli**, the upper of the two passages, begins in the vestibule; in the basal coil its diameter is less than that of the scala tympani, but in the upper coils it is greater.

FIG. 1020.—FUNDUS OF LEFT INTERNAL AUDITORY MEATUS DIVIDED INTO UPPER AND LOWER AREAS BY TRANSVERSE CREST.

The **fundus** of the **internal auditory meatus** has been referred to as corresponding to the medial wall of the vestibule and the base of the modiolus. It is divided by a transverse crest into an upper and a lower area. In the anterior part of the upper area there is a single large opening for the transmission of the facial nerve; the posterior part is named the **superior vestibular area**, and is perforated by the nerves of the utricle and of the ampullæ of the superior and lateral semicircular ducts. The anterior part of the lower area is the **cochlear area**,

already referred to, and the posterior part is named the **inferior vestibular area** and is pierced by the nerves of the saccule; behind that area is the **foramen singulare**, which gives passage to the nerves of the ampulla of the posterior semicircular duct.

MEMBRANOUS LABYRINTH

The membranous labyrinth (Figs. 1021, 1027) repeats fairly accurately the form of the bony labyrinth, except that there are two membranous sacs in the vestibule, and only one membranous canal in the cochlea. The two sacs in the vestibule are the **utricle** behind and the **saccule** in front. The membranous labyrinth is a closed system and contains a fluid called **endolymph**; the membranous labyrinth does not completely fill the bony labyrinth, and the resulting space is occupied by a fluid termed **perilymph**. Neither of these fluids has any connexion with the fluid of the lymphatic system. The perilymphatic space is closed except for the communication with the subarachnoid space through the aqueduct of the cochlea.

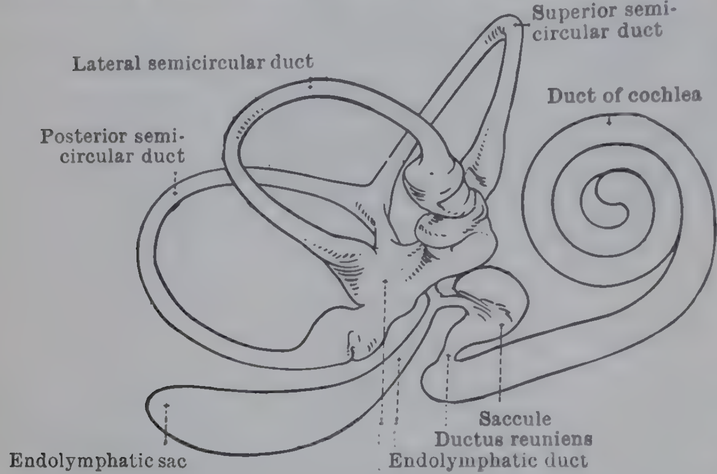


Fig. 1021.—Diagrammatic Representation of Model of Right Membranous Labyrinth. (From a model by J. K. Milne Dickie.)

The **utricle** is an elongated sac and occupies the posterosuperior portion of the vestibule. Its highest part lies in the elliptical recess, and the ampullæ of the superior and lateral semicircular ducts open into this part. The non-ampullated end of the lateral semicircular duct and the crus commune of the superior and posterior semicircular ducts open into its central part. The ampulla of the posterior semicircular duct opens into its lower and medial part. The floor and anterior wall of the highest part are thickened to form the **macula of the utricle**, to which the utricular fibres of the auditory nerve

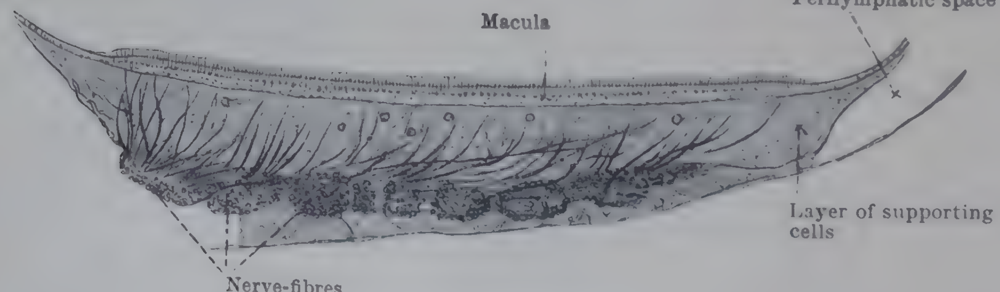


Fig. 1022.—Vertical Section of Wall of Highest Part of Utricle with the Macula and Bundles of Nerve-Fibres.

are transmitted through the foramina in the pyramid of the vestibule. The macula is pale in colour and of an oval or nearly rhombic shape; it measures 3 mm. in length and 2·3 mm. in its greatest breadth.

The **saccule** is smaller than the utricle, and occupies the spherical recess in the lower and anterior part of the vestibule. It is of an oval shape and measures 3 mm. in its longest diameter, and about 2 mm. in its shortest. It presents anteriorly a pale, oval thickening, called the **macula of the saccule**, which has a breadth of about 1·5 mm., and to which the saccular fibres of the auditory nerve are distributed. The upper end of the saccule is directed upwards and backwards and comes into contact with the utricle, and there the utricle and saccule are separated by a common wall (Dickie, 1920). From the lower

part of the saccule a short canal—the **ductus reuniens**—descends and gradually widens into the vestibular end of the duct of the cochlea. A second small channel, named the **endolymphatic duct**, is continued from the posterior part of the saccule, and is joined by a small canal, called the **utriculo-saccular duct**, which arises from the medial side of the utricle. The endolymphatic duct then enters and traverses the aqueduct of the vestibule and ends, under the dura mater on the posterior surface of the petrous part of the temporal bone, in a dilated blind pouch termed the **endolymphatic sac.**

Structure.—The walls of the utricle and saccule are composed of (*a*) an external layer of fibrous tissue which blends with the endosteal lining of the vestibule, (*b*) a middle, transparent layer and (*c*) an internal layer of epithelium. The walls are thickened at the maculæ; on them the epithelium is columnar, towards their periphery it is cubical, and elsewhere it is of the pavement type.

In the maculæ of the utricle and saccule two kinds of cells are found—(*a*) supporting cells, and (*b*) hair-cells. The **supporting cells** are fusiform, with the nucleus near the middle. Their deep ends are branched; their free ends lie between the hair-cells and form a thin, inner, limiting layer. The **hair-cells** are flask-shaped, their rounded ends lying between the supporting cells. Each hair-cell contains a large nucleus in its deepest part, the rest of the cell being granular and pigmented. From the free end of each there projects a stiff, hair-like process which, on the application of reagents, splits into several filaments. The nerve-fibres ramify around the deep ends of the hair-cells (Fig. 1022). A collection of small crystals of carbonate of lime, termed *otoliths*, adheres to each of the maculæ.

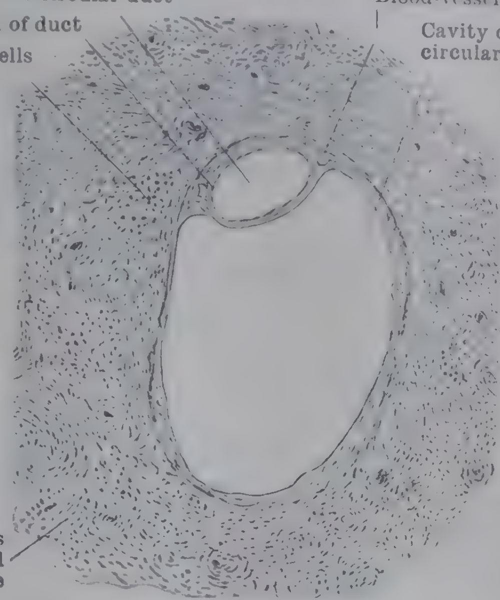


FIG. 1023.—SECTION OF A SEMICIRCULAR CANAL AND DUCT.

The **semicircular ducts** are elliptical on transverse section (Fig. 1023), and are very much smaller than the bony canals which contain them. Each duct is fixed by one of its walls to the endosteal lining of the canal, whilst the opposite wall bulges into the lumen of the canal. Like the bony canals, each of the semicircular ducts is dilated at one end into an ampulla, and the ampulla nearly fills the corresponding portion of the bony canal.

Structure.—Each semicircular duct has the same structure as the utricle and the saccule. In each ampulla the middle, transparent layer is thickened and projects into the cavity as a transverse elevation which, when seen from above, is fiddle-shaped; the most prominent part of the elevation is named the *ampullary crest*. The cells which cover the crest consist of **supporting cells** and **hair-cells**, and are similar in their arrangement to those in the maculæ of the utricle and saccule; the hairs of the hair-cells are, however, considerably longer, and project as far as the middle of the ampullary lumen.

The **duct of the cochlea** is a spirally arranged canal inside the bony cochlea. Its lower end occupies the cochlear recess of the vestibule and communicates with the saccule through the ductus reuniens; its upper end is closed and is named the **cæcum cupulare**; it is fixed to the cupola of the cochlea and partly bounds the helicotrema. As already stated (p. 1195), the basilar lamina stretches from the free edge of the osseous spiral lamina to the outer wall of the cochlea. A second more delicate membrane, called the **vestibular membrane**, stretches from the thickened endosteum of the upper surface of the osseous spiral lamina to the outer wall of the cochlea, some distance above the external attachment of the basilar lamina. A tunnel, triangular in transverse section, is thus enclosed between the basilar lamina below, the vestibular membrane above, and the wall of the scala vestibuli on the lateral side; this is the *duct of the cochlea*.

The **roof** of the duct is the vestibular membrane, which is an extremely delicate,

nearly homogeneous membrane, covered on both surfaces with a layer of epithelium. Its entire thickness is about 3 μ.

The **outer wall** is the endosteal lining of the bony cochlea, which is thickened and greatly modified to form the *spiral ligament of the cochlea*. This ligament

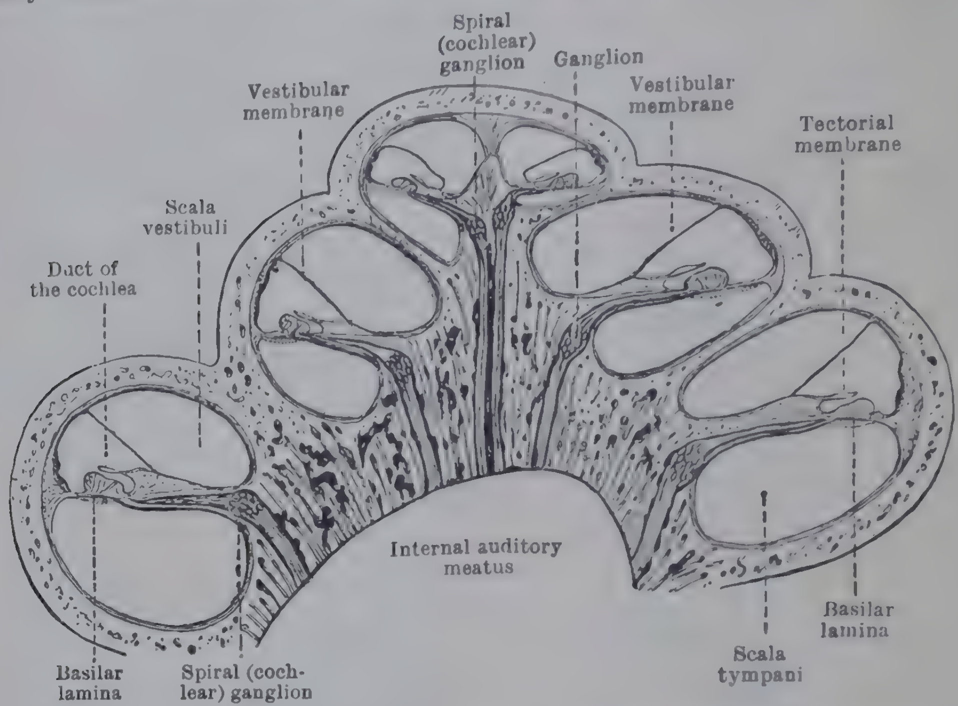


FIG. 1024.—AXIAL SECTION OF HUMAN COCHLEA. (Schafer's *Essentials of Histology.*)

projects inwards inferiorly as a triangular crest to which the outer edge of the basilar lamina is attached. The upper part of the spiral ligament contains, immediately under its epithelial lining, numerous small blood-vessels and capillary

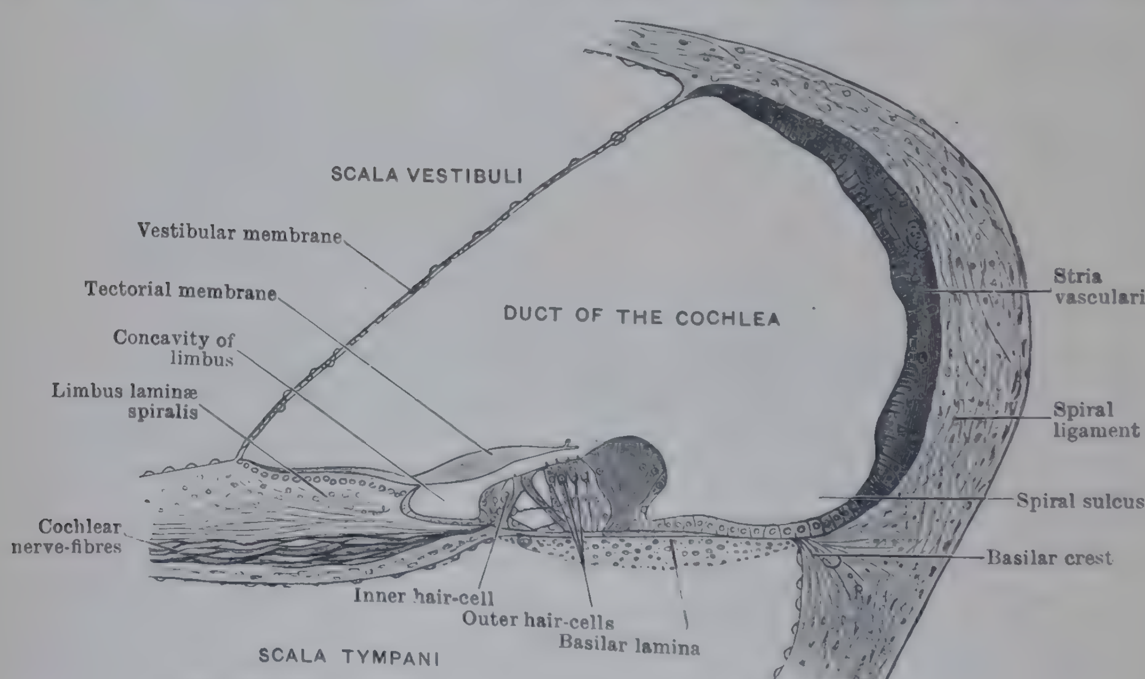


FIG. 1025.—SECTION ACROSS DUCT OF COCHLEA. (Retzius, 1881.)

loops, forming the **stria vascularis**. The lower limit of this stria is bounded by a prominence called the *spiral prominence*, in which a larger vessel—the **vas prominens** —is sometimes seen and below this prominence is a concavity, called the *spiral sulcus*. The height of the outer wall of the duct diminishes towards the apex of the cochlea.

The **floor** of the duct is formed by the lateral part of the osseous spiral lamina and by the basilar lamina. On the inner part of the basilar lamina the complicated

structure termed the *spiral organ* is situated. The osseous spiral lamina consists of two plates of bone between which the canals for the branches of the cochlear nerve are placed. On the upper plate the endosteum is thickened and modified to form the **limbus laminæ spiralis**, the outer border of which is concave, and appears, in radial sections, as a C-shaped indentation. The portions of the limbus which project above and below this concavity are termed respectively the *vestibular lip* and the *tympanic lip*. The tympanic lip is perforated by the branches of the cochlear nerves, and is continuous with the basilar lamina. The upper surface of the limbus and of its vestibular lip is divided into a series of blocks or segments by furrows that intersect each other at right angles; this gives to the free edge of the vestibular lip a dentated appearance, and here the segments are named the *auditory teeth.* The limbus is covered with a layer of apparently squamous epithelium; the deeper protoplasmic portions of the cells, however, with their contained nuclei, lie in the intervals between the blocks or segments just mentioned.

The **basilar lamina** stretches from the tympanic lip of the limbus to the crest of the spiral ligament. Its inner part is thin, and supports the spiral organ. Its

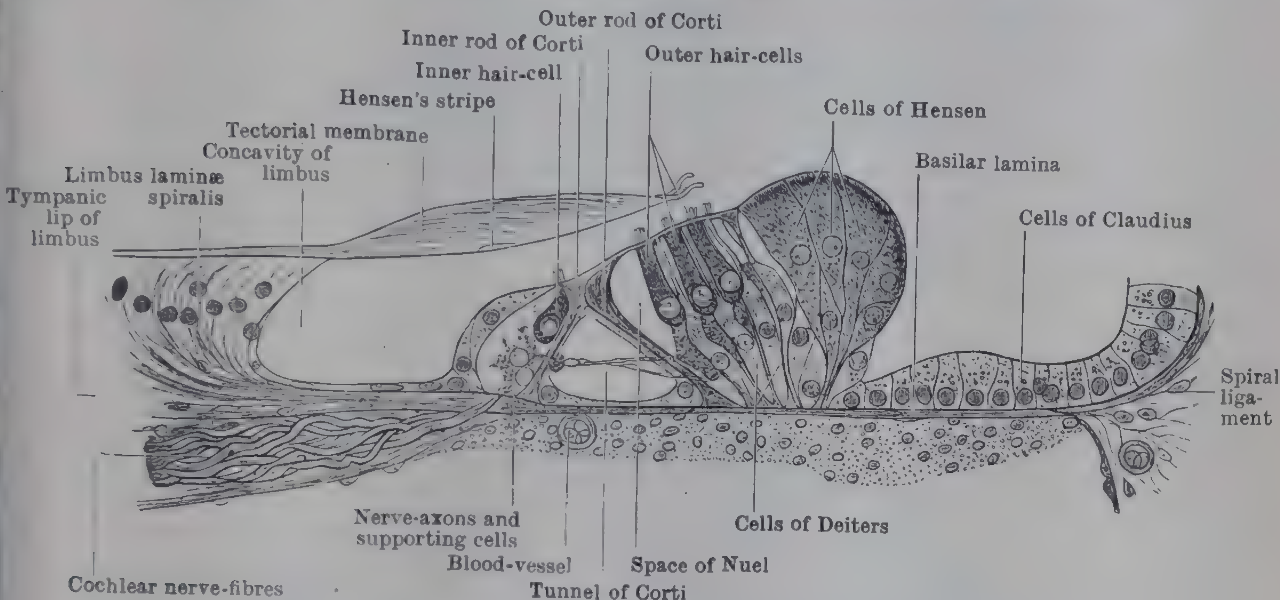


FIG. 1026.—TRANSVERSE SECTION OF SPIRAL ORGAN FROM CENTRAL COIL OF DUCT OF COCHLEA. (Retzius, 1881.)

outer part is thicker and striated. The under surface of the basilar lamina is covered with a layer of fibrous tissue which contains, in its inner part, small blood-vessels; one of them which lies below the more medial part of the spiral organ is considerably larger than any of the others. The width of the basilar lamina increases from 0·21 mm. in the basal coil to 0·36 mm. in the apical coil; its total length is 32 mm. (Hardy, 1938; Keen, 1940).

Spiral Organ.—This is an epithelial eminence of complicated structure, placed on the inner part of the basilar lamina. It extends throughout the entire length of the duct of the cochlea, and comprises the following structures: (1) Corti's rods or pillars, (2) hair-cells (inner and outer), (3) supporting cells of Deiters, (4) the cells of Hensen and Claudius, (5) the reticular lamina, and (6) the tectorial membrane (Fig. 1007).

The **rods of Corti** form two rows, **inner** and **outer**, of stiff, pillar-like structures, and each rod presents a base or foot-plate, an intermediate elongated portion, and an upper end or head. The bases of the rods are planted on the basilar lamina—those of the inner row at some little distance from those of the outer. The intermediate portions of the rods incline towards each other and the heads come into contact, so that the two rows and the basilar lamina enclose a triangular passage, called the **tunnel of Corti**; this tunnel increases both in height and width on passing towards the apex of the cochlea. The **inner rods** number nearly 6000, and the head of each resembles the upper end of the ulna—presenting externally a deep concavity for the reception of a corresponding convexity on the head of the outer rod. The part of the head which overhangs that concavity is prolonged outwards, under the name of the **head-plate**, and overlaps the head of the outer rod. The expanded bases of the inner rods are placed immediately on the outer side

of the foramina for the cochlear nerves in the tympanic lip of the limbus; the intermediate parts of these rods are sinuously curved, and form, with the basilar lamina, an angle of about 60°. The **outer rods** number about 4000, and are longer than the inner, especially in the upper turns of the cochlea. They are more inclined towards the basilar lamina, and form with it an angle of about 40°. The head of each is convex inwards, to fit the concavity on the head of the inner rod, and is prolonged outwards as a plate called the **phalangeal process**. The main part of each rod consists of a nearly homogeneous material which is finely striated. At the base of each rod, on the surface next Corti's tunnel, there is a nucleated mass of protoplasm which reaches as far as the head of the rod, and covers also a part of the floor of the tunnel; this protoplasm may be regarded as the undifferentiated part of the cell from which the rod was developed. Slit-like intervals, for the transmission of nerves, exist between the intermediate portions of adjacent rods.

Hair-Cells.—These, like Corti's rods, are arranged in two sets—**inner** and **outer**. The inner set is a single row lying immediately internal to the inner rods; the outer set is arranged in three or four rows placed to the outer side of the outer rods. The **inner hair-cells** are about 3500 in number; the diameter of each is greater than that of an inner rod, and so each inner hair-cell is supported by more than one rod. The free end of each hair-cell is surmounted by about twenty fine hair-like processes, arranged in the form of a crescent with its concavity directed inwards. The deep end of the cell contains a large nucleus and is rounded; it reaches only about half-way down the rod, and is in contact with the terminal arborizations of the nerves. To the inner side of this row of hair-cells there are two or three rows of elongated columnar cells which act as supporting cells, and are continuous with the low columnar cells that line the concavity of the limbus. The **outer hair-cells** number about 12,000, and are arranged in three rows in the basal coil and four rows in the upper two coils, although in the higher coils the rows are not so regularly arranged. The free, rounded end of each hair-cell supports about twenty hairlets arranged in the form of a crescent opening inwards; the deep end reaches about half-way to the basilar lamina and is in contact with the arborization of the nerves.

Deiters' supporting cells alternate with the rows of the outer hair-cells; their lower ends are expanded on the basilar lamina, and their upper ends are tapered. The nucleus is placed near the middle of each cell, and, in addition, each cell contains a bright, thread-like structure called the **supporting fibre**. That fibre is attached by a club-shaped base to the basilar lamina, and expands, at the free end of the cell, to form one of the phalanges of the reticular lamina, which is described below.

The **cells of Hensen**, or outer supporting cells, are arranged in about half a dozen rows immediately outside Deiters' cells, and are the most elevated part of the spiral organ. Their lower ends are narrow and attached to the basilar lamina, whilst their free ends are expanded. The columnar cells situated to the outer side of the cells of Hensen, and covering the outer part of the basilar lamina, are named the **cells of Claudius**. An interval exists between the outer rods of Corti and the neighbouring row of hair-cells and is termed the **space of Nuel**; it communicates with Corti's tunnel, and extends outwards between the outer hair-cells as far as Hensen's cells.

The **reticular lamina** is a thin sheet that extends from the heads of the outer rods to Hensen's cells, and is formed from expansions of these two structures. These expansions are termed the **phalanges** of the lamina, and are arranged in rows corresponding with the heads of the outer rods, the cells of Hensen, and the cells of Deiters, which also contribute to its formation. The free ends of the hair-cells occupy the intervals between the phalanges.

The **tectorial membrane** is a projecting shelf, composed of multitudes of delicate fibres in a matrix of jelly-like consistence, which overhangs the inner half of the spiral organ. Attached by its inner border to the limbus near the vestibular membrane, it reaches outwards as far as the outer row of hair-cells. Its inner portion is thin and overlies the auditory teeth of the limbus. Its outer part is thickened but becomes attenuated near its free border, which is fringed. The under surface rests on the inner and outer rows of hair-cells like a pad, and it shows, about half-way along its width, a clear spirally arranged band named **Hensen's stripe**.

Auditory Nerve (Fig. 1027).—This nerve divides in the internal auditory meatus into a cochlear nerve and a vestibular nerve.

The **cochlear nerve** is the nerve of hearing. Its fibres originate from the cells of the **spiral ganglion**. This ganglion is situated in the spiral canal of the modiolus; and from the ganglion the centrally directed fibres traverse the

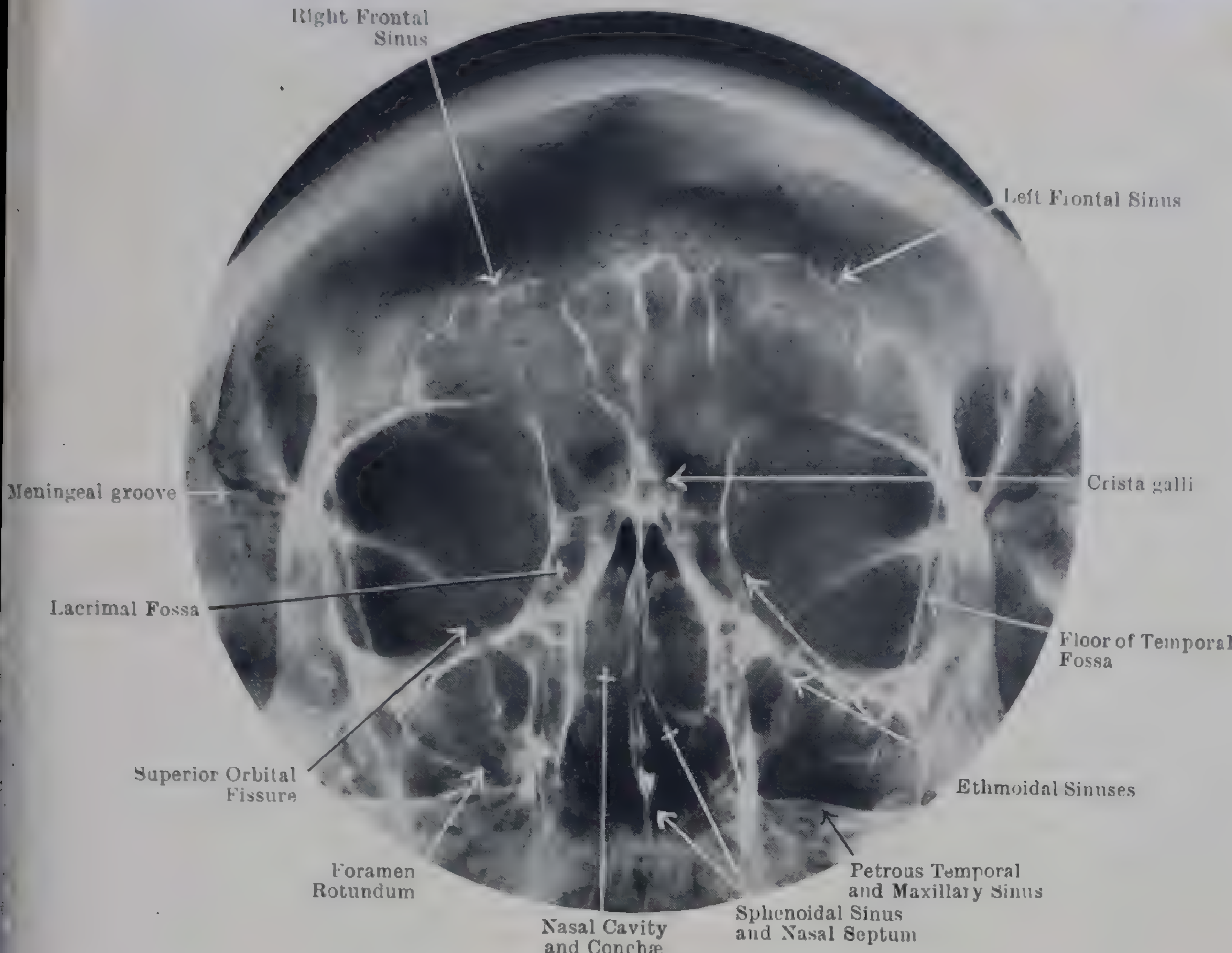


FIG. 1.—OCCIPITO-MENTAL RADIOGRAPH OF SKULL TO SHOW IN PARTICULAR THE EXTENT AND ASYMMETRY OF THE FRONTAL SINUSES.

FIG. 2.—LATERAL RADIOGRAPH OF SKULL WITH SLIGHT TILT.

PLATE LXXVII.—RADIOGRAPHS OF SKULL TO SHOW THE PARANASAL AIR-SINUSES FROM TWO POINTS OF VIEW.

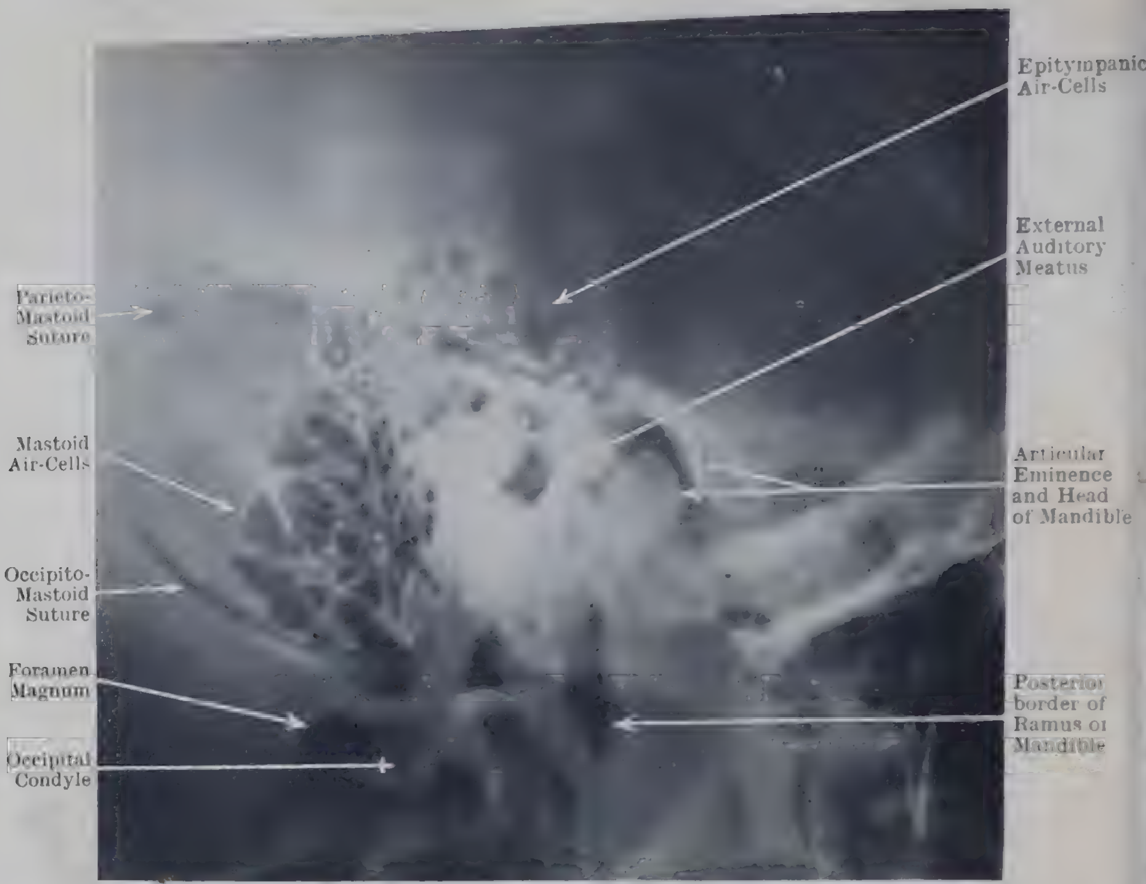


FIG. 1.—OBLIQUE LATERAL RADIOGRAPH OF LEFT MASTOID REGION (YOUNG WOMAN, AGED 22), SHOWING MASTOID AND EPITYMPANIC AIR-CELLS.

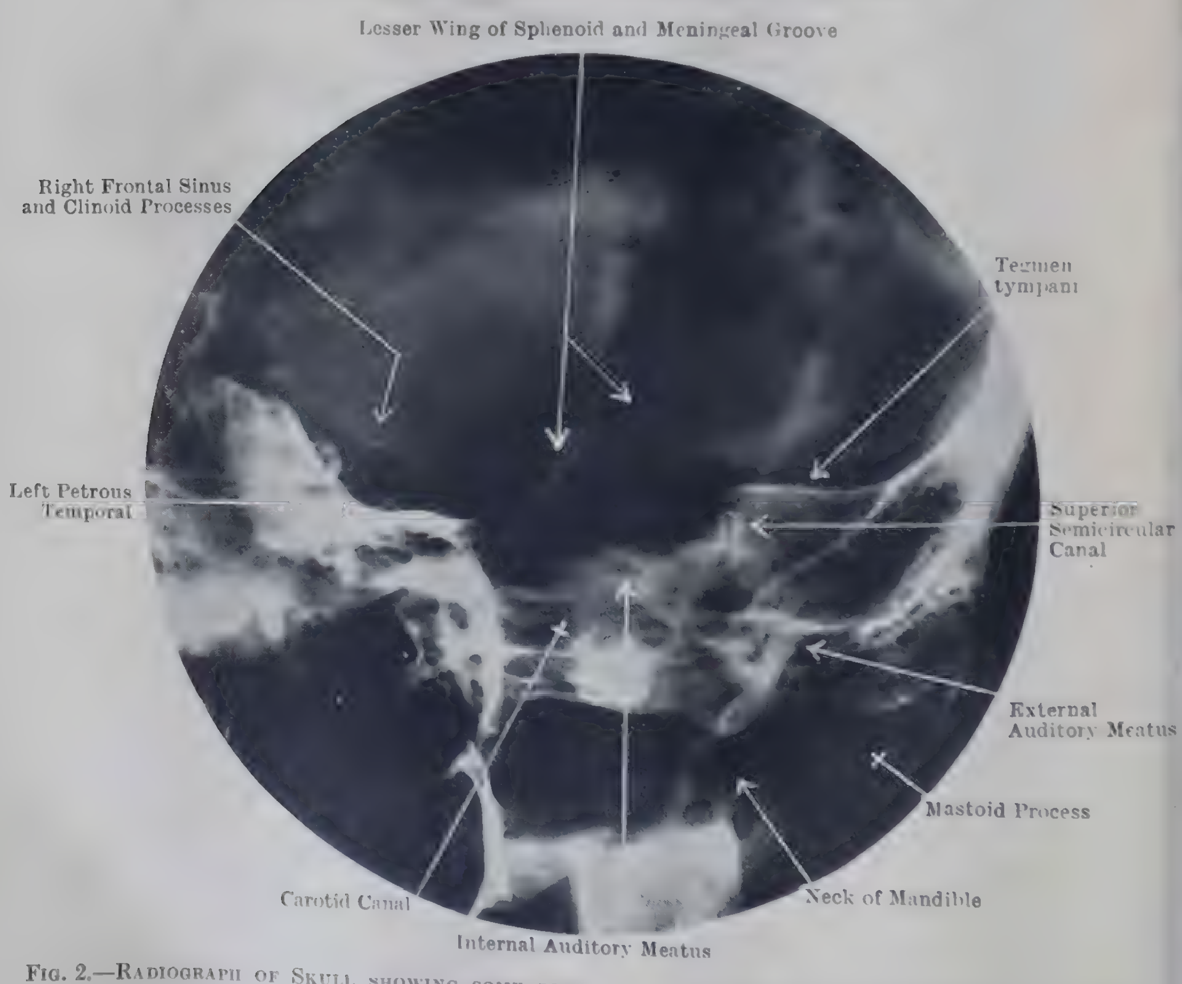


FIG. 2.—RADIOGRAPH OF SKULL SHOWING SOME DETAILS OF THE TEMPORAL BONES (Stenver's projection).

modiolus—those from the apical coil emerging at the internal auditory meatus through the central foramen and those from the basal coils through the holes in the tractus spiralis foraminosus. The peripherally directed fibres extend outwards, at first in bundles, and then in a more or less continuous sheet; from the outer edge of the sheet they are again collected into bundles which pass through the foramina of the tympanic lip of the limbus laminæ spiralis. Beyond this point they appear as naked axis-cylinders, and turn in a spiral manner towards the inner row of hair-cells. Other fibrils run between individual inner rods and through Corti's tunnel, from which they enter Nuel's space, and pass towards the bases of the outer hair-cells. The hair-cells in the basal and middle coils of the cochlea are more richly supplied with nerves than those in the apical coil. The cochlear nerve also gives

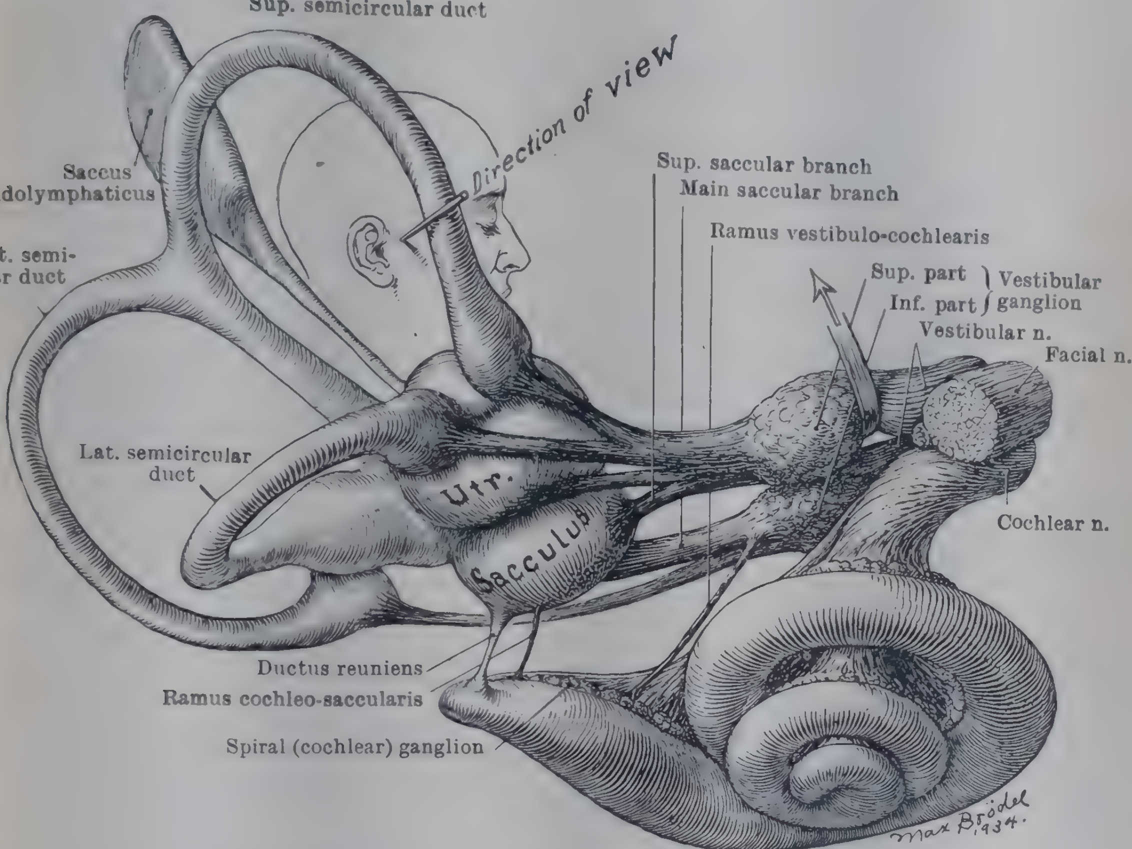


FIG. 1027.—DISTRIBUTION OF AUDITORY NERVE TO THE MEMBRANOUS LABYRINTH. (M. Hardy, *Anatomical Record*, 1934.)

off a branch whose terminal filaments go through the foramina in the cochlear recess to be distributed to the hair-cells of the vestibular end of the cochlear duct.

The **vestibular nerve** is the nerve of equilibration and is distributed to the utricle, the saccule, and the ampullæ of the semicircular ducts; its fibres are derived from cells in the **vestibular ganglion**, which is usually placed in the internal auditory meatus. From the ganglion, which may be split into two or even three parts, two main branches arise—a superior and an inferior. The filaments from the superior branch go through the foramina in the superior vestibular area of the internal auditory meatus and supply the macula of the utricle, the ampullary crests of the superior and lateral semicircular ducts, and the anterior end of the macula of the saccule; those from the inferior branch run through the foramina in the inferior vestibular area to supply the greater part of the macula of the saccule and, through the foramen singulare, to the ampulla of the posterior semicircular duct, which receives some six to eight filaments. In addition, there arises from the inferior division of the vestibular nerve a branch, the ramus vestibulo-cochlearis, which passes to the spiral ganglion of the cochlea at the beginning of its basal coil. Another branch has been described (Hardy, 1934) which passes from the beginning of the cochlear ganglion to the surface of the saccule running a course parallel to the ductus reuniens (Fig. 1027).

Vessels of Internal Ear.—The **arteries** are the internal auditory branch of the basilar artery and the stylo-mastoid branch of the posterior auricular artery. The internal auditory artery enters the internal meatus and divides into vestibular and cochlear branches which are distributed to the structures supplied by the corresponding nerves. The **veins** from the cochlea and vestibule unite, at the bottom of the internal meatus, with the veins from the semicircular canals to form the **internal auditory vein**, which may open either into the posterior part of the inferior petrosal sinus or into the sigmoid sinus. A small vein passes through the aqueduct of the cochlea and opens into the inferior petrosal sinus or into the internal jugular vein. Another small vein traverses the aqueduct of the vestibule and ends in the superior petrosal sinus.

Development of Ear

External Ear.—The development of the external ear is associated with the first and second (mandibular and hyoid) pharyngeal arches and the intervening (first) external pharyngeal groove.

In a 12 mm. embryo the dorsal end of each of these two arches is divided into three tubercles or "*hillocks*"; these are seen more clearly in some specimens than in others and they are always

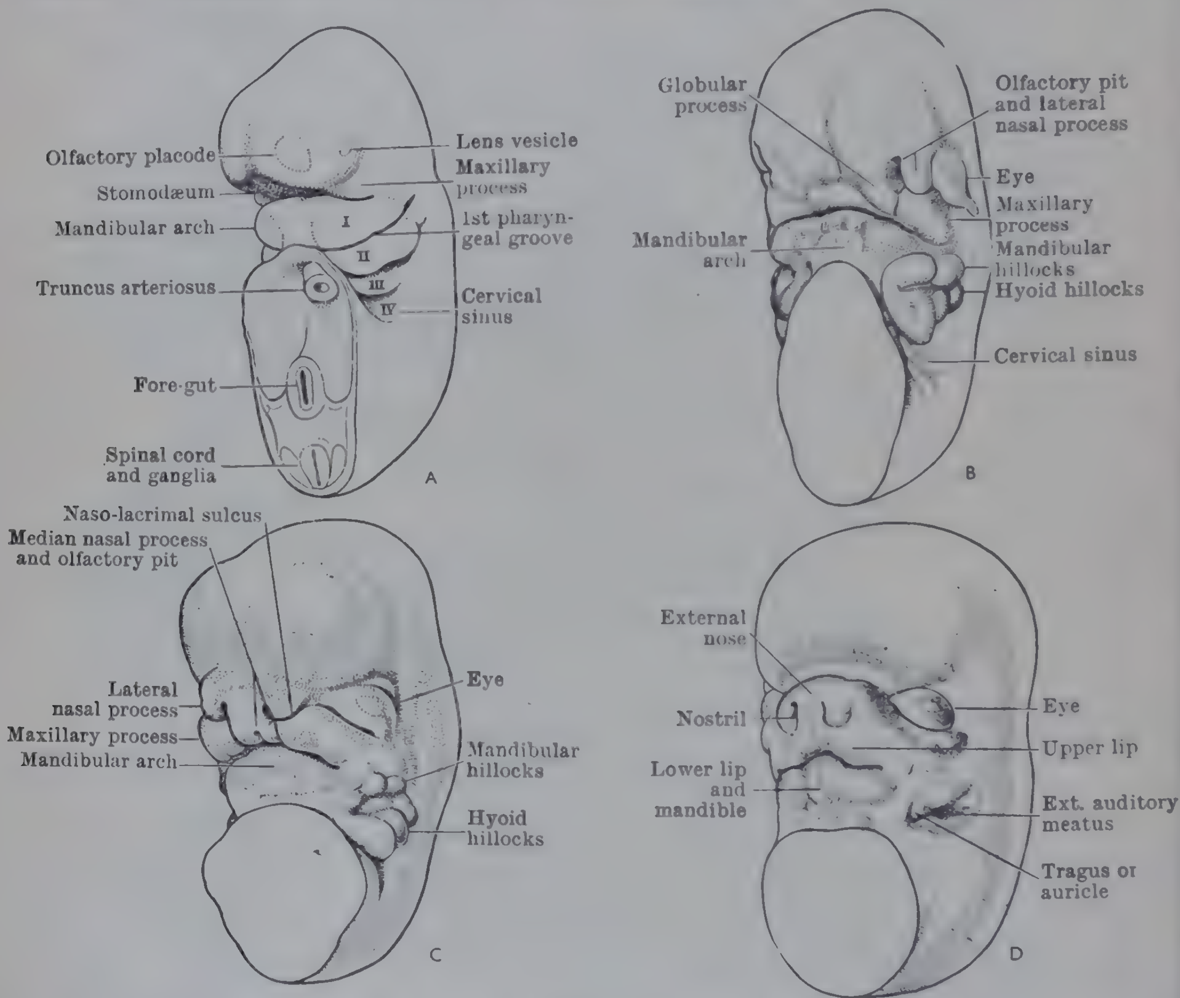


Fig. 1028.—Ventro-Lateral view of Head in series of Human Embryos showing Development of Face and External Ear. (After G. L. Streeter, 1922.) Note the lateral and dorsal migration of the auricle coincident with the formation of the lower lip and mandible.

A, 6 mm. embryo × 11; B, 12 mm. × 7·5; C, 14 mm. × 7·5; D, 18 mm. × 6.
I, II, III, IV, pharyngeal arches.

developed better on the hyoid arch than on the mandibular (Fig. 1028, B, C). In an 18 mm. embryo, the hillocks have disappeared as separate entities and are replaced by a general swelling of the dorsal end of each arch (Streeter, 1922). During the course of development, the mandibular arch grows in a ventral direction to meet the arch of the opposite side and form the basis of the lower jaw; and thus its auricular swelling is carried ventrally and only the most dorsal part remains in relationship to the future auricle, of which it forms the tragus. The auricular swelling of the hyoid arch undergoes greater development, and it grows round the dorsal end of the first external pharyngeal groove and on to its anterior border. It ultimately gives rise to the whole **auricle except the tragus** (Wood Jones & I-Chuan, 1934). It is clear from the descriptions given by Streeter and Wood Jones: (1) that the early development of hillocks on the margins of the first pharyngeal groove is merely an expression of exuberant local growth of mesoderm;

(2) that the hillocks do not give rise directly to the several parts of the auricle, as originally described by His; and (3) that the hyoid arch takes a much greater share than the mandibular in the formation of the auricle.

It will be understood that the first external pharyngeal groove therefore forms the greater part of the **external auditory meatus**, which is lined with the original ectoderm of the groove; but the external meatus has an additional origin.

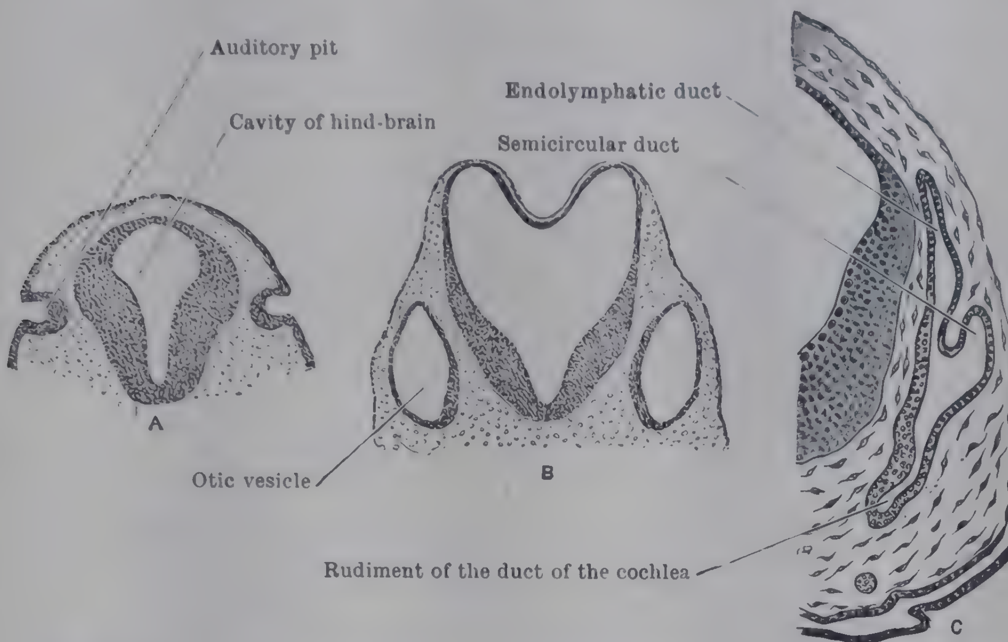


FIG. 1029.—SECTIONS THROUGH HIND-BRAIN OF FŒTAL RABBITS TO ILLUSTRATE DEVELOPMENT OF MEMBRANOUS LABYRINTH.

About the end of the second month of intra-uterine life, the ectoderm at the bottom of the groove grows in towards the future tympanic cavity as a solid mass of cells—the *meatal plate.* This ingrowth of ectoderm does not, however, come into contact with the entoderm of the tympanic cavity but is separated from it by mesoderm in which there occurs a condensation to form **the handle of the malleus**, which thus comes to be covered with entoderm on its inner surface and ectoderm on its outer. In the later months of fœtal life the deeper part of the external auditory meatus is formed by a breaking down of the central cells of the meatal plate—the cells at the bottom of the ingrowth forming the cuticular layer of the tympanic membrane, the mesoderm in which the condensation for the malleus occurs forming the fibrous layer of the membrane, and the entoderm of the tympanic cavity forming its mucous layer.

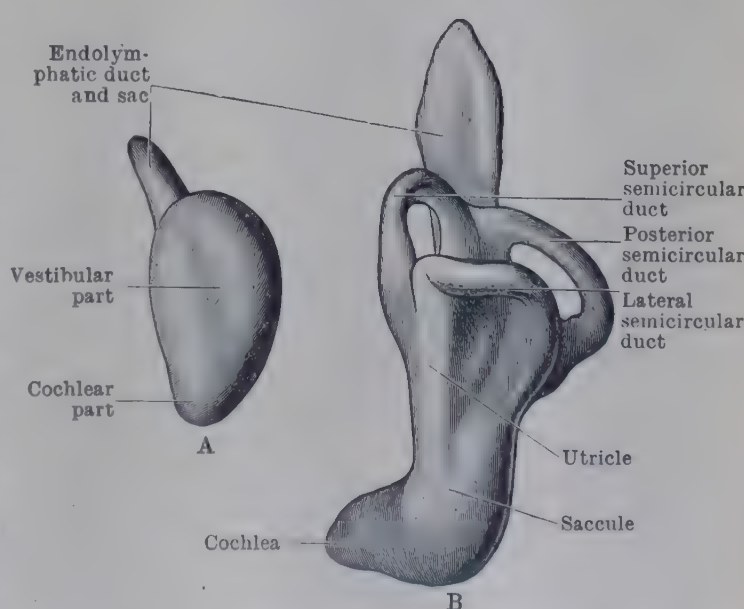


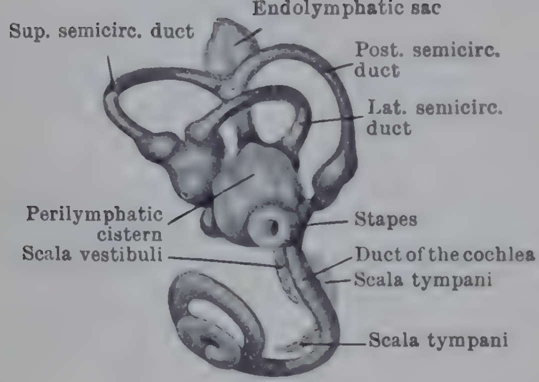
FIG. 1030.—THE LEFT MEMBRANOUS LABYRINTH SEEN FROM THE LATERAL SIDE, A, AT ABOUT THE FOURTH WEEK, AND B, AT ABOUT THE FIFTH WEEK. (W. His, Jr.)

Middle Ear and Pharyngo-Tympanic Tube.—These are developed from the *tubo-tympanic recess* (Frazer, 1914), which is an upward and lateral outgrowth from the widest part of the pharynx involving the first and second internal pharyngeal pouches and the mandibular and hyoid arches. Its distal end is expanded and becomes partly constricted off to form the **tympanic cavity**; but it retains its connexion with the pharynx through a narrow channel which becomes the **pharyngo-tympanic tube**.

The tubo-tympanic recess grows in an oblique direction so that both its roof and floor are set obliquely; its roof becomes the medial wall of the tympanic cavity and its floor becomes the lateral wall. The floor is separated from the meatal plate by the mesoderm in which the malleus develops, and it comes to form the mucous lining of the tympanic membrane, the oblique position of this structure being due to the original oblique position of the floor of the recess. In relation to the roof of the recess there is the *otic vesicle*, from which the membranous labyrinth is developed, and which thus lies on the medial side of the tympanic cavity in the adult.

Just as the first external pharyngeal groove is not the only source of formation of the external auditory meatus, so the tubo-tympanic recess is not the sole origin of the tympanic cavity. The handle of the malleus has been described as being formed from a mesodermal condensation between the meatal plate and the tubo-tympanic recess; the remainder of the **malleus**, the **incus**, and the **stapes** are likewise formed from a condensation of mesoderm at the dorsal end of the mandibular and hyoid arches, the perforated condition of the stapes being due to the fact that the condensation occurs around the artery of the second pharyngeal arch—the *stapedial artery*—which later atrophies but leaves its original track as the foramen in the stapes. Ossification of all three bones begins in the third month of intra-uterine life. The malleus is ossified from two centres, one for the head and handle and one for the anterior process; the incus from one centre appearing in the upper part of the long process; and the stapes from one centre in the base of the bone.

The muscles of the ossicles—**tensor tympani** and **stapedius**—are similarly developed in association with the dorsal ends of the mandibular and hyoid arches and thus come to receive a supply from the nerves of these arches—the fifth and seventh cranial nerves. For many years it has been considered that the malleus and incus are derived from the end of Meckel's cartilage (the cartilage of the first arch), and that the stapes is derived from Reichert's cartilage (the cartilage of the second arch); the arrangement of the muscles of the ossicles and their nerve-supply was



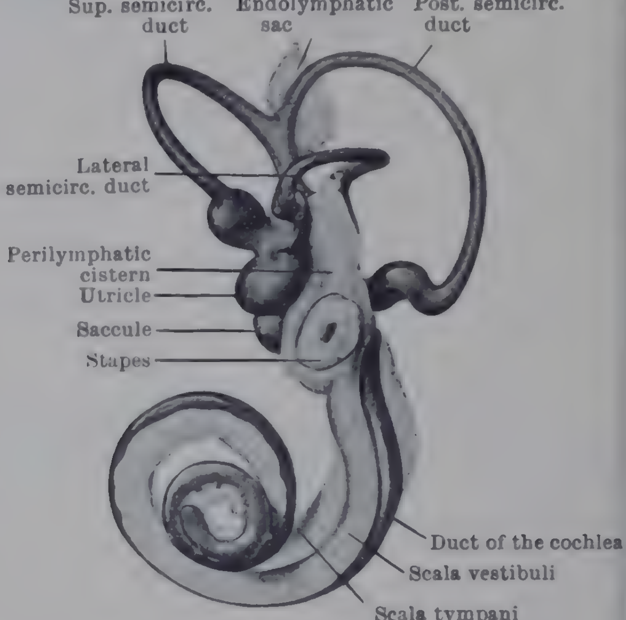


FIG. 1031.—MEMBRANOUS LABYRINTHS OF HUMAN EMBRYOS (Streeter, 1918). A, 50 mm. B, 85 mm.

considered to be evidence for this source of origin of the ossicles. It has, however, been suggested by Lightoller (1939) that the head of the malleus is the only part of any of the ossicles which is derived from the mandibular arch, and the rest of the malleus, the incus, and the stapes are all derivatives of the hyoid arch. Such a suggestion is not contrary to the arrangement of the muscles and their nerves, referred to above, for the tensor tympani is attached to that part of the malleus which is a derivative of the first arch. The ossicles at first do not lie in direct relationship to the tubo-tympanic recess but are placed dorsal and lateral to it, and are developed in a mass of mesoderm; a subsequent solution of this mesoderm around the ossicles gives rise to the formation of a series of cavities which come into communication with the cavity of the tubo-tympanic recess; and thus the ossicles appear to lie in the tympanic cavity whilst they are really separated from it by the entodermal lining of the recess and by a thin film of the mesoderm in which they were developed. They thus have the same sort of relationship to the tympanic cavity that the abdominal viscera have to the peritoneal cavity.

About the end of the sixth month of fœtal life the **tympanic antrum** begins to develop as an extension of the tympanic cavity, and from birth onwards further extensions produce the **mastoid cells**.

Internal Ear.—The epithelial lining of the labyrinth is derived from an ectodermal thickening, the **auditory placode**, which appears opposite the hind-brain immediately above the first pharyngeal groove in an embryo of 2 mm. CR length. An invagination of this placode gives rise to the **auditory pit**. The mouth of the pit is closed by the growing together of its margins, and the pit then assumes the form of a vesicle—the **otic vesicle**—which severs its connexion with the ectoderm and sinks into the mesoderm. The vesicle soon becomes pear-shaped; and its middle part gives off a diverticulum which later forms the **endolymphatic duct** and **sac**. About the fifth week the ventral part of the vesicle is prolonged medialwards and forwards as a diverticulum—the future **duct of the cochlea**. The diverticulum is at first short and straight, but it elongates and curves on itself, so that at the twelfth week all three coils of the cochlear duct are differentiated. From the upper part of the vesicle the three **semicircular ducts** are developed, and appear as hollow, disc-like evaginations; the central parts of the walls of each disc coalesce and disappear,

leaving only the peripheral ring or canal. The three ducts are free about the beginning of the second month, and are developed in the following order, viz.: superior, posterior, and lateral. The part of the otic vesicle from which the endolymphatic duct arises becomes divided by a constriction into an anterior part—the **saccule**—which communicates with the duct of the cochlea, and a posterior part—the **utricle**—which communicates with the semicircular ducts. The constriction extends for some distance into the endolymphatic duct, and thus the utricle and saccule are connected by a Y-shaped tube. Another constriction makes its appearance between the saccule and the vestibular end of the duct of the cochlea and forms the **ductus reuniens**. The epithelial lining is at first columnar, but becomes cubical throughout the whole labyrinth, except opposite the terminations of the auditory nerve, where it forms the columnar epithelium of the maculæ of the utricle and saccule, of the ampullary crests, and of the spiral organ. On the floor of the duct of the cochlea two ridges appear, of which the inner forms the limbus laminæ spiralis, whilst the cells of the outer become modified to form the rods of Corti, the hair-cells, and the supporting cells of Deiters and Hensen. (See Bast, Anson & Gardner, 1947.)

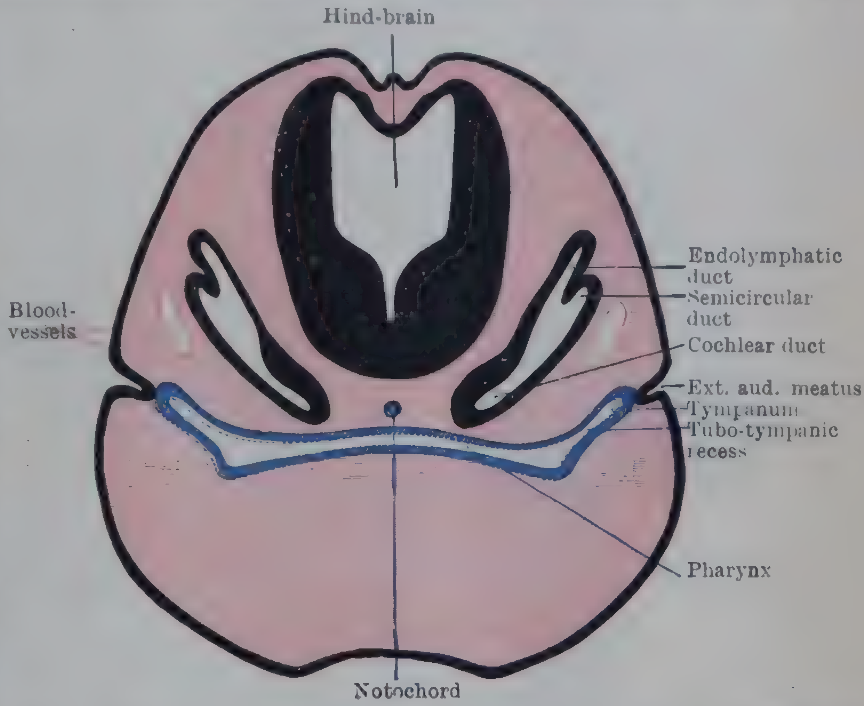


FIG. 1032.—DIAGRAM OF TRANSVERSE SECTION THROUGH THE HEAD OF AN EMBRYO. Showing the rudiments of the three parts of the ear and their relation to the tubo-tympanic recess and the first pharyngeal groove.

In the development of the perilymphatic spaces, the mesoderm surrounding the otic vesicle and its subsequent derivatives becomes differentiated into three layers—an inner reticular, a middle precartilaginous, and an outer cartilaginous. Room must be made in the enclosing cartilaginous labyrinth for the growing membranous portion, and this is brought about by a reversion of the precartilaginous layer next the membranous labyrinth into the more primitive type of reticular tissue; a breaking down of the fibrillæ of this tissue allows of a confluence between the enclosed spaces, which thus come to form the more or less completely open perilymphatic spaces that enclose the membranous labyrinth. The **scala vestibuli** appears as an outgrowth from the primitive cistern-like space which is developed in relation to the saccule and utricle, while the **scala tympani** appears independently a little earlier; these scalæ follow the turns of the cochlear duct and unite at the helicotrema about the sixteenth week.

For the development and ossification of the **auditory capsule**, see pp. 212, 224. Bast & Anson (1949) give a detailed account of the anatomy of the internal ear from the developmental point of view, with full bibliography.

ORGAN OF SMELL

The nose is the peripheral **organ of smell** and consists of: the external nose, which projects from the face; and the cavity of the nose, which is divided by a vertical septum into right and left chambers.

External Nose.—This resembles an irregular three-sided pyramid. Two sides of the pyramid are almost symmetrical and are the sides of the nose, which join the face at wide open angles and are separated from each other by a more or less sharp margin named the **dorsum** of the nose. The dorsum is continuous with the forehead at the **root** of the nose and ends below in the **apex** of the nose, beyond which the nose is continued into the upper lip. The third side of the pyramid is the smallest, is directed downwards, and has in it two orifices called the **nostrils**. These are usually elliptical in the adult but more circular in children; they are separated from each other by a median septum, and each is bounded on the lateral side by the **ala** of the nose, which is the expanded lower part of the side of the nose. The upper part of the nose is fixed in position, being supported

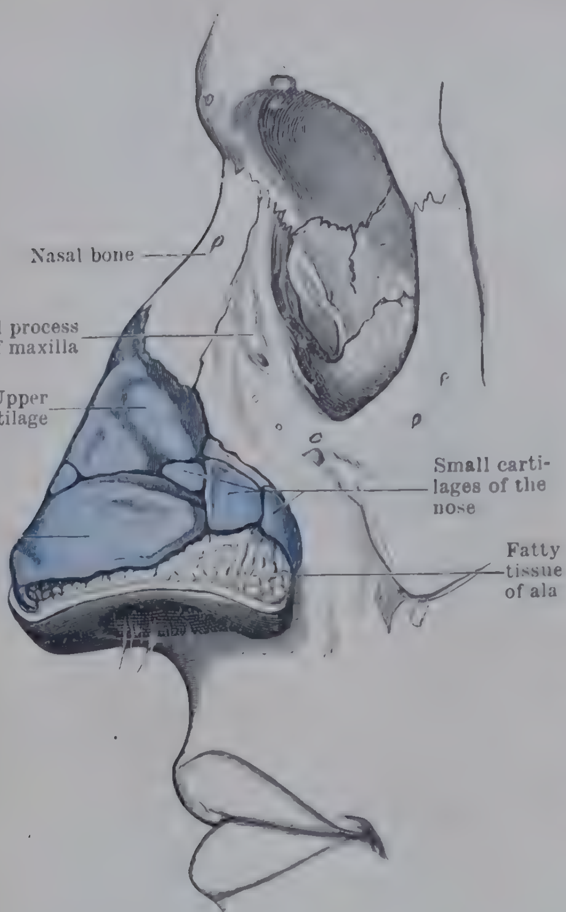


FIG. 1033.—PROFILE VIEW OF BONY AND CARTILAGINOUS SKELETON OF EXTERNAL NOSE.

by the nasal bones and the frontal processes of the maxillæ, and it is covered with thin and movable skin; the lower part, being supported only by pliable cartilages, is movable, and it is covered with thick and closely adherent skin in which there are many large sebaceous glands.

Vessels and Nerves.—The arteries are branches of the *facial artery* and of the *ophthalmic artery*. The **veins** open into the *anterior facial vein* and also communicate with the *ophthalmic vein*. The principal **lymph-vessels** follow the course of the anterior facial vein and open into the *submandibular lymph-glands*; but from the upper part of the nose a few vessels run sidewards in the upper and lower eyelids and end in the **superficial parotid lymph-glands**. The **nerves** to the muscles of the external nose come from the *facial nerve*, and to the skin from the infra-orbital branch of the *maxillary nerve* and from the infra-trochlear and external nasal nerves, which are derived from the naso-ciliary branch of the *ophthalmic nerve*.

CARTILAGES OF NOSE

Five chief cartilages are concerned in the formation of the nose; they are the upper and lower cartilages on each side, and the septal cartilage.

The **upper cartilage** (Figs. 1033, 1034) is triangular in shape and is situated immediately below the nasal bone. Its posterior edge is thin and is attached to the maxilla and to the nasal bone by fibrous tissue. The anterior edge is thick; its upper part is directly continuous with the cartilage of the septum, but its lower part is separated from that cartilage by a narrow fissure. The lower edge is joined by fibrous tissue to the lower cartilage.

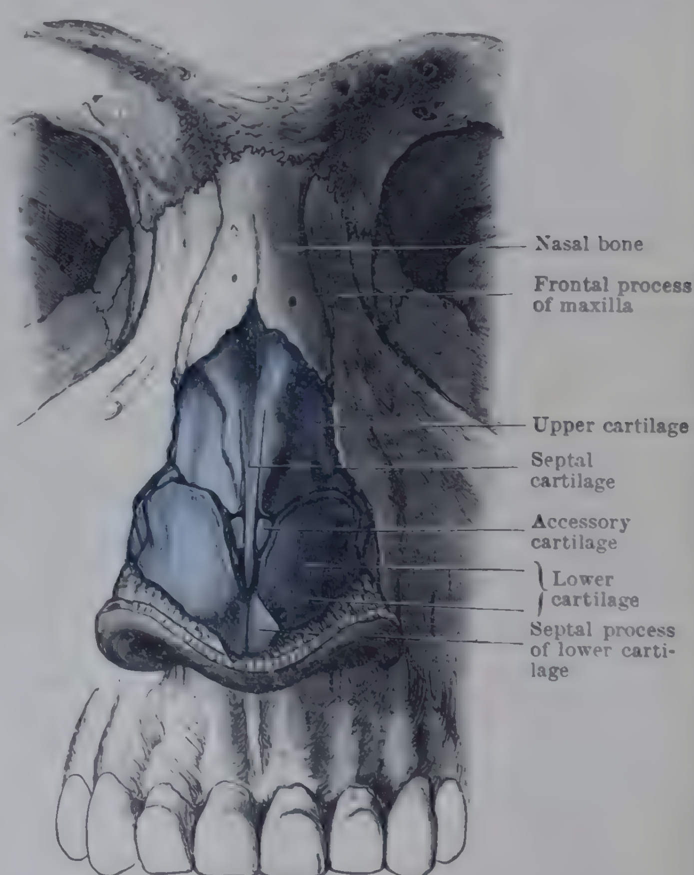


FIG. 1034.—FRONT VIEW OF BONY AND CARTILAGINOUS SKELETON OF EXTERNAL NOSE

The **lower cartilage of the nose** (Figs. 1033, 1034) is elliptical, with the long axis directed downwards and forwards. It forms a support for the lateral side and front of the nostril. Its anterior end is turned inwards as a small hook-like process called the **septal process**. The lower cartilage is connected above with the upper and septal cartilages, and behind with the maxilla by fibrous tissue, in which two or three *small cartilages of the nose* are embedded; in

front it is separated from its fellow by a gap, filled with fibrous tissue, which can easily be felt in the living subject.

The **septal cartilage** (Fig. 1035) is of an irregular quadrilateral form. Its postero-superior edge is attached to the perpendicular plate of the ethmoid bone; its postero-inferior margin to the vomer and to the nasal crests of the maxillæ. Its antero-superior border is thick and is fixed above to the back of the internasal suture; immediately below that suture it is directly continuous with the upper parts of the upper cartilages of the nose, which may be looked upon as its wing-like expansions. Its lower part is separated from the upper and lower cartilages of the nose by a narrow fissure filled with fibrous tissue in which a small accessory cartilage is usually seen. The antero-inferior border of the septal cartilage is short and is

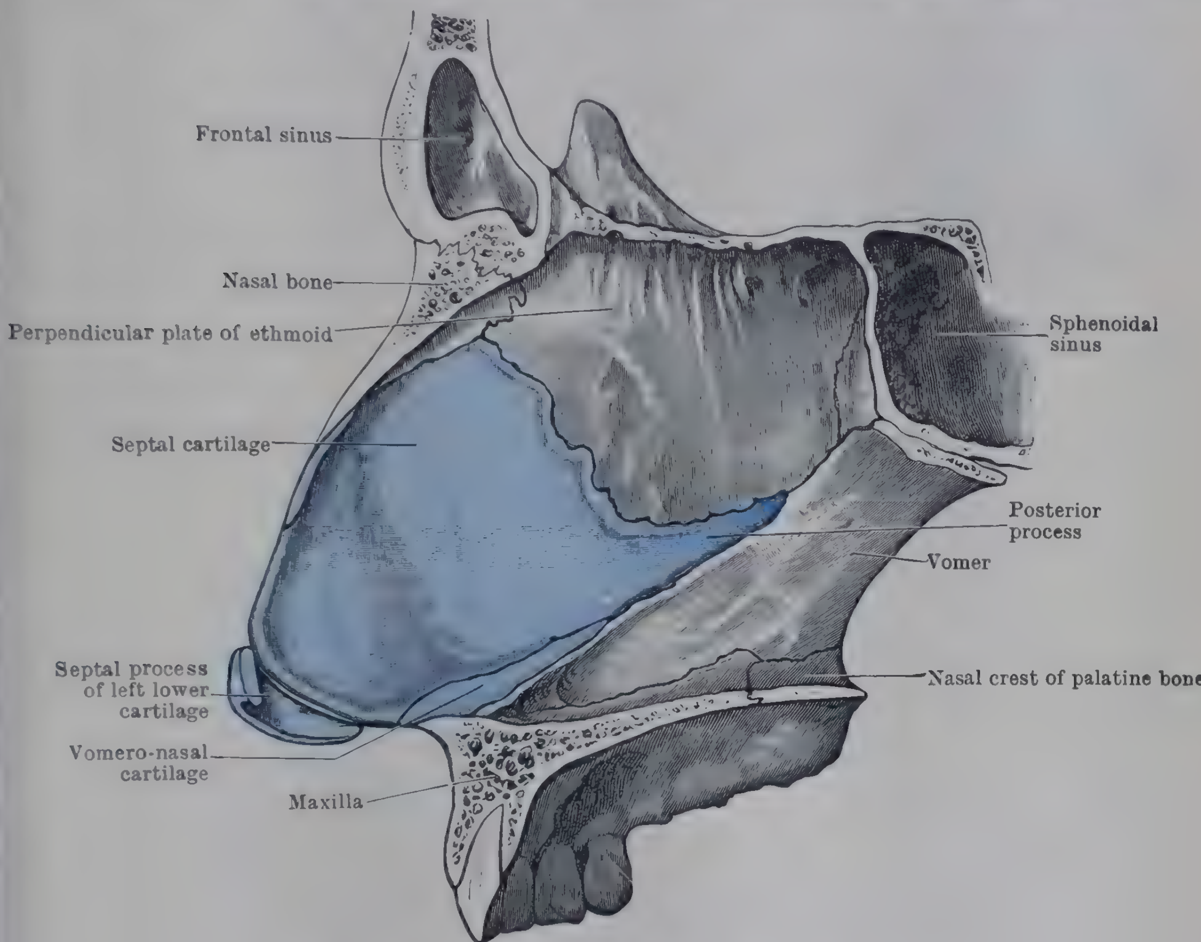


FIG. 1035.—VIEW OF NASAL SEPTUM FROM THE LEFT SIDE.

attached by fibrous tissue to the septal processes of the lower cartilages; its anterior angle is rounded and does not reach as far as the apex of the nose. The septal cartilage may be prolonged backwards (especially in children) as a narrow process into the angle between the vomer and the ethmoid bone.

On each side of the postero-inferior edge of the septal cartilage there is a narrow band of cartilage, called the **vomero-nasal cartilage** (Fig. 1035) since it lies below the rudimentary vomero-nasal organ (p. 1208).

The lowest part of the nasal septum is not formed by the septal cartilage but by the septal processes of the lower cartilages and by the skin; it is therefore double and, being freely movable, is termed the **movable part of the septum.**

CAVITY OF NOSE

The **cavity of the nose** extends from the *nostrils* in front to the *posterior apertures* of the nose behind; it is divided into right and left cavities by the *septum* of the nose, and it opens through the posterior apertures into the space known as the nasal part of the pharynx. The medial or septal wall of each nasal cavity is smooth and flat, while the lateral wall is irregular owing to the presence of the nasal conchæ.

Immediately above the nostril there is a slightly expanded portion, called the **vestibule**, which is bounded laterally by the lower cartilage of the nose, and medially by the lower part of the septum. It is lined with skin; and it is prolonged as a small recess towards the apex of the nose. The vestibule is partly divided by a curved ridge; in the lower part there are hairs and sebaceous glands, the hairs being curved downwards to guard the entrance to the nostril; the upper part is smooth, and is limited superiorly by a slight, arched prominence caused by the lower edge of the upper cartilage.

Each nasal cavity is divided into an upper or olfactory region and a lower or respiratory region. The **olfactory region**, to which alone the olfactory nerves are distributed, is the slit-like upper and posterior part of the cavity below the cribriform plate of the ethmoid bone; the remainder of the cavity is the **respiratory region**.

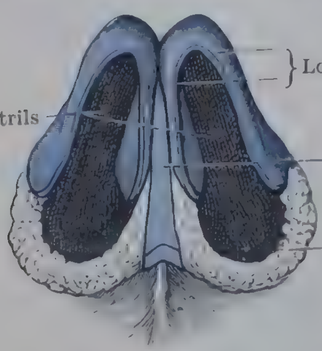


Fig. 1036.—Cartilages of Nose from below.

Septum of Nose.—The septum is partly bony and partly cartilaginous.

The upper part of the **bony septum** is formed chiefly by the perpendicular plate of the ethmoid, and slightly by the crest of the nasal bones in front and the crest of the sphenoid behind. The lower part is formed by the vomer and by the nasal crests of the maxillæ and of the palatine bones. The cartilaginous part of the septum is its antero-inferior part and is formed by the septal cartilage, which, as described on p. 1207, fills the gap between the ethmoidal and vomerine parts of the bony septum. In the septum, a little above and in front of the incisive canals, on each side of the median plane, there is a minute orifice, not always recognizable, from which a blind pouch—the **vomero-nasal organ**—extends upwards and backwards for a distance of from 2 to 9 mm.; it lies above the vomero-nasal cartilage. In Man the vomero-nasal organ is vestigial (Fig. 1039), but in many of the lower animals, *e.g.*, lizard, rabbit, it is well developed and is lined with epithelium similar to that of the olfactory region, and is supplied by branches of the olfactory nerve.

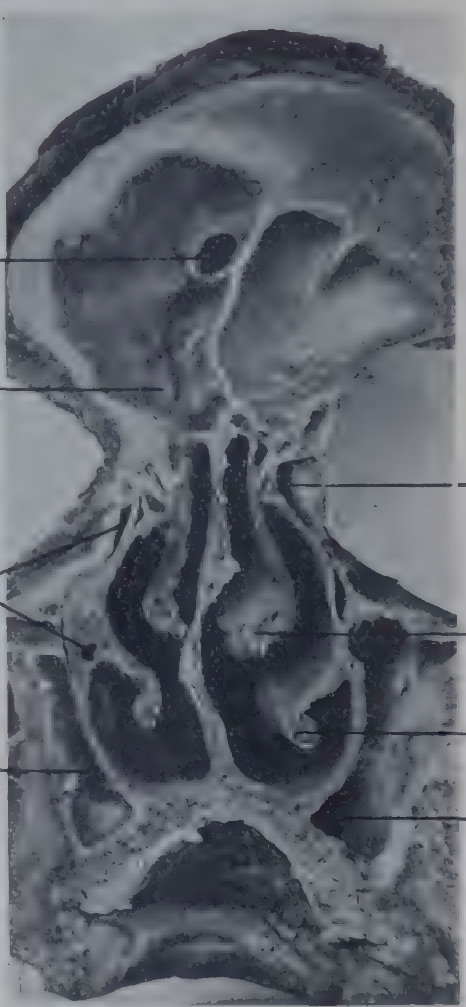


Fig. 1037.—Photograph of Coronal Section through the Nose; in Front of Section shown in Fig. 1038. Viewed from behind.

Until the seventh year of life the nasal septum is, as a rule, in the median plane, but after that age it is very often bent to one or other side—more frequently to the right—the deflexion being greatest usually along the line of junction of the vomer with the perpendicular plate of the ethmoid. Deflexion of the septum is more common in European than in non-European skulls—occurring in about

53 per cent of the former and in about 28 per cent of the latter (Zuckerkandl, 1893). Associated with that deviation, or apart from it, crests or spurs of bone are found projecting from the septum into one or other nasal cavity in about 20 per cent. of skulls.

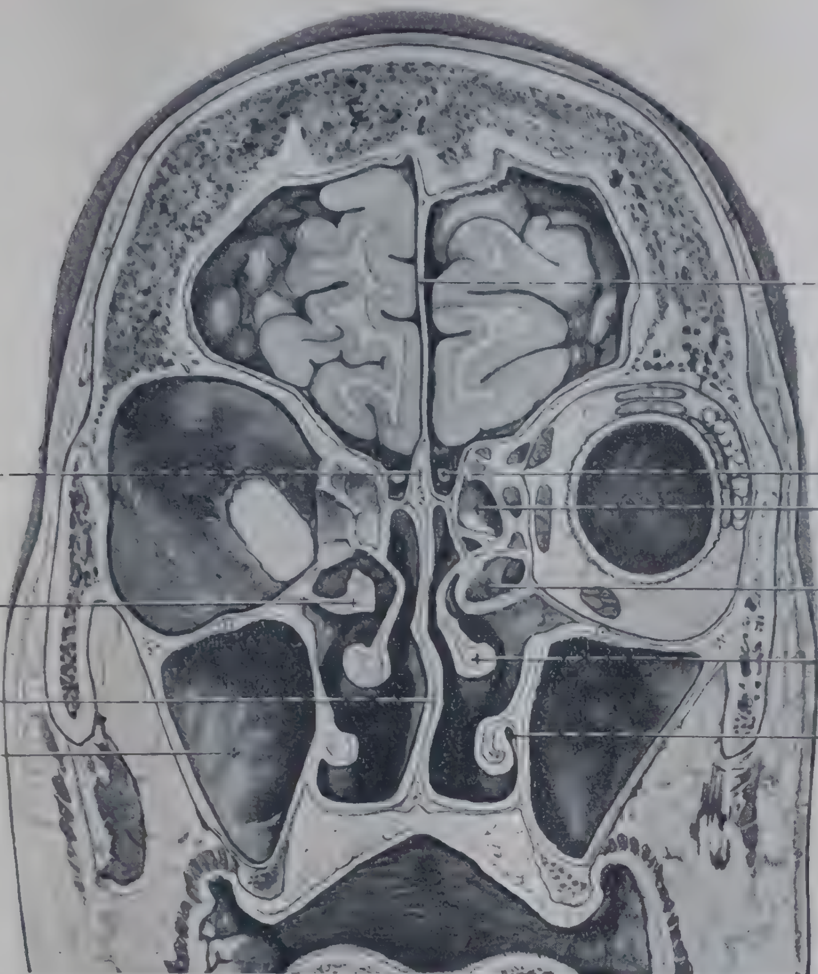


FIG. 1038.—CORONAL SECTION OF HEAD; BEHIND SECTION SHOWN IN FIG. 1037. VIEWED FROM THE FRONT. The contents of the right orbit have been removed.

Lateral Wall (Fig. 1040).—The lateral wall of the nasal cavity shows the three elevations caused by the superior, middle, and inferior conchæ and frequently a fourth due to a "highest" concha. Below and lateral to each concha there is a space or cleft—the superior, middle, and inferior meatus of the nose. Another small space may be present below the "highest" concha; and, above and behind the superior concha, there is a small space, called the **spheno-ethmoidal recess**, into which the sphenoidal sinus opens. Above and behind the vestibule and immediately in front of the middle meatus there is a slight concavity of the lateral wall known as the **atrium of the middle meatus**; the atrium is limited above by a ridge, called the **agger nasi**, which is the representative of the naso-turbinal found in many mammals. Above the agger nasi, a

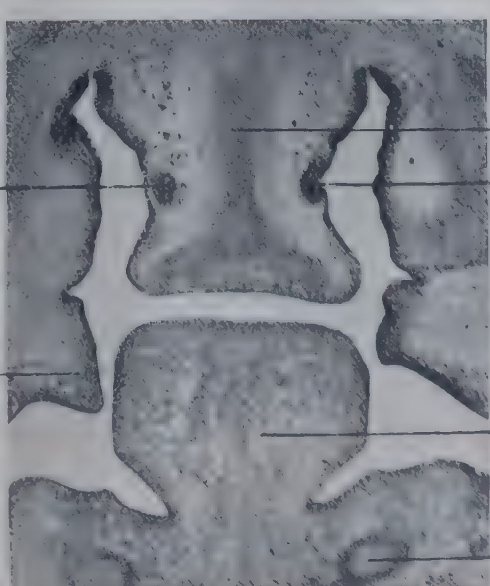


FIG. 1039.—SECTION THROUGH NOSE AND MOUTH OF 20 MM. HUMAN EMBRYO TO SHOW POSITION OF VOMERO-NASAL ORGAN (×28).

groove known as the **olfactory sulcus** leads to the olfactory portion of the nose. Certain of the paranasal sinuses open into the various meatuses of the nose: the

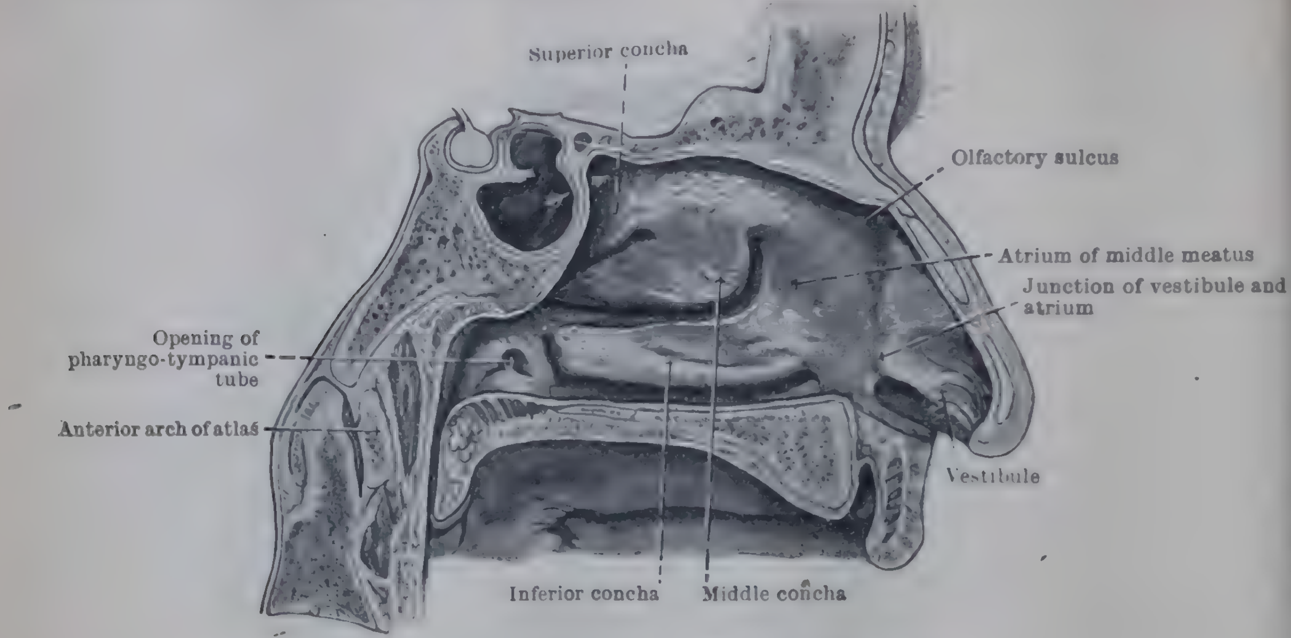


FIG. 1040.—LATERAL WALL OF LEFT NASAL CAVITY.
The arrow passes from the sphenoidal sinus to the spheno-ethmoidal recess.

sphenoidal sinus into the spheno-ethmoidal recess, the posterior ethmoidal sinuses into the superior meatus, the anterior and middle ethmoidal sinuses and the

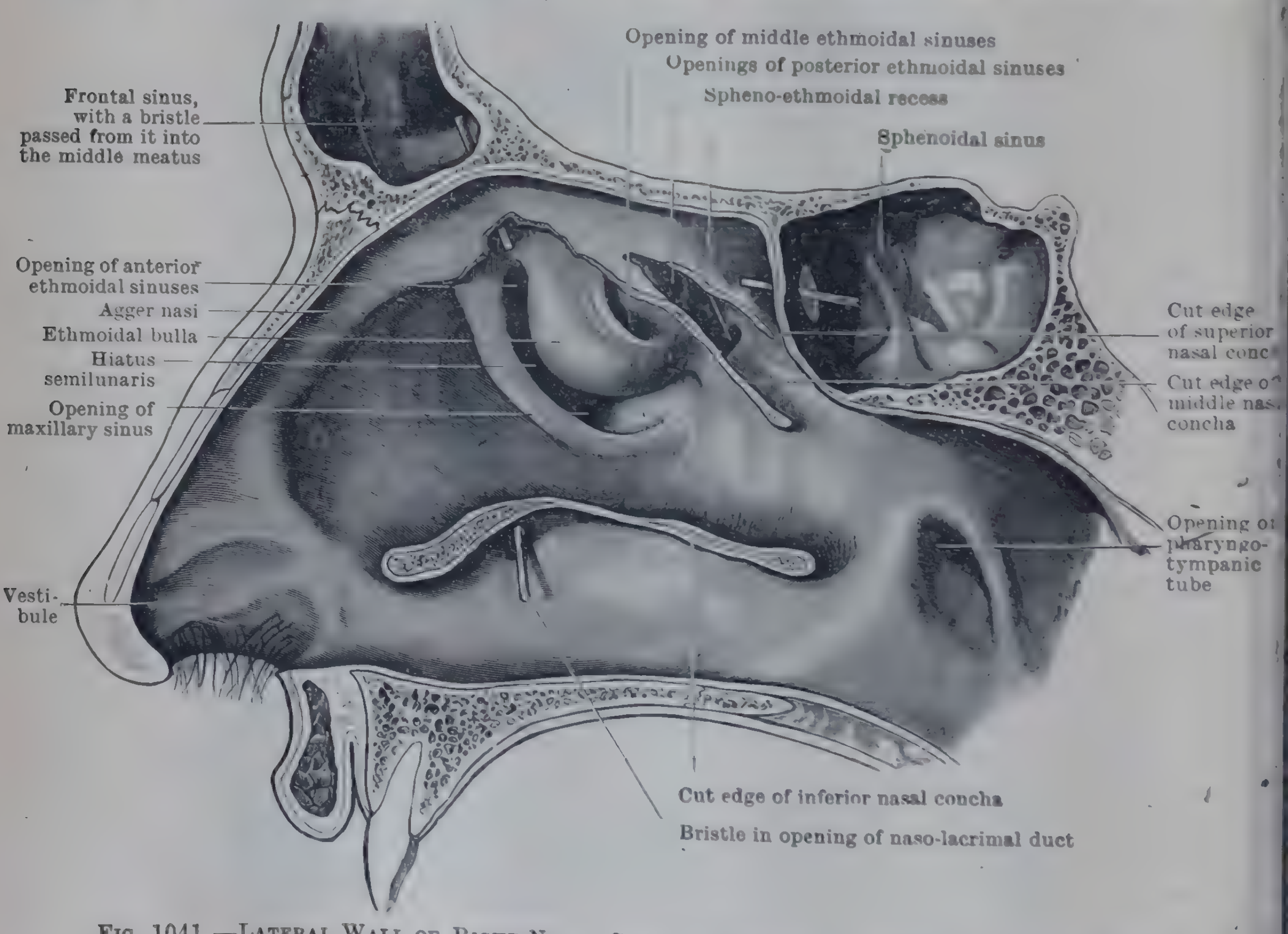


FIG. 1041.—LATERAL WALL OF RIGHT NASAL CAVITY—THE NASAL CONCHÆ HAVE BEEN REMOVED.
For the bones of the lateral wall, see Fig. 164, p. 193.

maxillary and frontal sinuses into the middle meatus. The naso-lacrimal duct opens into the inferior meatus. On removal of the middle concha, the lateral wall is seen to be marked by a curved groove, called the **hiatus semilunaris**,

which is limited above by an elevation—the **ethmoidal bulla**—due to the bulging of the middle ethmoidal sinuses, and below by the sharp edge of the **uncinate process** of the ethmoid bone; the anterior end of the hiatus semilunaris opens into the **ethmoidal infundibulum**, which leads to the frontal sinus; the openings of the middle ethmoidal sinuses are usually placed above the bulla; the anterior ethmoidal sinuses and the maxillary sinus open into the hiatus.

Roof.—The roof of the nasal cavity is very narrow, except at its posterior part, and it is divisible into three portions—fronto-nasal, ethmoidal, and sphenoidal—in accordance with the bones which enter into its formation.

Floor.—The floor of the nasal cavity is formed by the palatine process of the maxilla and the horizontal plate of the palatine bone. In it, close to the lower margin of the septum and immediately over the incisive canal, a funnel-shaped depression called the *naso-palatine recess* is sometimes seen; it is directed downwards and forwards, and indicates the position of a communication which existed between the nasal and oral cavities in early intra-uterine life.

Mucous Membrane of Nose.—The mucous membrane lines the entire nasal cavity except the vestibule; it is firmly bound to the subjacent periosteum and perichondrium. It is continuous, through the posterior apertures of the nose, with the mucous lining of the nasal part of the pharynx; through the apertures leading into the paranasal sinuses, with the lining of those cavities; and through the naso-lacrimal duct and the lacrimal sac and canaliculi, with the conjunctiva.

In the respiratory region the mucous membrane is thick and highly vascular and contains many acinous glands, especially in the posterior half of the cavity; in the olfactory region it is thin and yellow and contains the peripheral endings of the olfactory nerves.

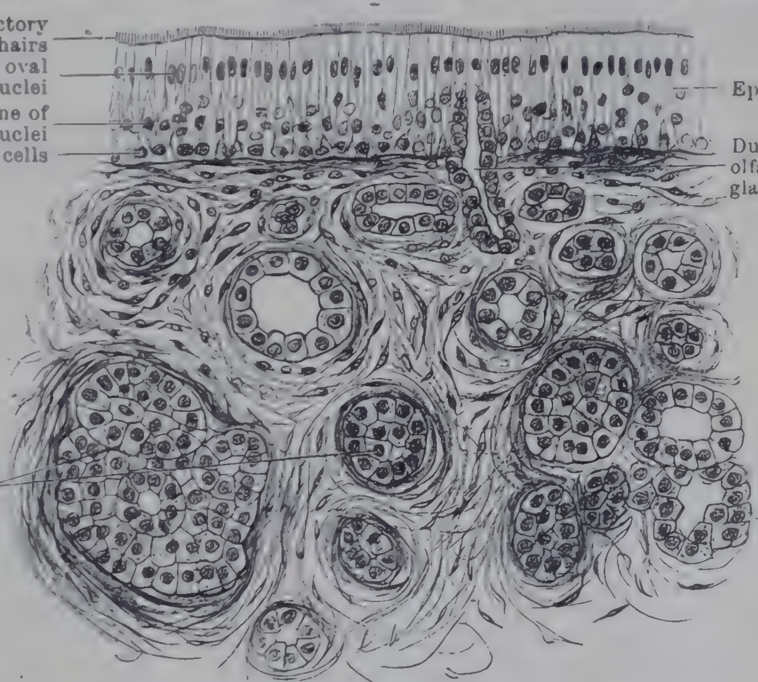


Fig. 1042.—Section through Olfactory Mucous Membrane.

Structure.—In the respiratory region the mucous membrane is covered with ciliated columnar epithelium; between the bases of the columnar cells smaller pyramidal cells occur, and goblet or mucous cells also are found. In children a considerable amount of adenoid tissue is present. In the olfactory region the mucous membrane is covered with non-ciliated columnar epithelium in which the cells may be divided into *supporting*, *olfactory* and *basal* cells.

The superficial parts of the **supporting cells** are columnar and contain fine granules of yellow pigment; the deep parts are continued for some distance as attenuated processes which may be branched. Their nuclei are elliptical or oval, and are situated at the deep ends of the columnar parts of the cells—forming the *zone of oval nuclei.*

The **olfactory cells** are bipolar nerve-cells, and their central processes are delicate and beaded filaments which are continued through the cribriform plate of the ethmoid to the brain. They are homologous with the nerve-cells of the spinal ganglia, but differ from them in that they retain their primitive position in the surface epithelium. The cell-bodies are spindle-shaped and are arranged in several rows between the deeper, attenuated parts of the supporting cells. Their nuclei are large and spherical, and form a layer of some thickness termed the *zone of round nuclei.* The peripheral process of each olfactory cell is rod-like, and extends between the columnar portions of the supporting cells as far as their free surfaces, where it pierces the external limiting membrane and divides into a number of fine hair-like processes named **olfactory hairs.**

The **basal cells** are branched, and they lie between the deep ends of the supporting and olfactory cells.

Olfactory Nerves.—The fibres of the olfactory nerves are non-myelinated but have a neurolemma; they arise as the central processes of the olfactory cells. They are collected into fasciculi which, in the rabbit (Le Gros Clark & Warwick, 1946), pass upwards to the cribriform plate in separate parallel bundles without forming any plexus in the nasal mucous membrane. Having passed into the cranial cavity they arborize around the dendrites of the mitral cells of the olfactory bulb, thus assisting in the formation of the **olfactory glomeruli** (Fig. 840, p. 957).

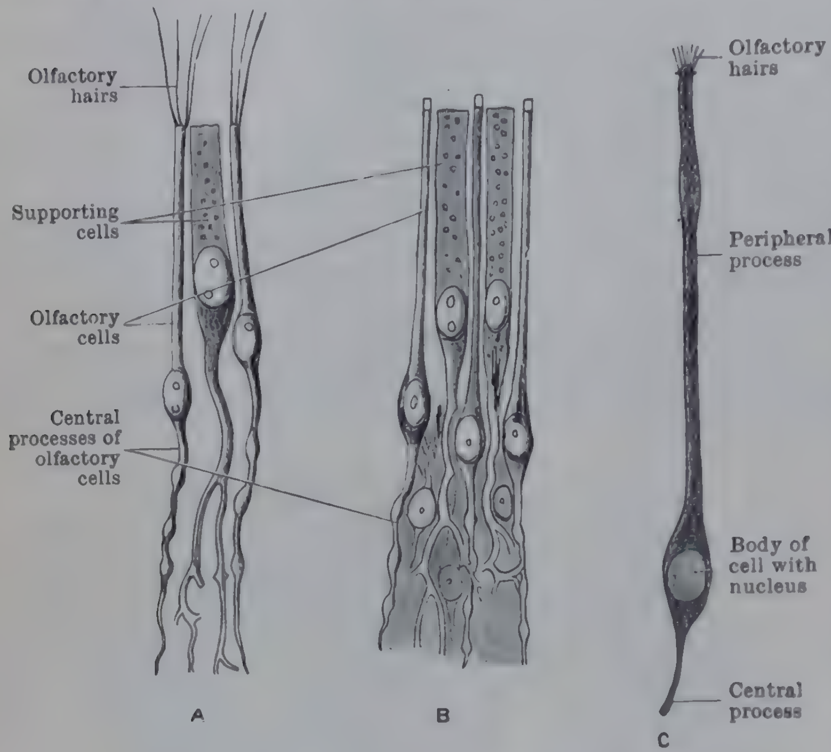


Fig. 1043.—Olfactory and Supporting Cells.

A. Frog, B. Human } M. Schultze. C. Human olfactory cell (v. Brunn).

The trigeminal nerve supplies branches of ordinary sensation to the nasal mucous membrane as follows: The septum is chiefly supplied by the long and short spheno-palatine nerves, and in its anterior portion by the anterior ethmoidal nerve. The lateral wall is supplied by the short spheno-palatine nerves; by the lower nasal branches of the greater palatine nerve; and in front by the anterior ethmoidal nerve. The floor and the anterior part of the inferior meatus are supplied by a nasal branch of the anterior superior dental nerve.

Blood-Vessels.—The chief **artery** of the nose is the spheno-palatine branch of the maxillary artery. It reaches the nasal cavity through the spheno-palatine foramen, and it divides into (*a*) an artery to the septum and (*b*) branches which ramify over the meatuses and conchæ and also supply the maxillary, frontal, and ethmoidal sinuses. In the conchæ the main arteries lie within the bone, and their branches then pass out to form a fine sub-epithelial plexus. This plexus, in turn, opens into wide venous 'blood-spaces' which are important constituents of the mucous membrane. In addition, there are direct arterio-venous anastomoses between the mucosal arteries and the 'blood-spaces' (Harper, 1947). The upper portion of the cavity receives a supply from the ethmoidal arteries, and the posterior part some small branches from the greater palatine artery. The nostrils are supplied by a branch of the facial artery and by the septal branch of the superior labial artery. The maxillary sinus is supplied by the infra-orbital and posterior superior dental arteries, and the sphenoidal sinus gets its chief supply from the spheno-palatine artery. The **veins** form a dense, cavernous plexus which is well seen in the respiratory region, and particularly over the inferior nasal concha and the lower and posterior parts of the septum. In the case of the conchæ the veins drain first into a periosteal venous plexus and thence into a system of veins contained in bony canals in the conchæ. The venous blood is carried in three chief directions, viz., *forwards* into the anterior facial vein, *backwards* into the pterygoid plexus through the spheno-palatine vein, and *upwards* into the ethmoidal veins. The ethmoidal veins communicate with the ophthalmic veins and the veins of the dura mater; one ethmoidal vein passes up through the cribriform plate, and opens either into the venous plexus of the olfactory bulb or directly into one of the veins on the orbital surface of the brain.

Lymph-Vessels.—These form an irregular network in the superficial part of the mucous membrane; they are separated from prolongations of the subarachnoid space along the olfactory nerves by very thin walls which act as semi-permeable membranes. The chief lymph-vessels are directed backwards towards the posterior apertures of the nose, and, on each side, are collected into two trunks, one passing to a retropharyngeal lymph-gland, the other to one or two upper deep cervical lymph-glands.

Paranasal Sinuses

The paranasal sinuses are the frontal, ethmoidal, sphenoidal, and maxillary; they open into the nasal cavities, and are lined with mucous membrane which is continuous with that of the nasal cavities.

The **frontal sinuses**—a right and a left—are placed behind the superciliary arches; they are rarely symmetrical because the septum which separates them frequently deviates from the median plane. Their average measurements are: height, 3·16 cm.; breadth, 2·58 cm.; depth from before backwards, 1·8 cm. Each opens, through the infundibulum, into the anterior part of the middle meatus of the nose.

The **ethmoidal sinuses**, about ten in number on each side, are thin-walled air-cavities, each about the size of a pea (Whitnall, 1932), that occupy the labyrinth of the ethmoid bone; their walls are completed by the frontal, maxillary, lacrimal, sphenoid, and palatine bones, with which the labyrinth articulates. They are separated from the orbits by thin bony laminæ; and they are arranged on each side in three groups—anterior, middle, and posterior. The anterior and middle groups open into the middle meatus of the nose, and the posterior group into the superior meatus.

The **sphenoidal sinuses** are a pair of cavities in the body of the sphenoid bone; they are rarely symmetrical, since the septum between them is often bent to one or other side. Their average measurements are: height, 2 cm.; width, 1·8 cm.; antero-posterior depth, 2·1 cm. Each opens into the spheno-ethmoidal recess of the nose.

The **maxillary sinuses** are pyramidal cavities in the bodies of the maxillæ. Their average measurements are: height, opposite the first molar tooth, 3·5 cm.; width, 2·5 cm.; antero-posterior depth, 3·2 cm. In the upper part of the medial wall of each sinus there is an opening through which it communicates with the lower part of the hiatus semilunaris in the middle meatus of the nose. An accessory opening is frequently seen above the posterior part of the inferior concha.[1]

The relations of the sinuses are given in the Section on Osteology (p. 197); their appearance in radiographs is dealt with in the Section on Surface and Surgical Anatomy and may be studied in Plates VII and VIII, p. 154, XLVII, p. 558, LXXIII, p. 944, LXXV, p. 960, and LXXVII, p. 1200.

Development of Nose

The first indication of the developing organ of smell is the **olfactory placode**—a proliferation of ectodermal cells on the ventro-lateral surface of the head—which can be recognized in an embryo of 4 mm. (Fig. 1028 A). The tissue on the medial and the lateral side of each placode becomes raised up into ridges which soon form rounded prominences called respectively the *globular* and the *lateral nasal processes*. The two globular processes, separated by a median groove, are parts of a *median nasal process*, and the whole area on which the nasal processes and the olfactory placodes appear constitutes the *fronto-nasal process* (Fig. 76A, p. 63).

As the nasal processes are developed the olfactory placodes sink into the substance of the head so as to form two grooves. The maxillary process grows from the first or mandibular pharyngeal arch and is at first separated from the lateral nasal process by a groove—the *naso-lacrimal sulcus*—which leads to the region of the developing eye, and when the maxillary process, by its growth in a ventral direction, joins the fronto-nasal process, this groove comes to be buried, and it later gives rise to the naso-lacrimal duct (Fig. 1044).

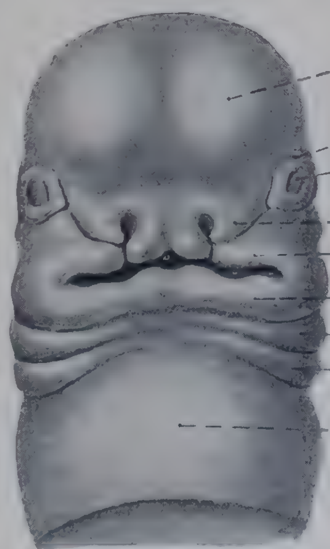


Fig. 1044.—Head of Human Embryo showing the relation of the Nasal and Maxillary Processes to the Olfactory Pit and the Naso-Lacrimal Sulcus.

As the maxillary process grows ventrally to form the upper lip, it fuses with the lateral nasal process and then with the globular process, and so forms a floor for the original olfactory groove, which thus becomes converted into a blind pit that opens on to the surface through an almost circular aperture—the primitive nostril. At the far end of the pit the floor breaks through, about the seventh week, and the pit then opens behind the maxillary process into the primitive mouth; this opening constitutes the *primitive posterior aperture* of the nose.

The olfactory pit enlarges, particularly in an upward direction, and forms the **nasal cavity**; the original ectodermal cells of the olfactory placode come to be situated in the upper part of the

[1] The measurements of the sinuses are those given by Logan Turner (1901); see also Onodi (1895).

cavity, and they become differentiated into the **olfactory epithelium**. The right and left nasal cavities are at first continuous with each other below the fronto-nasal process, and they open into the mouth cavity. In the meantime, the maxillary processes project towards the median plane as a pair of shelves—the *palatine processes* (Fig. 1039)—which about the tenth week join in the median plane and form a roof for the mouth so that the posterior apertures of the nose can no longer open into the cavity of the mouth but must open behind the fused palatine processes into the future naso-pharynx. At the same time the two nasal cavities become separated from each other by the fusion of the posterior edge of the fronto-nasal process with the upper surface of the fused palatine processes (Fig. 1045). From about the second to the sixth month the anterior aperture of the nose—the nostril—is closed with a plug of epithelial cells.

While the nasal cavities are being isolated changes are taking place on their medial and lateral walls which result in the formation of the *vomero-nasal organ* on the medial wall and the conchæ and paranasal sinuses on the lateral wall. The vomero-nasal organ (Fig. 1039) appears about the fifth or sixth week as an indentation of the nasal septum; it grows in an upward and backward direction, and, by about the sixth month, it attains a depth of 4 mm.; later, it atrophies.

The nasal conchæ develop as a series of ridges on the lateral wall, known as the *maxillo-turbinal*, which forms the **inferior concha**, and the *ethmo-turbinals*, of which the first forms the **middle concha** and the second and third the **superior concha**; an additional ethmo-turbinal may persist as the highest concha. A more anterior elevation on the lateral wall—the *naso-turbinal*—is represented in the adult by the **agger nasi**.

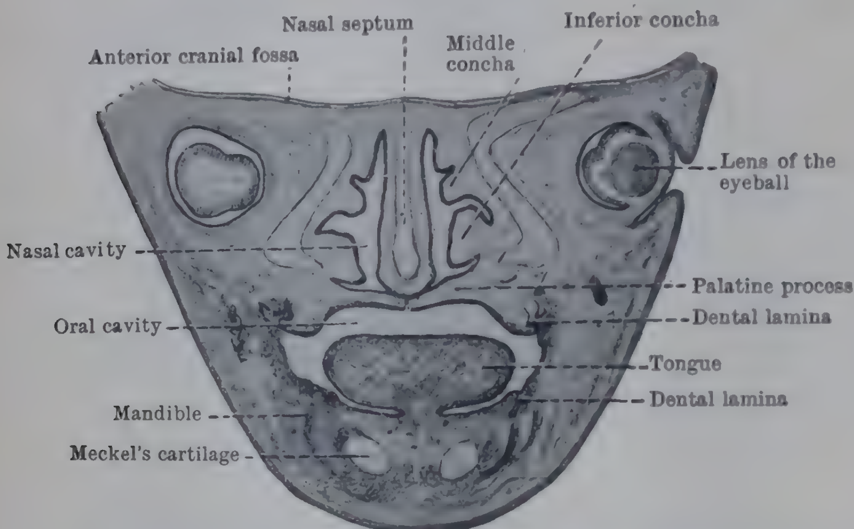


Fig. 1045.—Coronal Section through Face of Human Embryo about 9 weeks old.

With the continued growth of the maxillary processes, the fronto-nasal process, with its contained nostrils, becomes raised up from the surface of the face so as to form the rudiment of an external nose (Fig. 1028 D); and the nostrils come to be directed forwards, as they still are at birth.

The supporting skeleton of the nose constitutes what is called the *nasal capsule*. This arises by a process of chondrification in both the medial and lateral walls of the nasal cavities. The process begins near the surface and follows the growth of the cavities in an upward direction, so that finally fusion takes place with the base of the skull itself. An upward curling of the lateral cartilage gives rises to the inferior concha, and subsequent chondrification in the lateral wall forms the basis of the other conchæ. The chondrification in the lower part of the lateral wall forms what are known as the *paranasal cartilages* (p. 213). Chondrification occurs in the median part of the fronto-nasal process also, and this cartilage persists as the **septal cartilage**. Subsequent ossification, partly in cartilage and partly in membrane, forms the later bony framework of the nose.

When the outgrowths from the lateral wall to form the conchæ take place, the areas left between them constitute the primitive meatuses, and outgrowths from these form the various paranasal sinuses. The first of these to appear is the maxillary sinus, as an outgrowth from the middle meatus about the end of the third month; this is followed by the ethmoidal, frontal, and sphenoidal sinuses, but all of the sinuses undergo the major portion of their development only after birth—the frontal sinus not reaching that bone till the second year, and the sphenoid not excavating its cavity till the fifth year, the maxillary sinus, which is still only a mere groove at birth, not acquiring its full development till after puberty.

ORGAN OF TASTE

The peripheral **organ of taste** consists of groups of modified epithelial cells, termed **taste-buds**, found on the tongue, the palato-glossal arch, the oral surface of the soft palate, the posterior surface of the epiglottis, and the posterior wall of the upper part of the pharynx. They occupy nests in the epithelium of these regions.

They are most numerous on the tongue:—They are present in large numbers around the circumference of the vallate papillæ (Fig. 1046), and some are found also on the opposing walls of the vallum (Fig. 493, p. 576). They are very numerous over the folia linguæ, and are found also over the posterior part and

sides of the tongue, and on the fungiform papillæ. The full number of taste-buds developed on the papillæ is present at birth, and at a later date on the vallum. Atrophy of the taste-buds begins in adult life and increases rapidly with age. The mean number of taste-buds related to a vallate papilla is, at 20 years of age, 245 on the papilla and 74 on the vallum. In advanced age the numbers decrease to 88 and 13 respectively (Arey, Tremaine & Monzingo, 1935).

Structure (Fig. 1048).—The taste-buds are oval or flask-shaped; the deep end of each is expanded, and the free end shows a minute opening termed the **gustatory pore**. The taste-buds are composed of two kinds of epithelial cells—supporting cells and gustatory cells (Fig. 1047). The **supporting cells** are elongated, nucleated spindles, and are mostly arranged like the staves of a cask to form the outer envelope of the taste-bud; but some are found in the interior amongst the gustatory cells. The **gustatory cells** occupy the centre of the taste-bud, and each has a nucleated cell-body which is prolonged into a peripheral and a central process. The peripheral process is rod-like, and terminates at the gustatory pore in a slender filament called the **gustatory hair**. The central process passes towards the deep extremity of the taste-bud, where it ends in a single or branched varicose filament.

Nerves of Taste.—The chorda tympani (through the lingual nerve) supplies the taste-buds on the anterior two-thirds of the tongue; and the glosso-pharyngeal

Fig. 1046.—Section through Vallate Papilla of Human Tongue.

1. Papilla. 2. Vallum. 3. Taste-buds.

Fig. 1047.—Isolated Cells from Taste-Bud of Rabbit (Engelmann).

a, Supporting cells. *b*, Gustatory cells.

supplies those on the posterior third and on the palato-glossal arch. The buds on the soft palate are supplied by the greater superficial petrosal nerve by way of the spheno-palatine ganglion and the palatine nerves; and the internal laryngeal

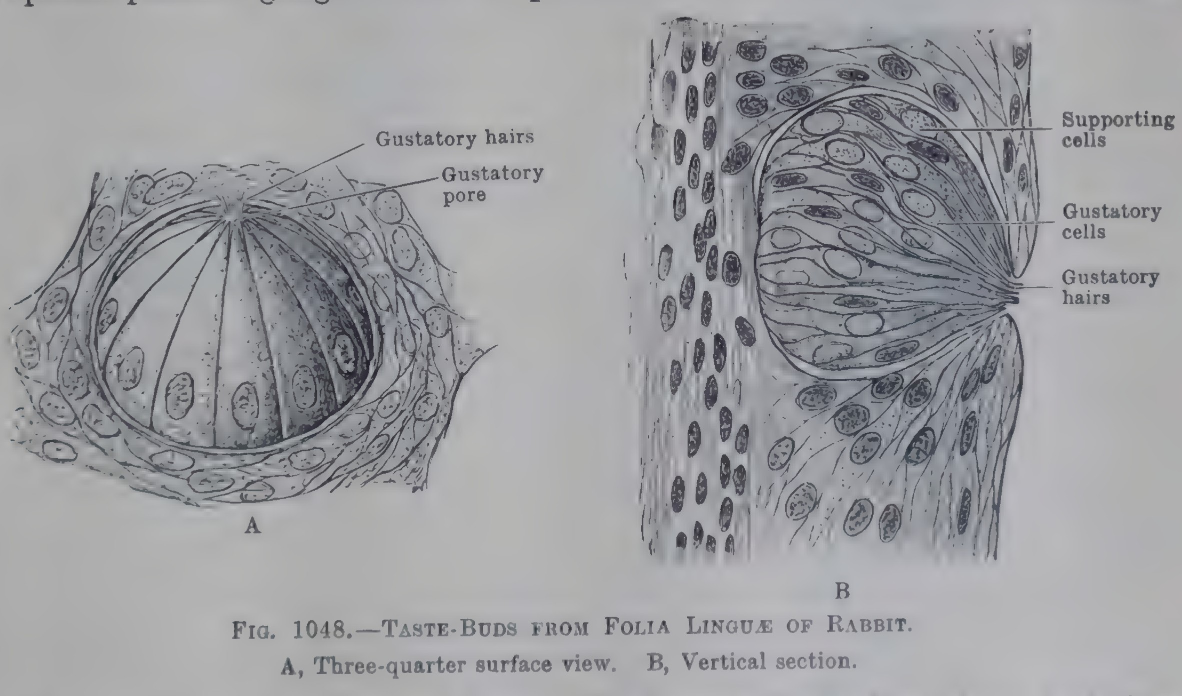


Fig. 1048.—Taste-Buds from Folia Linguæ of Rabbit.

A, Three-quarter surface view. B, Vertical section.

nerve supplies those on the epiglottis. The nerve-fibrils lose their medullary sheaths and ramify in the taste-buds, partly between the gustatory cells and partly among the supporting cells.

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PLATE LXXIX

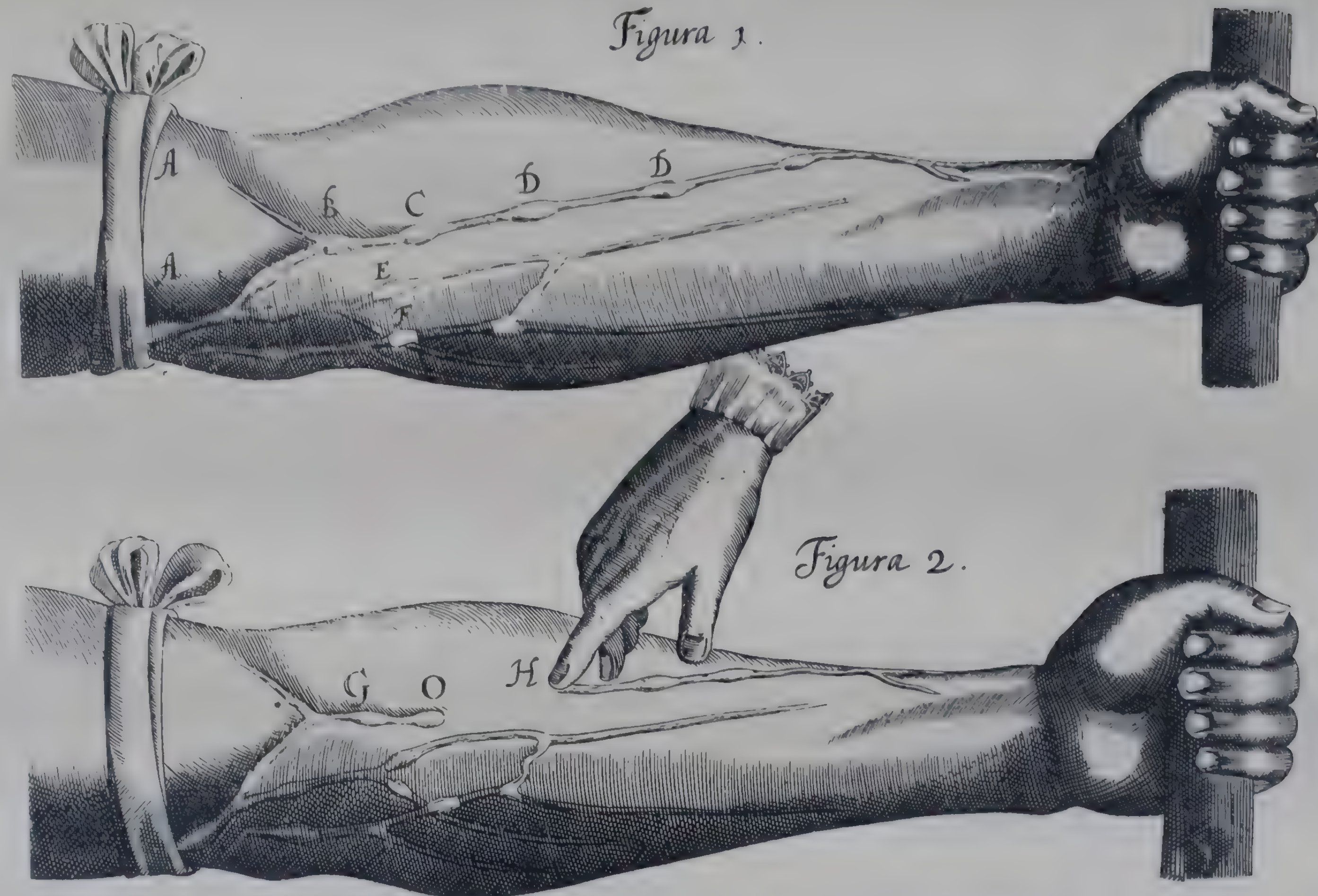

PLATE LXXIX.—PLATE FROM WILLIAM HARVEY'S *Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus* (1628).

These figures illustrate Harvey's simple, classical experiments that demonstrate the presence and function of the valves of the veins and the movement of the blood in the veins towards the heart (see p. 1223).

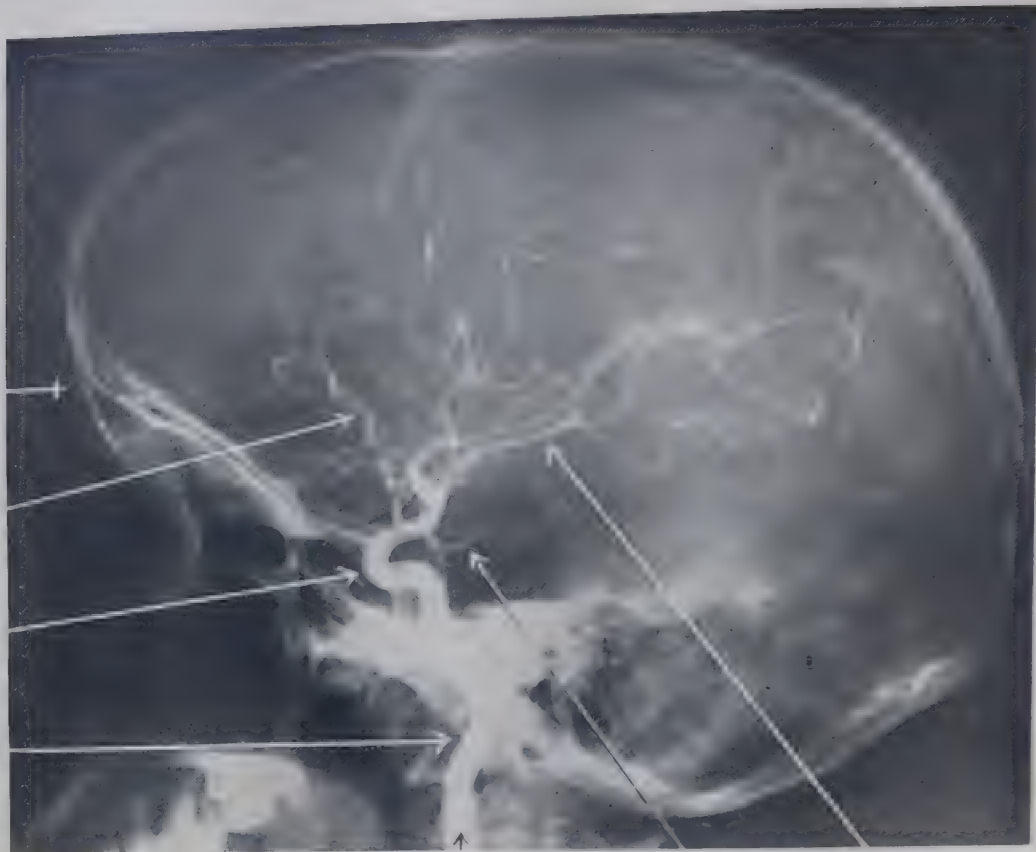

Fig. 1.—After injection into the Right Internal Carotid Artery.
Note the posterior communicating artery.

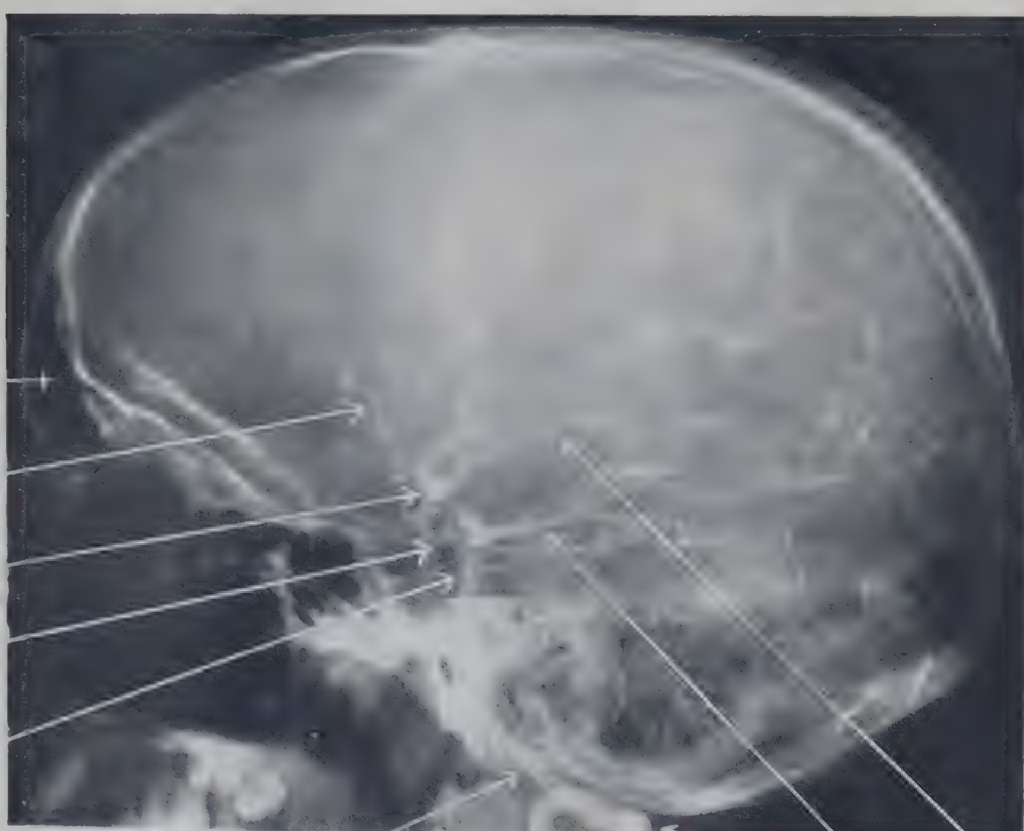

Fig. 2.—After injection into the Right Vertebral Artery.
Note that the internal carotid system has been injected through the posterior communicating artery.

Plate LXXX.—Lateral Radiographs of Living Head of Young Woman, aged 1 after injection of organic iodine compound into (1) the Right Intern Carotid and (2) the Right Vertebral Arteries (Cerebral Arteriographs: Pr fessor Norman M. Dott).

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BLOOD-VASCULAR

AND

LYMPHATIC SYSTEMS

by J. C. Brash, *M.C.*, M.A., M.D., D.Sc., F.R.C.S.Ed., F.R.S.E.,
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All the tissues of the body require that food and other materials necessary for their growth, maintenance, and work shall be carried to them in a fluid form, and that their metabolic products shall be removed and conveyed either to the tissues by which they can be used, as in the case of internal secretions, or to the lungs and kidneys for elimination from the body.

The tubular, vascular system with the **blood** and **lymph** meets these necessities. It consists of the **heart, arteries, capillaries, veins,** and **lymph-vessels.**

The anatomical demonstration of the Circulation of the Blood by William Harvey (1628) was thus the starting point of modern Physiology. From consideration of the function of the valves of the veins (p. 1223)—described by Fabricius (1603)—by experiment, calculations and logical argument from the structure of the heart and the arrangement of its valves, Harvey reached the conclusion that " the movement of the blood is constantly in a circle, and is brought about by the beat of the heart ".

The heart is a rhythmically contractile muscular pump, and it is divided into receiving and ejecting chambers. During the intervals between its contractions blood flows from the **veins** into its receiving chambers, which are termed **atria**. As soon as the atria are full they contract and force their contents into ejecting chambers called **ventricles**; then the ventricles contract and project the blood into the **arteries.**

The two stem-arteries into which the blood is projected (the aorta and the pulmonary trunk) are necessarily large, but they break up into branches which again branch, and so, by repeated branchings, the arteries rapidly become smaller as they approach the tissue-areas they supply. Ultimately the smallest branches, which are called **arterioles**, end in plexuses of vessels of extremely small calibre which are known as **capillaries.**

Capillary networks, whose meshes vary in size and form in different regions, are found in all tissues except cartilage. They are drained by the **veins**, which gradually unite with one another to form larger trunks, and, through the terminal and largest trunks, the blood is returned to the atria of the heart.

As the blood enters the capillaries some of its fluid portion, which is termed **blood-plasma**, passes through their thin walls and permeates the tissues, from which a part re-enters the capillaries towards their venous ends, and so is returned to the heart. The remaining part is collected from the tissues by another set of capillary vessels from which it passes into **lymph-vessels**, which finally discharge into the great veins at the root of the neck; thus, all the fluid which irrigates the tissues is eventually returned to the heart.

Much watery fluid, however, is removed from the body as urine by the action of the kidneys. The fluid passes from the renal blood-capillaries into the renal tubules, and so by way of the ureters and urinary bladder to the exterior. A large quantity of fluid is also given off from the skin and in the breath from the lungs as watery vapour. The fluid thus passed out of the body is replenished by fluid taken in by the mouth

and passed through the walls of the abdominal part of the alimentary canal into the blood-capillaries and lymph-capillaries which lie in the tissues of those walls.

Besides ordinary food, **oxygen** is an indispensable necessity for the proper performance of tissue work; and one of the effete products which must be discharged is **carbon dioxide.**

The lowest vertebrates obtain their oxygen from water by means of capillary-plexuses in their gills through which the blood passes on its way from the heart to the tissues. In fishes, therefore, the heart is essentially a single tube, divided mainly into a single receiving chamber and a single ejecting chamber. With the evolution of land animals, however, other means for obtaining oxygen had to be adopted; and new respiratory organs called lungs were developed, in communication with the external air through the mouth and nose.

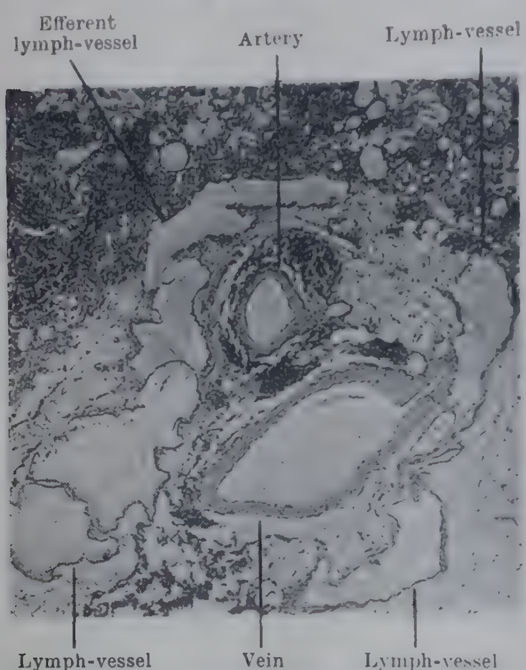

Fig. 1049.—Photomicrograph of Section of Artery, Vein, and Lymph-Vessels in the Hilum of a Lymph-Gland.

The question whether the lungs of higher vertebrates were evolved from the swim-bladder of the bony fishes is a complex morphological study; but in any case the development of lungs necessitated an alteration of the circulation whereby it would be possible for the venous blood, returned to the heart by the veins, to be sent first through the lungs, where it could lose its carbonic acid and obtain oxygen, and then through the body generally.

This could be brought about only by profound changes in the arrangement of the chambers of the heart; and the process of evolution whereby the object was attained was gradual during the period of transition from fish to mammal. It was fully achieved by the complete division of the single longitudinal tube of the primitive heart into right and left halves by the formation of septa. The right ventricle became connected with arteries passing to the lungs, and the left atrium with the veins returning blood from the lungs, whilst the left ventricle was connected with the arteries supplying the body generally and the right atrium with the veins returning blood from the body. In that way two circulations were established—the pulmonary and the systemic. The arteries, capillaries, and veins of the lungs constitute the **pulmonary circulation**, and those of the body generally the **systemic circulation.**

It should be added that there is a special arrangement, of great physiological significance, whereby the blood from the abdominal part of the alimentary canal, the spleen and the pancreas is conveyed by the *portal vein* to the liver, where it passes through a second capillary plexus before reaching the heart via the hepatic veins and the inferior vena cava. This is sometimes referred to as the **portal circulation** (p. 1328).

There is, in addition, the system of lymph-vessels which return some of the fluid from the tissues to the systemic veins. Lymph-glands are associated with the lymph-vessels, and together they constitute the **lymphatic system.**

TISSUES OF VASCULAR SYSTEM

The tissues of which the various parts of the vascular system are composed are: endothelium, areolar tissues, white fibrous tissue, elastic tissue, plain muscle, and cardiac muscle. Of these, endothelium alone is found in all parts of the system. It lines the cavities of the heart, the arteries, the arterioles, the veins, and the lymph-vessels, and it is almost the only constituent of the walls of the majority of the capillaries.

The **heart** consists mainly of cardiac muscle with a certain amount of areolar tissue, white fibrous tissue and elastic tissue; and its cavities are lined with a single layer of endothelial cells.

The cardiac muscle is peculiar, inasmuch as its cells are striated like voluntary muscle but are devoid of a cell-membrane (p. 1235). They branch and anastomose with one another, and their nuclei are central (Fig. 351, p. 403).

The **arteries** are composed of plain muscle, areolar tissue, white fibrous tissue, elastic tissue, and endothelium. All the arteries are lined with a single layer of endothelial cells, but the other tissues are present in different amounts in different vessels. The tissues are arranged in three coats.

In arteries of the largest size elastic tissue predominates, so that by their

FIG. 1050.—PHOTOMICROGRAPH OF LONGITUDINAL SECTION OF SMALL ARTERY.

A, Inner coat. B, Middle coat. C, Outer coat. D, Fibro-areolar sheath.

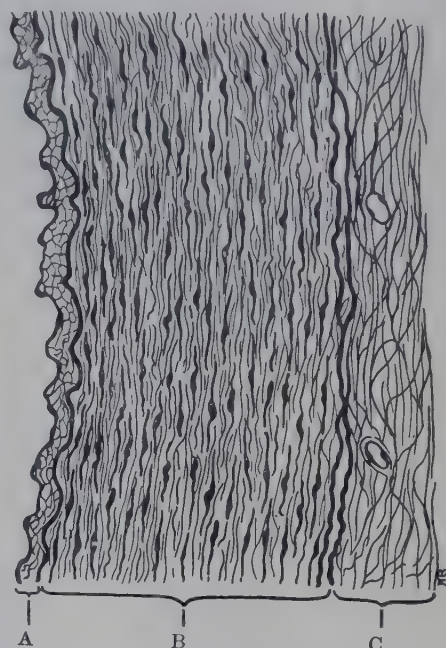

FIG. 1051.—TRANSVERSE SECTION OF WALL OF LARGE ARTERY.

A, Inner coat. B, Middle coat. C, Outer coat.

distension, as blood is suddenly forced into them by the contractions of the heart, the smaller vessels may be preserved from sudden great strain, whilst the elastic recoil of the distended walls keeps up a steady onflow of blood in the arteries in the intervals between the contractions of the heart.

All parts of the body are not equally active at the same time, and it is obvious that an active part will require more blood during its activity than it does when it is quiescent. Therefore it is necessary that the flow of blood to any particular tissue or organ shall be capable of regulation. The regulation is obtained by means of plain muscle, which predominates in the arteries of medium and small size.

The muscle consists of spindle-shaped cells which, for the main part, are arranged in spiral bundles in the middle parts of the walls of the arteries, where they form, with a little intermingled areolar tissue, the middle coat (*tunica media*) of the artery.

The muscle-fibres are not under control of the will, but they are under control of the nervous system. Therefore, when there is a call from any area for more blood the muscle-fibres relax, the calibres of the arteries enlarge, and more blood is permitted to flow through them; and, when less blood is required, the muscle-fibres contract and the lumina of the arteries are diminished.

The constituent parts of the **inner coat** (*tunica intima*) in arteries of medium size are the *endothelial lining*, a thin *subendothelial layer* of fine areolar tissue and a layer of elastic fibrils, running more or less longitudinally, or an elastic

fenestrated membrane called the *elastic lamina*. In the smaller arteries the subendothelial tissue disappears. The smallest arteries are devoid of the elastic lamina also.

In the larger arteries, on the other hand, the subendothelial tissue increases in amount and contains more elastic fibrils which merge into the elastic lamina, so that the boundary between the two is lost; whilst in the largest arteries the combined subendothelial tissue and elastic lamina are blended with the middle coat, which itself consists mainly of layers of elastic fibrils.

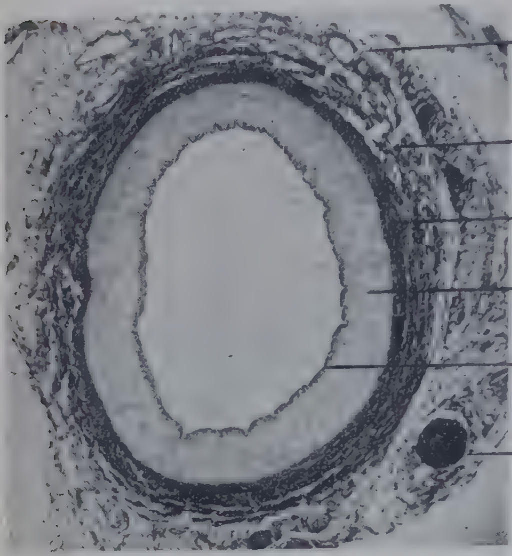

FIG. 1052.—PHOTOMICROGRAPH OF TRANSVERSE SECTION OF SMALL ARTERY.

In typical arteries — that is, arteries of medium size—the **middle coat** (*tunica media*) consists mainly of plain muscle-fibres bound together in more or less spiral strata by fine areolar tissue.

As the arteries become smaller and the middle coat is reduced, the muscular strata become fewer and fewer until only a single layer of scattered fibrils remains (Fig. 1053). In the largest arteries the muscle-fibres are largely replaced by elastic fibrils.

The **outer coat** (*tunica adventitia*) of an artery consists almost entirely of fine fibrous tissue in which lie many fibrous tissue cells. In all but the smallest arteries numerous elastic fibres also are present. The elastic element is specially strong near the middle coat in small and medium-sized vessels, and is sometimes described as an external elastic membrane. The outer coat of some arteries contains also plain muscle-fibres arranged longitudinally.

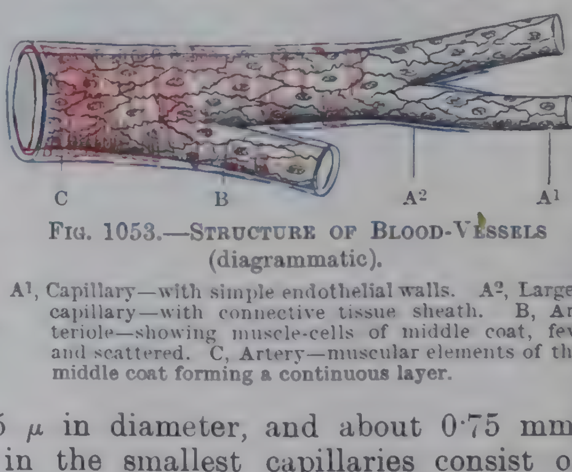

FIG. 1053.—STRUCTURE OF BLOOD-VESSELS (diagrammatic).

A1, Capillary—with simple endothelial walls. A2, Larger capillary—with connective tissue sheath. B, Arteriole—showing muscle-cells of middle coat, few and scattered. C, Artery—muscular elements of the middle coat forming a continuous layer.

The outer coat is the strongest and least friable coat of the artery. It disappears from the smallest arteries as the muscle-fibres disappear, but is very strong around small, medium, and large arteries.

In addition to their three coats, arteries are enclosed in a **sheath** of the surrounding fibro-areolar tissue.

Capillaries measure from 8 μ to 12·5 μ in diameter, and about 0·75 mm. in length. Their walls are simple, and in the smallest capillaries consist of elongated elastic and contractile endothelial cells with sinuous edges, pointed extremities, and oval nuclei. The cells are cemented to one another along their margins by intercellular cement which readily stains with nitrate of silver. In places the cement-substance appears to accumulate, forming minute spots indicative of the less perfect apposition of the edges of the cells. Here and there on the outer surfaces of the capillaries there are isolated cells called **Rouget cells.** They have been thought to be contractile, but their function is uncertain. For detailed discussion of anatomical and functional aspects of capillaries, consult Krogh (1929).

The larger capillaries are invested by an areolar tissue sheath consisting largely of branched cells which are united to one another and to the endothelial cells of the capillary-wall.

Capillaries are arranged in networks, and there are great variations in the size and form of the meshes of these networks in different tissues.

In some organs (*e.g.*, liver, suprarenal glands) the capillary-like spaces between the cells of the organ are not true capillaries. They have been developed by the growth of columns of cells of the organ into blood-spaces which are then

broken up into narrow channels. These channels are not completely lined with endothelium and the cells of the organ are therefore in direct contact with the blood; they have been called **sinusoids** (Minot, 1900).

In erectile tissue also there are no true capillaries, since the small arteries open directly into cavernous spaces, lined with endothelium, from which the blood is drained by the small veins.

The walls of **veins** are similar in structure to those of arteries; they are, however, thinner—so much so that, although veins are cylindrical tubes when

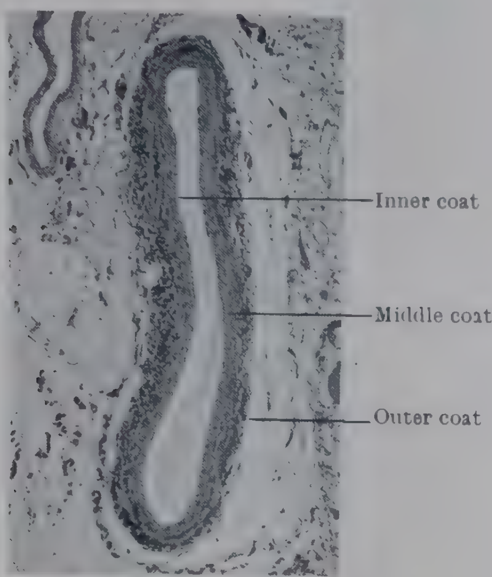

FIG. 1054.—PHOTOMICROGRAPH OF TRANSVERSE SECTION OF SMALL VEIN.

FIG. 1055.—TRANSVERSE SECTION OF WALL OF GASTRIC VEIN.

A, Inner coat. B, Middle coat.
C, Outer coat (with longitudinal muscle).

full of blood, they collapse when empty and their lumina almost disappear. The structural details of the three coats vary considerably in different veins. Like the arteries, the veins are enclosed in fibro-areolar sheaths.

In the majority of the veins the **inner coat** includes an internal endothelial layer, a middle layer of subendothelial areolar tissue, and an outer layer of elastic tissue. The inner coat of a vein is less brittle than the inner coat of an artery, and is more easily peeled off from the middle coat. The subendothelial tissue is a fine fibrillated areolar tissue, less abundant than in the arteries, and in many cases it is absent. The elastic layer consists of lamellæ of elastic fibres which are arranged longitudinally; it rarely has the appearance of a fenestrated membrane.

One of the chief peculiarities of the inner coat of veins is the presence of folds of its substance which constitute **valves** (Fig. 1056). The cusps of the valves are of semilunar shape, and they are usually arranged in pairs. Their convex borders are continuous with the vessel-wall, and their free borders are turned towards the heart; whilst, therefore, they do not interfere with the free flow of blood from the periphery, they prevent any backward flow towards it, and they help to sustain the column of blood in all vessels in which there is an upward flow. Each cusp is formed by a fold of the endothelial layer, strengthened by a little areolar tissue. As a general rule, the wall of the vein is dilated on the cardiac side of each valve into a shallow pouch or sinus; consequently, when the veins are distended they assume a nodulated appearance. Competent valves do not occur in the large veins of the trunk or in the portal system of veins in the adult (p. 1364). They are more numerous in the deep veins than in the superficial veins of the limbs, and in the veins of children than in the veins of adults. (See also Franklin, 1927, 1929.)

The presence of valves in the superficial veins of the forearm is readily demonstrated by Harvey's simple, classical experiment (Pl. LXXIX, p. 1216). The venous return being obstructed by pressure on the upper arm, a finger is placed on one of the distended veins, which is then emptied of its blood as far as the nearest valve by stroking it upwards. The column of blood will be sustained by the valve while the part of the vein below it

between the right and left pulmonary veins forms the anterior boundary of a section of the pericardial cavity called the oblique sinus.

The base is limited below by the inferior part of the atrio-ventricular groove, in which the principal vein of the heart—the coronary sinus—lies ; its upper border is in relation with the pulmonary arteries. At the upper part of its left border a small fold of pericardium, called the *fold of the left vena cava*, descends from the left pulmonary artery to the upper left pulmonary vein (see p. 1242). Further, it is from the base that the visceral layer of the pericardium, which elsewhere completely

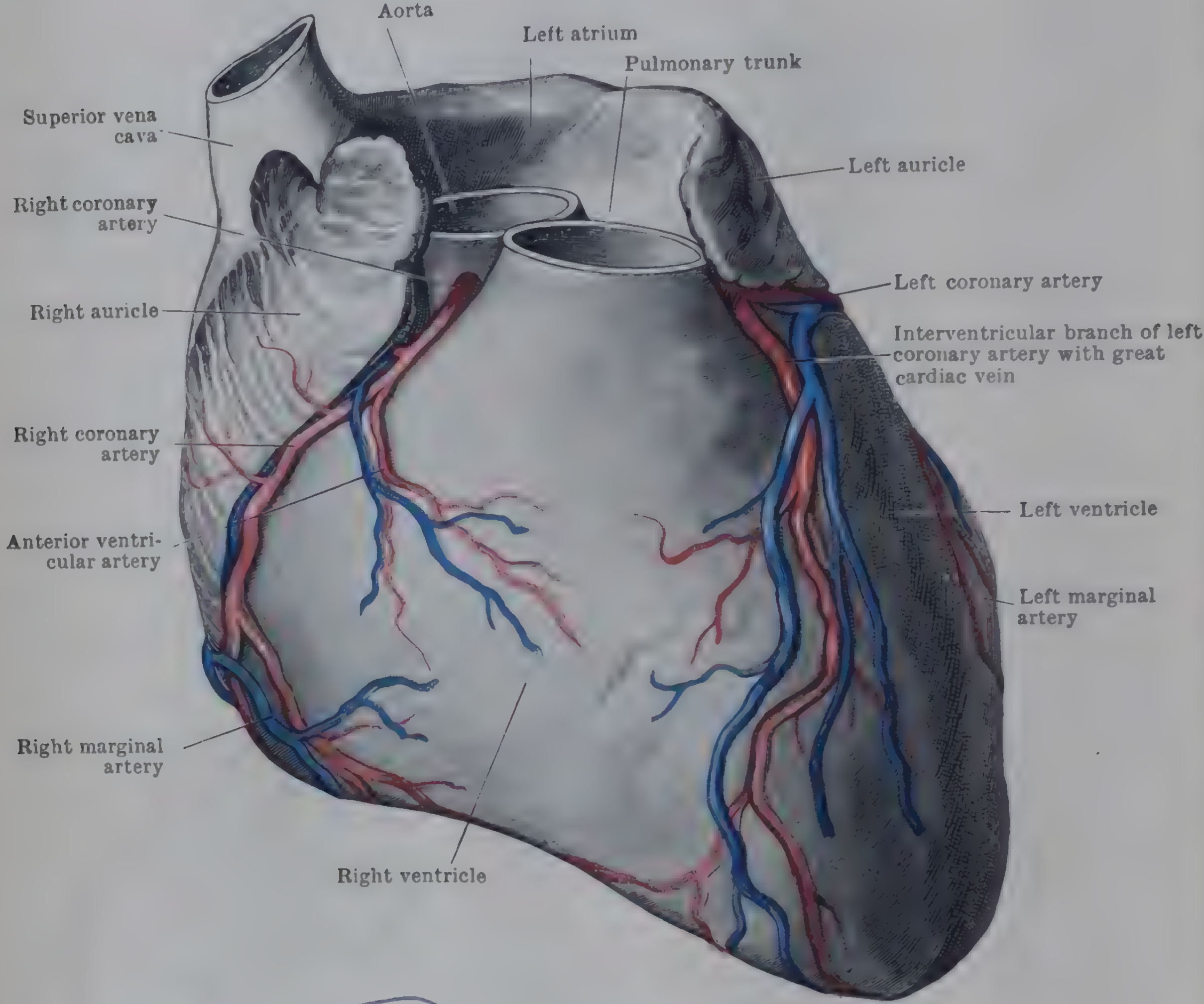

Fig. 1058.—Sterno-Costal Surface of Heart.

invests the heart, is reflected on to the fibrous layer, the lines of reflexion corresponding with the orifices of the great vessels.

In the fœtus and young child the atrial portion of the heart forms not only the base but also the posterior part of the inferior or diaphragmatic surface.

The **apex of the heart**, bluntly rounded, is formed entirely by the left ventricle. It is directed downwards, forwards, and to the left, and is situated, under cover of the left lung and pleura, behind the fifth left intercostal space, or behind the sixth rib, 3 or 3½ inches from the anterior median line. The *apex-beat* of the heart may be seen and felt in that situation, where also the stethoscope is placed to hear the sound of the mitral valve (p. 1489).

The **sterno-costal surface** is directed upwards, forwards, and to the left. It is opposite the body of the sternum and the medial ends of the cartilages of the third, fourth, fifth and sixth ribs of the right side, and a greater extent of the corresponding cartilages of the left side. This surface is incompletely separated into upper and lower sections by the upper part of the atrio-ventricular groove, which runs obliquely from the right side of the pulmonary trunk to the lower end of the right border (Fig. 1058). The upper section of the surface, which is concave forwards, is formed by the atria ; it is separated from the sternum by the ascending aorta and

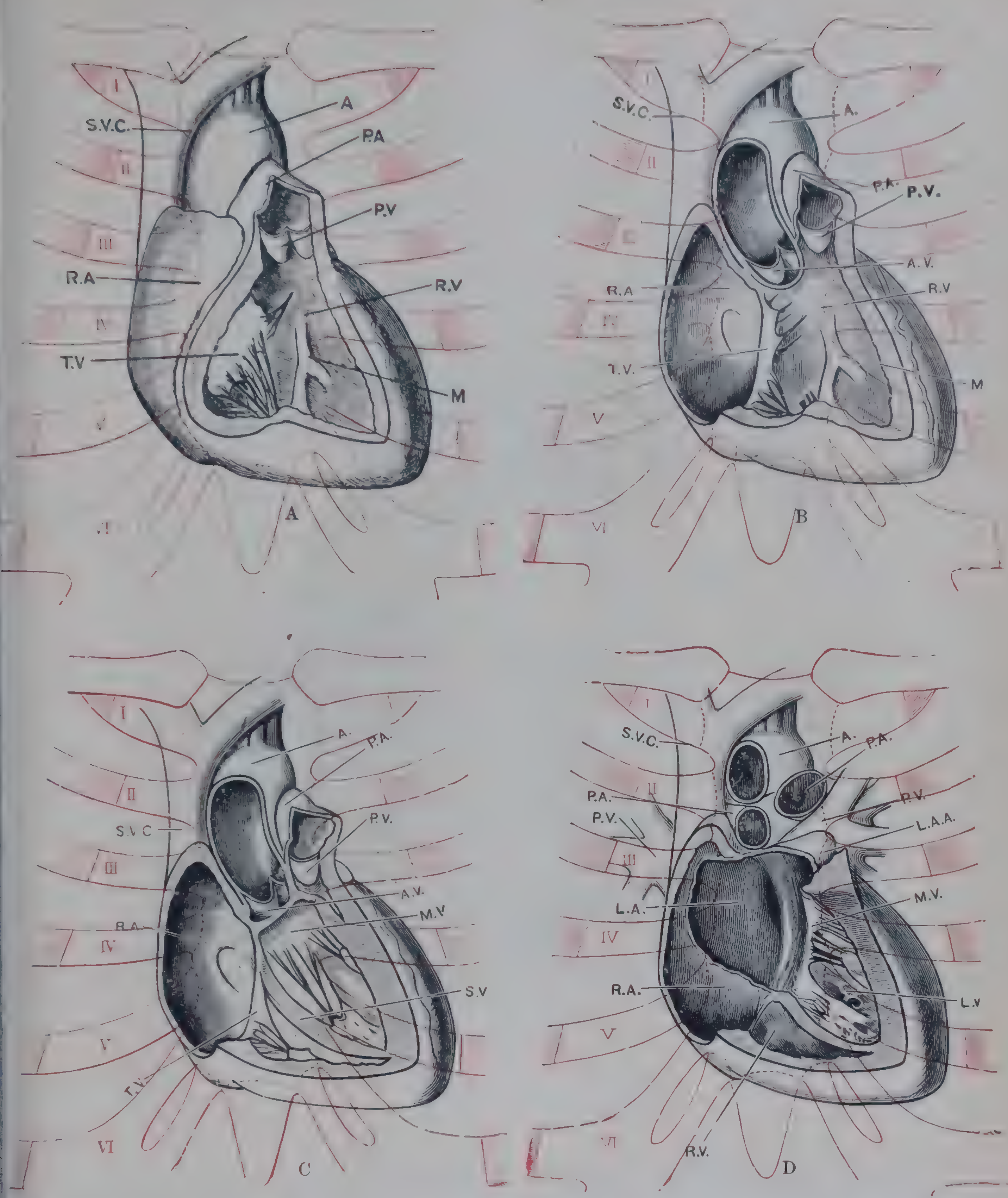

FIG. 1059.—RELATIONS OF CAVITIES AND VALVES OF HEART TO ANTERIOR WALL OF THORAX. (From photographs of a formalin-hardened subject, with the heart dissected *in situ.*)

In A the anterior wall of the right ventricle has been removed and the pulmonary trunk opened.

In B the anterior walls of the ascending aorta and of the right atrium have been removed ; also the anterior cusp of the tricuspid valve.

In C the greater part of the ventricular septum has been removed, and the anterior cusp of the mitral valve exposed.

In D the ascending aorta, anterior cusp of mitral valve, pulmonary trunk, and atrial septum have been removed ; the cavities of the left atrium and left ventricle are exposed.

A.	Aortic arch.	M.	Moderator band.	R.A.	Right atrium.
A.V.	Aortic valve.	M.V.	Mitral valve.	R.V.	Right ventricle.
L.A.	Left atrium.	P.A.	Pulmonary trunk and arteries.	S.V.	Ventricular septum.
L.A.A.	Left auricle.	**P.V.**	Pulmonary valve.	S.V.C.	Superior vena cava.
L.V.	Left ventricle.	P.V.	Pulmonary vein.	T.V.	Tricuspid valve.

the pulmonary trunk; from its lateral parts the auricles of the atria project forwards and, curving medially, embrace those great vessels. The lower section of the sterno-costal surface is convex; it is formed by the ventricular part of the heart, and is divided, by an **anterior interventricular groove**, into a smaller left and a larger right part. The orifices of the pulmonary trunk and the aorta, the former anterior to the latter, are at the junction of the atrial and ventricular parts of the sterno-costal surface.

The **upper border** of the sterno-costal surface is formed by the two atria—chiefly the left atrium. It is in relation with the bifurcation of the pulmonary trunk and its two branches; the superior vena cava enters the heart at its right end.

The **right border** is formed by the right atrium. It is in relation with the right pleura and lung (the phrenic nerve with its accompanying vessels intervening) and it is sometimes marked by a shallow groove—the *sulcus terminalis*—which passes from the front of the superior vena cava to the front of the inferior vena cava, and marks the position of a ridge in the interior of the atrium (p. 1229).

The **lower border** of the sterno-costal surface is sharp, thin, and usually concave, corresponding with the curvature of the anterior part of the diaphragm; it is formed mainly by the right ventricle, but near the apex by the left ventricle. It lies, almost horizontally, in the angle between the diaphragm and the anterior wall of the thorax, passing from the lower end of the right border behind the xiphisternal joint to the apex.

The **left border** separates the sterno-costal surface from the left surface of the heart.

The **left surface** is formed mainly by the left ventricle, and only to a small extent by the left atrium and its auricle; it is convex from above downwards and from before backwards. It is crossed at its widest part by the left part of the atrio-ventricular groove, and narrows towards the apex of the heart. It is separated by the pericardium and the pleura (the phrenic nerve and its accompanying vessels intervening) from the left lung, which is excavated to receive it. It descends obliquely, with a convexity towards the left, from the left end of the upper margin to the apex.

The **diaphragmatic surface** is formed by the ventricular part of the heart. It rests upon the diaphragm, chiefly on the central tendon, but, towards the left side, on a small portion of the muscular substance also; and it is divided into two areas —a smaller to the right and a larger to the left—by an oblique antero-posterior groove called the **inferior interventricular groove**. It is separated from the base by the inferior part of the atrio-ventricular groove.

For the surface-anatomy of the heart, see Figs. 1059, 1062 and p. 1488.

CHAMBERS OF HEART

Atria.—The **atrial portion** of the heart is cuboidal in form, with an anterior concave surface. Its cavity is divided into two chambers—the right and left atria—by a septum which runs from the anterior wall backwards and to the right so obliquely that the right atrium lies anterior and to the right, and the left atrium posterior and to the left.

The long axis of each atrium is vertical, and each possesses a well-marked ear-shaped prolongation, known as the **auricle**, which projects forwards from its anterior and upper angle.

The **right atrium** receives, posteriorly, the superior vena cava above and the inferior vena cava below. Between them, and a little above its middle, it is crossed behind by the lower right pulmonary vein on its way from the hilum of the lung to the left atrium. It is continuous below and in front with the right ventricle, at the atrio-ventricular orifice. Above and in front, it is in relation with the ascending aorta, and from that part of the atrium the right auricle is prolonged forwards and to the left. Its right side forms the right border of the heart, and is separated by the pericardium from the right phrenic nerve and its accompanying vessels, and the right pleura and lung. Behind and on

ie left, the right atrium is limited by the septum which separates it from the ‹ft atrium.

Interior of Right Atrium.—The walls are lined with a glistening membrane alled **endocardium**, and are smooth except anteriorly and in the auricle, where uscular bundles, called the **musculi pectinati**, form a series of small vertical olumns. The musculi pectinati spring from a network of ridges in the auricle and un downwards and backwards to end behind in a crest, called the **crista terminalis**. 'he crista terminalis, which corresponds in position with the sulcus terminalis p. 1228) on the external surface, indicates the junction of the primitive sinus 'enosus with the atrium proper (see p. 1371).

The opening of the superior vena cava, devoid of a valve, is situated at the

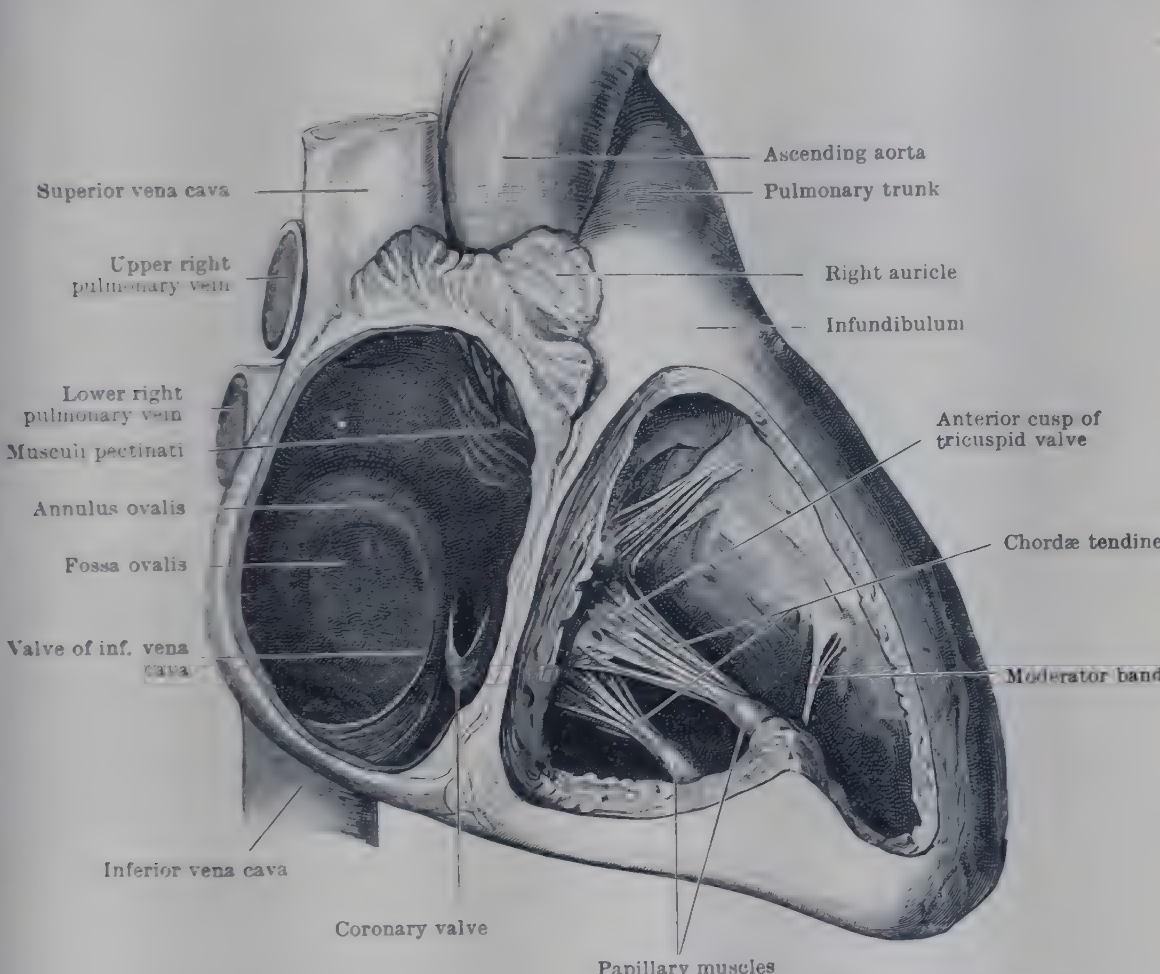

FIG. 1060.—CAVITIES OF RIGHT ATRIUM AND RIGHT VENTRICLE OF HEART.

upper and posterior part of the cavity. At the lower and posterior part is the orifice of the inferior vena cava, bounded, anteriorly, by the vestigial **valve of the inferior vena cava**, and immediately in front and to the left of that valve, between it and the atrio-ventricular orifice, is the opening of the coronary sinus, guarded by the unicuspid **coronary valve**. The **right atrio-ventricular orifice**, guarded on the ventricular side by a tricuspid valve, is known also as the **tricuspid orifice**. It is situated in the inferior part of the anterior boundary, and admits the tips of three fingers. A number of small fossæ are scattered over the walls, and into some of them small veins from the substance of the heart—**venæ cordis minimæ**—open directly by minute orifices. In the septal wall is an oval depression, called the **fossa ovalis**. It is bounded above and in front by a raised margin—the **annulus ovalis**—which is continuous, below, with the valve of the inferior vena cava; the fossa is the remains of the **foramen ovale**, through which the right atrium communicated with the left atrium before birth. Even in the adult a portion of the aperture persists at the upper part of the fossa in about one in five cases. Between the orifices of the superior and inferior venæ cavæ, and behind the upper part of the fossa ovalis, the posterior wall of the atrium may sometimes be seen to bulge forwards a little; the

bulge is called the **intervenous tubercle**, and it has been supposed to help in directing the blood from the superior vena cava to the tricuspid orifice during fœtal life (see p. 1385).

The **valve of the inferior vena cava** is a thin and sometimes fenestrated fold of endocardium and subendocardial tissue which extends from the anterior and lower margin of the orifice of the inferior vena cava to the anterior part of the annulus ovalis. It varies very much in size, and is usually of falciform shape; its apex is attached to the annulus ovalis and its base to the margin of the inferior caval orifice. It is an important structure in the fœtus, directing the greater part of the blood from the inferior vena cava through the foramen ovale into the left atrium (p. 1384).

The **valve of the coronary sinus** is a fold of endocardium placed at the right margin of the orifice of the coronary sinus. It is usually single and is almost invariably incompetent; but it serves to direct the blood from the coronary sinus forwards to the atrio-ventricular orifice.

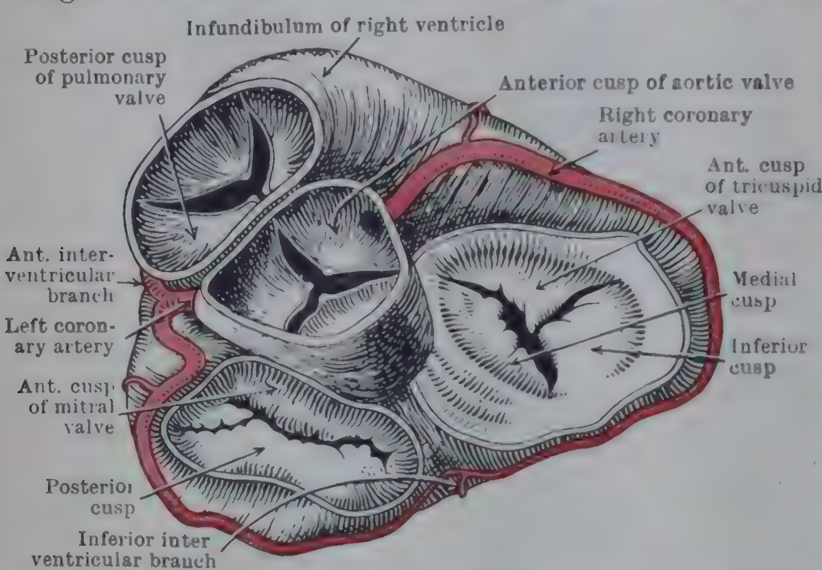

Fig. 1061.—Base of the Ventricles of the Heart, showing Atrio-Ventricular and Arterial Orifices with their Valves, and the Coronary Arteries.

The **left atrium** is in relation behind with the descending thoracic aorta and the œsophagus, but is separated from them by the pericardium and its oblique sinus (Fig. 1063). Its lower part is continuous in front with the left ventricle. Its sterno-costal surface is concave, and lies in close relation to the ascending aorta, the pulmonary trunk, and the left coronary artery. Its right side, formed by the interatrial septum, is directed forwards and to the right. Its left side forms a very small portion of the left surface of the heart, and from it, at its junction with the antero-superior surface, the long and narrow left auricle is prolonged forwards round the left side of the ascending aorta and the pulmonary trunk. Four pulmonary veins enter the upper part of the posterior surface, two on each side.

Interior of Left Atrium.—The walls are lined with endocardium, and are smooth except in the auricle, where musculi pectinati are present, and on the septum, in a position corresponding with the upper part of the fossa ovalis on the right side, where there are several musculo-fibrous bundles radiating forwards and upwards. These septal bundles are separated at their bases by small semilunar depressions, in the largest of which a remnant of the foramen ovale may be found. The apertures of venæ cordis minimæ are scattered irregularly over the wall, and in the inferior part of the anterior boundary is the **left atrio-ventricular** or **mitral orifice** (Figs. 1063, 1065). The orifice is oval in form; its long axis runs obliquely from above downwards and to the right. It is capable of admitting the tips of two fingers, and it is guarded on the ventricular side by a valve formed of two large cusps and known as the **left atrio-ventricular** or **mitral valve**.

Ventricles.—The **ventricular portion** of the heart is conical and slightly flattened. The base, directed backwards and upwards, is partly continuous with the atrial portion and partly free. It is perforated by four orifices—the two atrio-ventricular, the aortic, and the pulmonary. The atrio-ventricular orifices are placed inferiorly, one on each side; above and between them is the aortic orifice, whilst the orifice of the pulmonary trunk is still higher up and farther forward, and slightly to the left of the aortic orifice (Fig. 1061).

In the triangle between the atrio-ventricular and the aortic orifices a

mass of dense fibrous tissue is embedded—the *fibrous trigone*—which is the representative of the os cordis of the ox. It is continuous with the upper part of the interventricular septum, and with fibrous rings which surround the apertures at the bases of the ventricles.

The ventricular portion of the heart is divided into right and left chambers by the **ventricular septum**, which is placed obliquely, with one surface directed forwards and to the right, and the other backwards and to the left; its anterior end lies to the right of the apex of the heart. The margins of the septum are indicated on the two surfaces of the ventricular part of the heart by anterior and inferior interventricular grooves.

The **right ventricle** is triangular in form. Its base is directed upwards and to the right, and, in the greater part of its extent, it is continuous with the right atrium, with which it communicates by the atrio-ventricular orifice; but its left and upper angle is free from the atrium, and gives origin to the pulmonary trunk. Its inferior wall rests upon the diaphragm. The left or septal wall bulges into its interior, and on that account the transverse section of the cavity has a semilunar outline (Fig. 1064).

Interior of Right Ventricle.—The cavity itself is a bent tube consisting of two parts: an inferior portion or **body**, which communicates with the atrium through the atrio-ventricular orifice; and an antero-superior part—the **infundibulum**—which ends in the pulmonary trunk (Fig. 1060). In the angle between the two limbs there is a thick ledge of muscle called the **infundibulo-ventricular crest**.

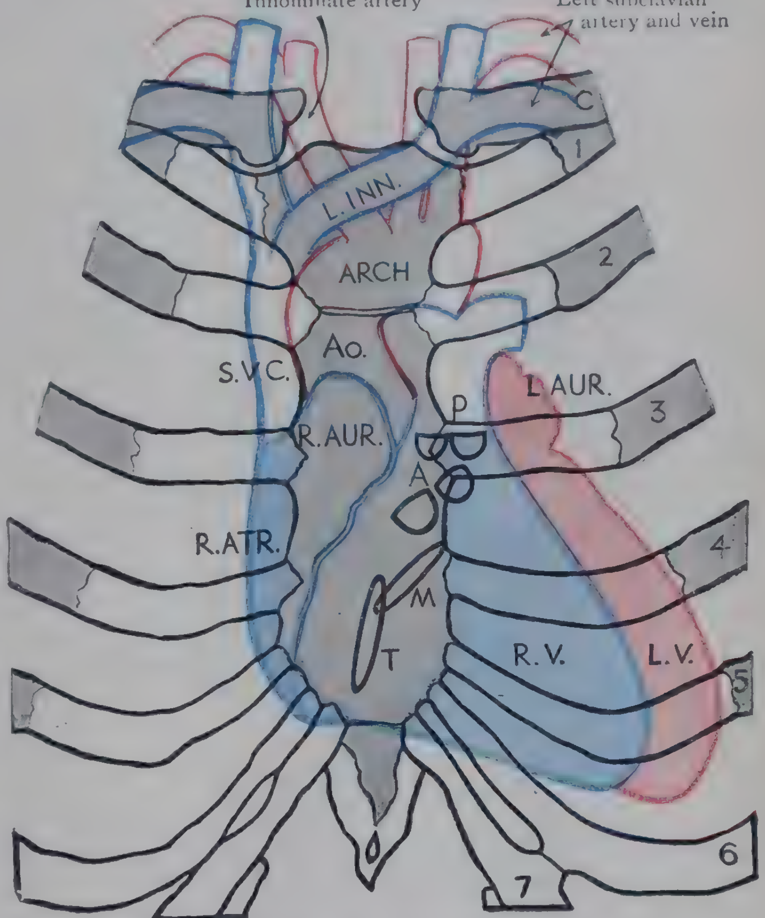

Fig. 1062.—Relation of Heart and Great Vessels to Anterior Wall of Thorax.

1 to 7. Ribs and costal cartilages.
A. Aortic orifice.
Ao. Ascending aorta.
C. Clavicle.
L.V. Left ventricle.
M. Mitral orifice.
P. Pulmonary orifice.
R.V. Right ventricle.
S.V.C. Superior vena cava.
T. Tricuspid orifice.

The **right atrio-ventricular or tricuspid orifice** is guarded by the **right atrio-ventricular or tricuspid valve**. The three cusps are an *inferior*, a *medial* or septal, and an *anterior* which intervenes between the atrio-ventricular orifice and the infundibulum. Each cusp consists of a fold of endocardium, strengthened by a little enclosed fibrous tissue. The bases of the cusps are attached to a fibrous ring at the atrio-ventricular orifice, where they are usually continuous with one another, but they may be separated by small secondary cusps which fill the angles between the main segments. The apices of the cusps project into the ventricle. The margins, which are thinner than the central portions, are notched and irregular. The atrial surfaces are smooth. The ventricular surfaces are roughened, and, like the margins and apices, they give insertion to the **chordæ tendineæ**. The chordæ tendineæ are fine tendinous cords which pass to the cusps from conical muscular projections on the wall of the ventricle called the **papillary muscles** (Fig. 1060).

The **pulmonary orifice** is in front and to the left of the tricuspid orifice. It is guarded by a **pulmonary valve** composed of three semilunar segments, two of

which are placed in front and one behind. The convex or outer border of each segment is attached to the wall of the pulmonary artery at its root. The inner border is free, and it presents at its middle a small **nodule**. On each side of the nodule there is a small, thin marginal portion, of semilunar form, called the **lunule**. Each segment of the valve is composed of a layer of endocardium on its ventricular surface, an endothelial layer on its arterial surface, continuous with the inner coat of the artery, and an intervening stratum of fibrous tissue. Both the attached and the free margins of the cusps are strengthened by fibrous bands, and strands of condensed fibrous tissue radiate from the outer border of

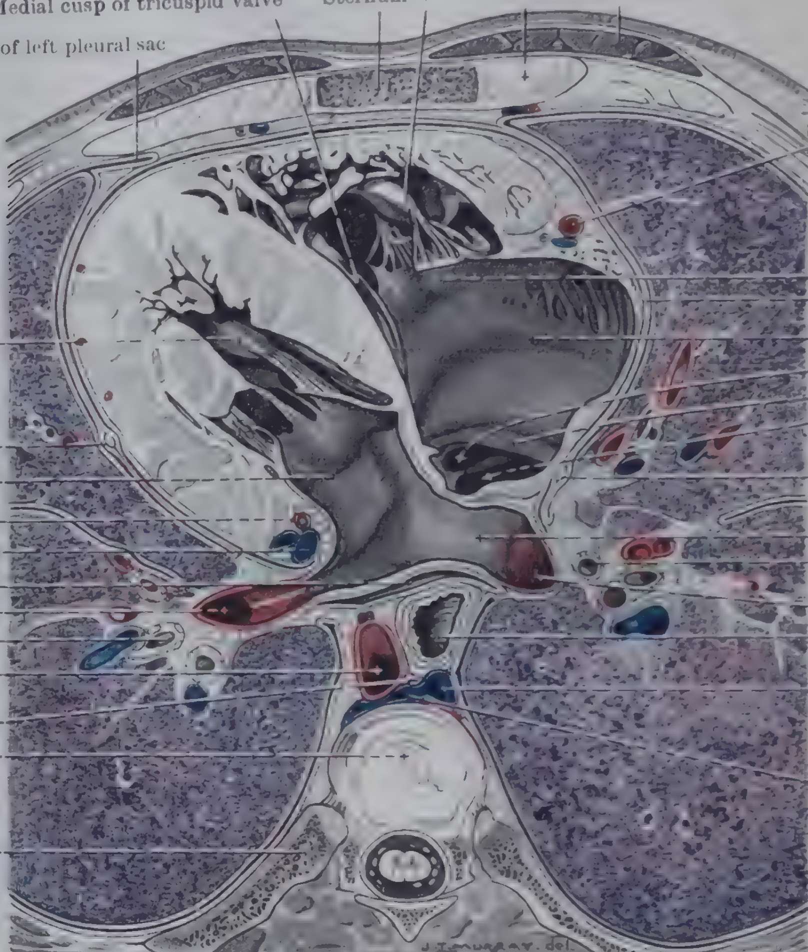

FIG. 1063.—TRANSVERSE SECTION OF THORAX OF YOUNG MAN SHOWING THE CAVITIES AND SOME RELATIONS OF THE HEART. The section is in the Plane D—D, Fig. 1109, p. 1330.

each cusp to the nodule, but they do not enter the lunules. When the valve closes, the nodules are closely apposed, the lunules of the adjacent segments of the valve are pressed together, and both nodules and lunules project vertically upwards into the interior of the artery.

The walls of the ventricle are lined with endocardium. They are smooth in the infundibulum, but are rugose and sponge-like in the body owing to the inward projection of numerous muscular bundles called the **trabeculæ carneæ**. The trabeculæ are of three kinds: the simpler are merely columns raised in relief on the wall of the ventricle. The second class are rounded bundles, free in the middle, but attached at each end to the wall of the ventricle. One special bundle of the second group, the so-called **moderator band**, is attached by one end to the septum, and by the other to the sterno-costal wall at the base of the anterior papillary muscle; it has been supposed to prevent over-distension of the cavity; but its chief importance is that it conducts the right septal division of the atrio-ventricular bundle from the septum to the anterior wall of the ventricle (see p. 1236). The **papillary muscles**—which may be reckoned as a third variety—project into the cavity of the ventricle. Their bases are continuous with the wall of the ventricle, and their

apices give origin to numerous chordæ tendineæ which are attached to the apices, the borders, and ventricular surfaces of the cusps of the tricuspid valve.

The papillary muscles of the right ventricle are—(1) a large *anterior* muscle, from which the chordæ pass to the anterior and inferior cusps of the valve; (2) a smaller and more irregular *inferior* muscle, sometimes represented by two or more segments, from which chordæ pass to the inferior and medial cusps; and (3) a group of small *septal* muscular cones, varying in size and number, which project from the septum and are united by chordæ to the anterior and medial cusps.

The walls of the right ventricle, other than the septal, are much thinner than those of the left, but the trabeculæ carneæ are coarser and less numerous in the right ventricle than in the left.

The **left ventricle** is a conical chamber, and its cavity is oval in transverse section. The base is directed upwards and backwards, and in the greater part of its extent it is continuous with the corresponding atrium, with which it communicates through the mitral orifice; but above and to the right of its communication with the atrium it is continued into the ascending aorta. Its apex is the **apex of the heart**. The inferior wall is related to the diaphragm; it is flat, and it forms two-thirds of the diaphragmatic surface of the heart. The sterno-costal wall is convex, and it forms nearly one-third of the ventricular part of the sterno-costal surface of the heart The right or septal wall is concave towards the interior. The walls of the left ventricle are three times as thick as those of the right ventricle (Fig. 1064). They are thickest around the widest part of the cavity, and that is about one-fourth of its length from the base. The muscular part is thinner at the apex than elsewhere; but the thinnest part of the wall is the upper posterior part of the septum, which is membranous.

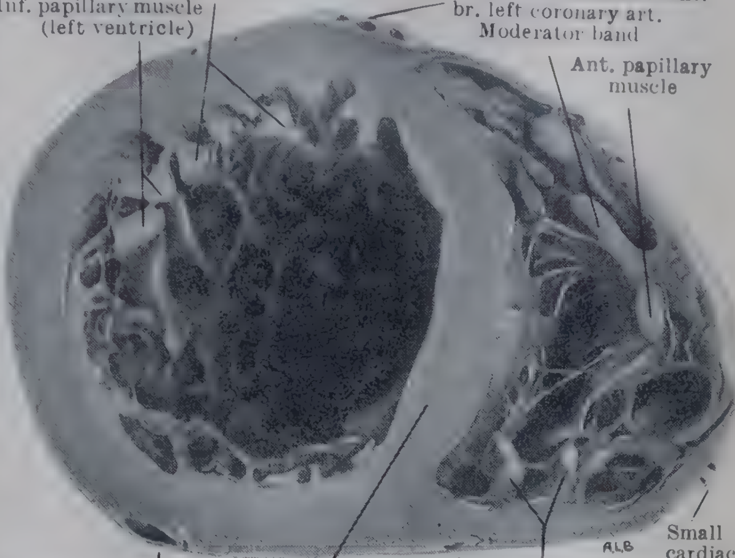

Fig. 1064.—Transverse Section of Ventricles of Heart.

Interior of Left Ventricle.—The cavity is separable into two parts. The lower part is the **body**, which communicates with the left atrium through the atrio-ventricular orifice. The upper and anterior part is called the **aortic vestibule**, for it leads into the aorta; its walls consist of tough fibrous tissue, and are therefore non-contractile (Fig. 1065).

The **left atrio-ventricular** or **mitral orifice** is oval; its long axis runs obliquely from above downwards and to the right; it is guarded by a bicuspid valve known as the **left atrio-ventricular** or **mitral valve**. The two cusps are triangular and of unequal size. The smaller *posterior cusp* is placed behind and to the left of the orifice; and the larger *anterior cusp* is placed in front and to the right, between the mitral and aortic orifices. The bases of the cusps are either continuous with each other at their attachments to the fibrous ring around the mitral orifice, or they are separated by small secondary cusps of irregular form and size. The apices of the cusps project into the cavity of the ventricle. The atrial surfaces are smooth; the ventricular surfaces are roughened by the attachments of the chordæ tendineæ, which are connected also with the apices and with the margins, which are notched and irregular. The structure is the same as that of the cusps of the tricuspid valve (p. 1231); but the ventricular surface of the anterior (*aortic*) cusp is relatively smooth, and therefore the blood-flow into the aorta is not impeded.

The **aortic orifice** is circular; it is immediately above and to the right of the mitral orifice, from which it is separated by the anterior cusp of the mitral

valve, and it is guarded by the **aortic valve**, formed of three semilunar segments, one of which is placed in front and the other two behind. The structure and attachments of the cusps of the aortic valve are similar to those of the cusps of the pulmonary valve (see p. 1231).

The walls of the left ventricle are lined with endocardium. The septum and the upper part of the sterno-costal wall are relatively smooth. The rest is sponge-like owing to numerous fine **trabeculæ carneæ**. There are two **papillary muscles**—a *superior* and an *inferior*. They are much larger than the papillary muscles of the right ventricle; and each is connected by chordæ tendineæ with both cusps of the mitral valve. Two or three fine strands, corresponding in

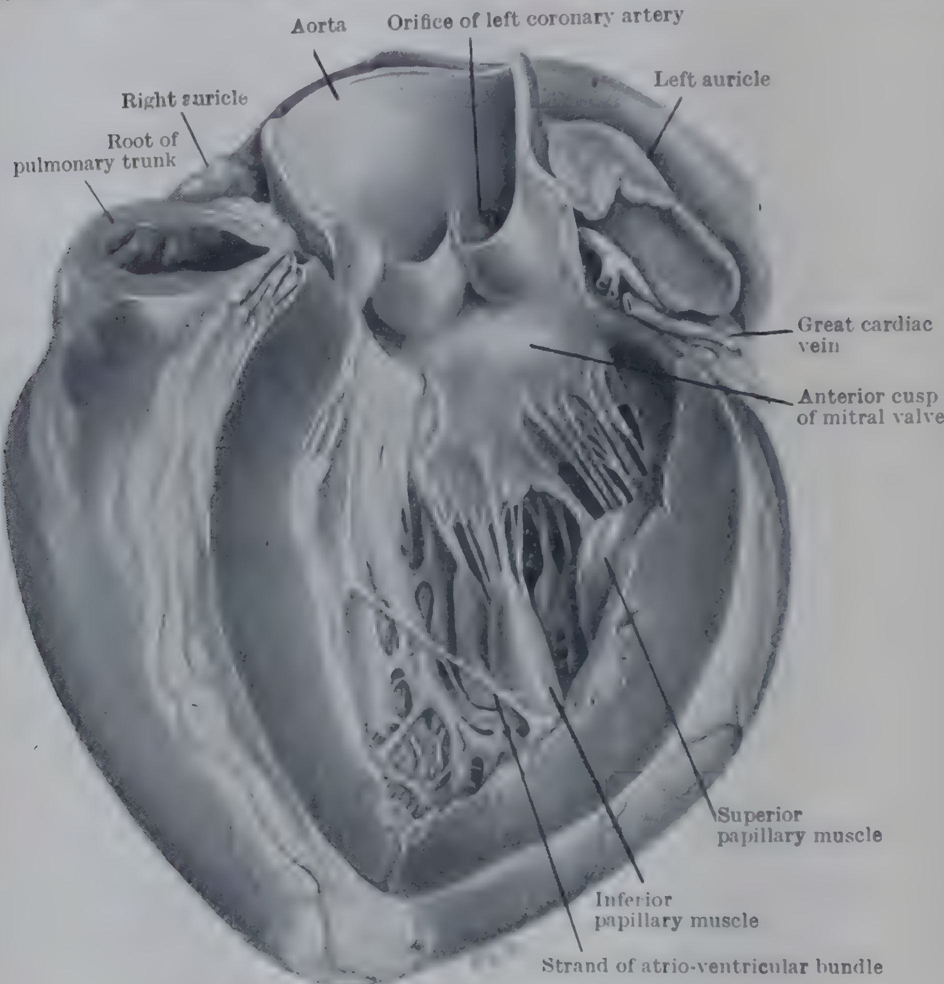

Fig. 1065.—Cavity of Left Ventricle of Heart.
The greater part of the pulmonary trunk has been removed, and the aorta opened to show the aortic valves.

position to the moderator band in the right ventricle, but formed entirely by branches of the atrio-ventricular bundle (p. 1237), are usually to be found passing across the cavity from the septum to the superior papillary muscle (Fig. 1065).

The **ventricular septum** is a strong musculo-membranous partition. It is placed obliquely, so that one surface looks forwards and to the right and bulges into the right ventricle, whilst the other looks backwards and to the left and is concave towards the left ventricle. It extends from the right of the apex to the interval that separates the pulmonary and tricuspid orifices from the aortic and mitral. Its sterno-costal and inferior borders correspond respectively with the anterior and inferior interventricular grooves. Almost the whole of the septum is muscular, and is developed from the wall of the ventricular part of the primitive heart. The upper posterior part is developed from the septum of the truncus arteriosus. It is called the **membranous part**, for it is entirely fibrous; and it is the thinnest portion of the ventricular walls. It separates the aortic vestibule not only from the upper part of the right ventricle, but also from the lower part of the right atrium. Occasionally it is defective or absent; the two ventricles then communicate with each other directly.

Structure of Heart

The walls of the heart consist mainly of peculiar striated muscle, called the myocardium, which is enclosed between the epicardium, or visceral layer of the pericardium, externally, and the endocardium internally.

The **epicardium** consists of white fibrous and of elastic tissue, the latter forming a distinct reticulum in the deeper part. The surface which looks towards the pericardial cavity is covered with flat polygonal mesothelial plates.

The **endocardium** lines the cardiac cavities and is continuous with the inner coats of the vessels. It is much thinner than the epicardium. It consists, like the inner coat of the blood-vessels, of an inner lining of flat endothelial cells, a layer of fine subendothelial areolar tissue, and an external elastic layer which usually assumes the form of a fenestrated membrane.

The fibres of the **myocardium** differ from those of ordinary voluntary striated muscle in several ways: they are less distinctly striated; they appear to be made up of short, oblong cells joined end-to-end by transverse discs, the exact nature of which is not quite certain; the nuclei of the cells lie centrally; many of the cells fork towards one end or give off a side-branch, and, as these branches are united by transverse discs to similar processes of adjacent fibres, the whole forms an irregular network (Fig. 351, p. 403). Moreover, still more peculiar fibres—the **fibres of Purkinje**—are found immediately subjacent to the subendocardial tissue. The fibres of Purkinje are large cells which unite with one another at their extremities; their central portions consist of granular protoplasm, in which sometimes one but more frequently two nuclei are embedded, and the peripheral portion of each cell is transversely striated. Those cells present, in a permanent form, a condition which is transitory in all other striated muscle-cells.

The network of cardiac muscle-cells forms sheets and strands which have a more or less characteristic and definite arrangement in different parts of the heart; they are separated and at the same time bound together by intervening lamellæ of fine areolar tissue. By careful dissection, and after special methods of preparation, it is possible to recognize many layers and bundles, some of which are, however, probably artificially produced.

In the **atria** the muscular fasciculi fall naturally into two groups: (*a*) superficial fibres common to both atria; (*b*) deep fibres peculiar to each atrium.

The superficial fibres are most numerous on the sterno-costal aspect and in the neighbourhood of the atrio-ventricular sulcus. They run transversely across the atria and a few of them dip into the atrial septum.

The deep fibres are:—(1) Looped fibres; the ends of the looped fibres are attached to the fibrous rings around the atrio-ventricular orifices and the fibres pass antero-posteriorly over the atria. (2) Annular fibres which surround (*a*) the extremities of the large vessels which open into the atria, (*b*) the auricles, and (*c*) the fossa ovalis.

In the **ventricles** the muscular fasciculi form more or less definite V-shaped loops which begin and end at the fibrous rings which surround the large orifices at the bases of the ventricles. These loops embrace the cavities of either one or both ventricles, one limb of each loop lying on the outer surface of the heart and the other in the interior, and some of the loops possess very acute bends whilst others are very open.

The superficial fibres on the sterno-costal surface pass towards the left, those on the inferior surface towards the right. At the apex all are coiled into a whorl or *vortex* through which they pass into the interior of the ventricular walls and run towards the base, some in the septum and others in the papillary muscles. The various bundles which have been described can, according to Mall, be resolved into two main systems. One system arises from the infundibulum and the root of the aorta, that is, from the remains of the primitive aortic trunk: it is called the "bulbo-spiral" system. The other springs from the region of the primitive venous sinus and is termed the "sino-spiral". Both systems are separable into superficial and deep portions, and the general plan of more or less spirally curved V-shaped loops is retained in each; but the details of the arrangement are too complex for consideration within the limits of an ordinary text-book (see MacCallum, 1900; Mall, 1911). For an analysis of the muscular structure of the heart from a functional point of view, in relation also to its blood-supply and to the conducting system, see Robb & Robb (1942).

The heart also possesses a fibrous skeleton which strengthens its orifices, is continuous with the roots of the aorta and the pulmonary trunk, and gives attachment to the valves and the muscular layers. *Fibrous rings* surround the atrio-ventricular, pulmonary and aortic orifices, and the *fibrous trigone*, situated in the interval between the atrio-ventricular and aortic orifices, has already been mentioned (p. 1231). The back of the infundibulum is also connected to the aorta by a fibrous band which is continuous with the membranous part of the ventricular septum.

The valves of the heart consist of a thin layer of fibrous tissue, continuous with the fibrous rings that surround the orifices and covered by a reduplication of the lining membrane. Atrial muscle-fibres are found in the base of the atrio-ventricular valves, but the associated capillary vessels extend into the valves for a distance of not more than 3 mm. in health (Dow & Harper, 1932). Otherwise, these valves, like the pulmonary and aortic, are avascular.

Conducting System of Heart (Neuro-myocardium).—It would appear from the description of the muscular structure of the heart that the atrial and ventricular muscle-fibres are entirely separated from each other by the fibrous rings which surround

the atrio-ventricular orifices; that, however, is not the case, for the two groups are connected by a bundle of muscle-fibres of pale colour and rudimentary structure which lies immediately subjacent to the endocardium and constitutes the atrio-ventricular bundle. This, however, is only part of the conducting system of the heart.

The function of initiating the sequence of events in the cycle of heart-action, of controlling its regularity, and of transmitting the impulses from atria to ventricles, resides in certain special parts of the myocardium. Heart-muscle has the power of rhythmic contraction. One collection of the special myocardial tissue, situated in the wall of the right atrium, sets the pace of the rhythm; another, extending from the septal wall of the right atrium across the otherwise fibrous atrio-ventricular junction, and spreading out to form a subendocardial network in the walls of the ventricles, propagates the rhythm of the atrial contraction to the ventricles. If the connecting link is severed, experimentally or by disease, the remarkable result follows that the ventricles contract independently of the atria, and with a much slower rhythm. This condition is known as "heart-block".

FIG. 1066.—NERVE-FIBRILS AND NERVE-TERMINALS IN THE ATRIO-VENTRICULAR BUNDLE OF THE RHESUS MONKEY. (After Nonidez, 1943.)

The parts concerned in this controlling and conducting mechanism are composed of myocardial tissue, distinguished from the ordinary cardiac muscle not only because it is less highly differentiated from the original cells, but also because the muscle-fibres are intimately associated with numerous nerve-cells and nerve-fibrils (Fig. 1066), which probably have a share in the initiation and transmission of the rhythmic contraction of the heart (Morison, 1912; Meiklejohn, 1913; Stotler & McMahon, 1947; Akkeringa, 1949). The functional connexion between the parts of the heart has thus a neuro-muscular basis; and the system as a whole may therefore be distinguished as the "neuro-myocardium". Its parts are named the *sinu-atrial node*, the *atrio-ventricular node*, and the *atrio-ventricular bundle* with its right and left septal divisions, which end in the *terminal subendocardial network*. For references to the earlier literature, see Holmes (1921).

The **sinu-atrial node** (Keith and Flack) is a small collection of vascular neuromyocardium situated in the wall of the right atrium at the upper end of the crista terminalis.

The **atrio-ventricular node** (Tawara) is a nodule of the same kind of vascular tissue, situated in the septal wall of the right atrium immediately above the opening of the coronary sinus.

The atrio-ventricular bundle (Kent, His) is a pale bundle, about the thickness of a match, of the special muscle-fibres, with which nerve-fibres are associated. It springs from the node, runs forward on the septum, passes through the fibrous atrio-ventricular junction, and appears beneath the endocardium of the right ventricle under cover of the medial (septal) cusp of the tricuspid valve. There it swells out a little, and then passes forwards along the posterior and lower border of the membranous upper part of the ventricular septum to the upper end of the muscular part of that septum, where it divides into right and left branches (Figs. 1067, 1068).

The *right septal division* continues the course of the main bundle on the muscular part of the septum towards the moderator band, along which it passes from the septum to the anterior wall of the ventricle, which it reaches at the base of the anterior papillary muscle (see Truex & Copenhaver, 1947). Fine branches arise from it as it reaches the moderator band, and these continue along the septum to the base of the inferior papillary muscle. One or two of them occasionally appear as free threads passing across the cavity of the ventricle.

The *left septal division* pierces the ventricular septum between its membranous and muscular parts and appears on the left side of the septum, along which it runs, as a flattened band, to the base of the inferior papillary muscle of the left ventricle. As it passes over the septum, two or three fine strands usually spring from it and pass across the cavity of the ventricle to the base of the superior papillary muscle (Fig. 1065). These strands are very distinct in the hearts of the sheep and calf, in which both septal branches and the network in which they end can be recognized very easily by the naked eye as whitish structures beneath the endocardium.

The bundle and its divisions are readily dissected in the heart of an ungulate, but in the human heart they are less easily displayed (Walls, 1945).

The **terminal subendocardial network** (Purkinje) is spread out beneath the endocardium of the greater part of both ventricles. It receives the branches of the bundle at the bases of the papillary muscles, which are consequently the first parts of the ventricles to contract. The network forms a characteristic collar around each papillary muscle, the apex of the muscle being free of the network. The meshes of the network become finer, and

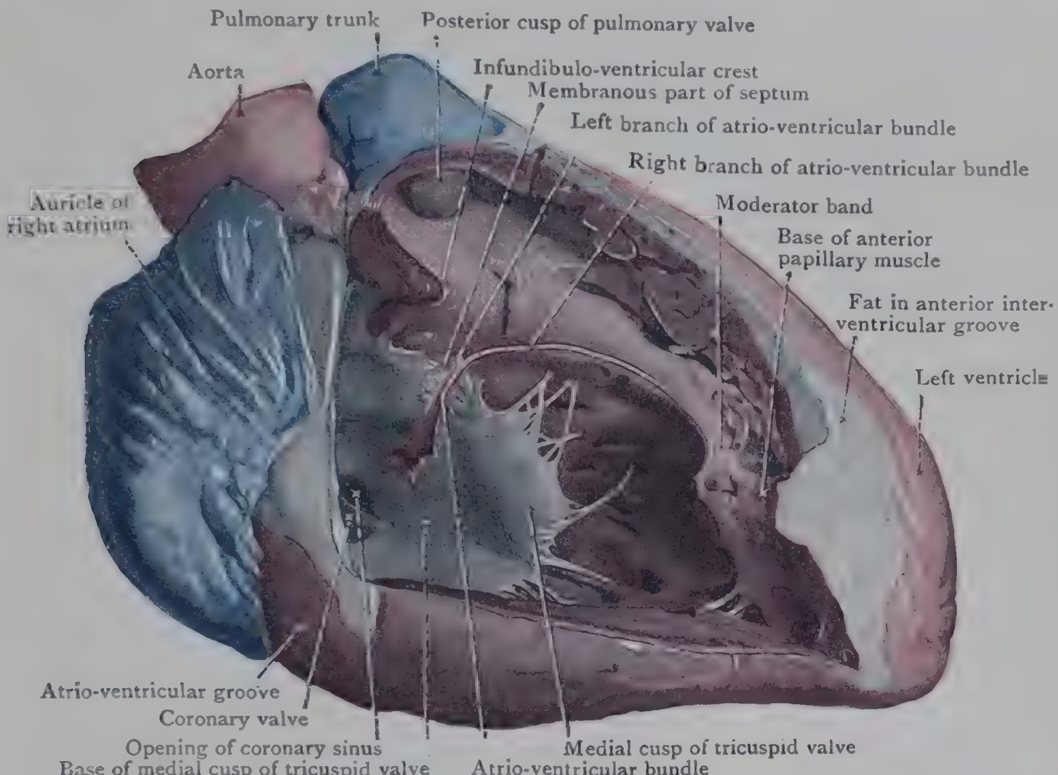

Fig. 1067.—Dissection of Right Ventricle of Heart showing Course and Division of Atrio-Ventricular Bundle.

then disappear, towards the atrio-ventricular and arterial orifices of the ventricles. A striking picture of the distribution of the subendocardial network and of the course of the bundle and its branches may be obtained by the injection of Indian ink or other suitable coloured liquid into the sheath which surrounds the whole system. Good results are most easily obtained in the heart of an ungulate (Fig. 1068).

For a review of the anatomy of the conducting system of the vertebrate heart and the history of its investigation with full bibliography to date, see Davies & Francis (1946). For general observations on the system, consult Blair & Davies (1935), and for its development Shaner (1930) and Walls (1947).

Action of Heart.—The differences between the various parts of the heart, *e.g.*, the relative thickness of the walls of the chambers, are associated with the functions of the various chambers, and with the action of the heart in the maintenance of the circulation of the blood. The heart is a muscular pump, provided with receiving and ejecting chambers. It has three phases of action: (1) a period of atrial *systole* or contraction; (2) a period of ventricular contraction, which immediately succeeds the atrial contraction; (3) a period of *diastole* or rest.

During the period of rest the chambers, previously contracted, expand as the muscular fibres of the heart relax. The expansion is aided by the respiratory movements of the thorax, and, as it progresses, blood flows into the right atrium from the venæ cavæ and the coronary sinus, and into the left atrium through the four pulmonary veins. As the blood enters the atria, it begins at once to flow into the ventricles through the open atrio-

ventricular orifices, and the onward movement is completed by the contraction of the atria. The atrial systole begins with the contraction of the circular fibres which surround the mouths of the veins entering the atria, and thus the blood is prevented from passing back into the veins. As the contraction spreads, the atria are emptied and the ventricles become distended. Then the ventricular systole begins, the atrio-ventricular valves close, the arterial valves open, and, as the contraction proceeds, the blood is driven out of the ventricles through the arterial orifices—from the right ventricle into the pulmonary trunk, and from the left ventricle into the aorta.

When the ventricular contraction is completed, the period of systole is at an end and the period of diastole begins; and, so long as the heart remains alive, the cycle is repeated.

The work of the atria is merely to complete the discharge of the blood through the

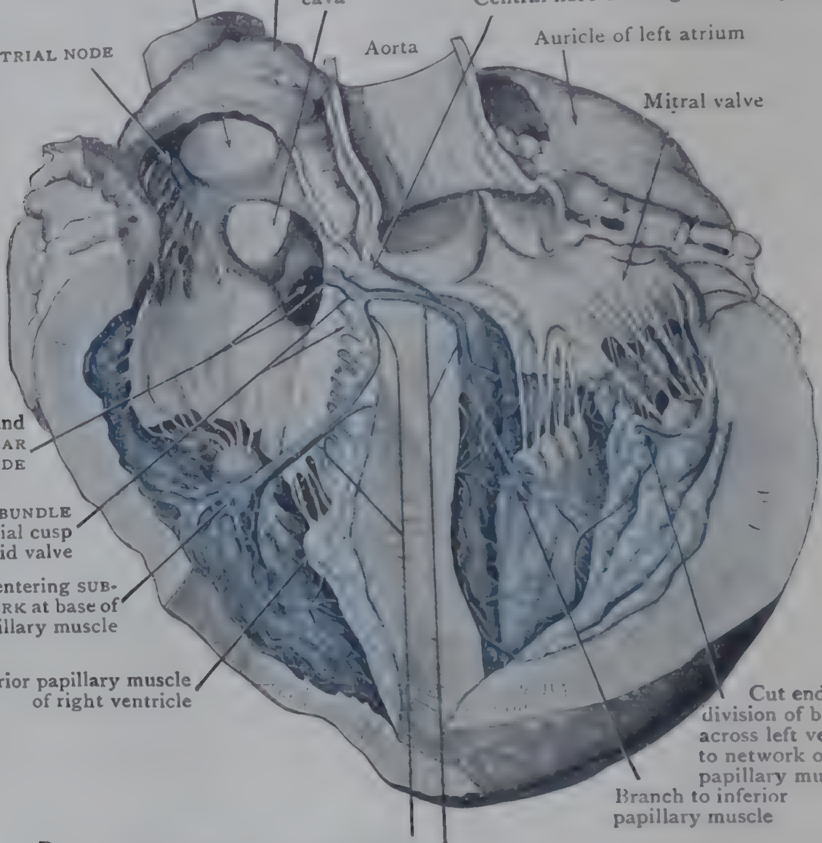

Fig. 1068.—Conducting System of Sheep's Heart; from Dissected and Injected Specimens.

widely open atrio-ventricular orifices into the ventricles and to expand the ventricles. For that purpose no great force is required; the walls of the atria are therefore thin. The work of the ventricles is much more severe; their walls are therefore thicker. The right ventricle, however, has only to exert sufficient force to drive the blood through the lungs to the left atrium—that is, through a comparatively short distance and against a relatively small resistance. Its walls are therefore thin compared with the walls of the left ventricle, which have to be sufficiently strong to force the blood through the whole body. The pressure created in the aorta (150 mm. Hg.) is about three times as great as that in the pulmonary arteries; corresponding to the relation between these pressures is the fact that the left ventricular wall is about three times as thick as the right (Fig. 1064).

Size of Heart.—The heart is about 5 inches (125 mm.) long, $3\frac{1}{2}$ inches (85 mm.) broad; its greatest depth from its sterno-costal to its diaphragmatic surface is $2\frac{1}{2}$ inches (60 mm.), and it is roughly estimated as being about the same size as the closed fist. The size, however, is variable even in health, the volume increasing at first rapidly, and then gradually, with increasing age, from 22 cc. at birth to 155 cc. at the fifteenth year, and to 250 cc. by the twentieth year. From that period to the fiftieth year, when the maximum volume (280 cc.) is attained, the increase is much more gradual, and after fifty a slight decrease sets in. The

volume is the same in both sexes up to the period of puberty, but thereafter it preponderates in the male.

Weight.—The average weight of the heart in the male adult is 11 ounces (310 grms.), and in the female adult 9 ounces (255 grms.); but the weight varies greatly, always, however, in definite relation to the weight of the body, the relative proportions changing at different periods of life. Thus, at birth the heart weighs 13½ drachms (24 grms.), and its relation to the body weight is as 1 to 130, whilst in the adult the relative proportion is as 1 to 205. The heart is said to increase rapidly in weight up to the seventh year, then more slowly up to the age of puberty, when a second acceleration sets in; but after the attainment of adult life the increase, which continues till the seventieth year, is very gradual.

These changes affect the whole heart, but the several parts also vary in their relation to one another at different periods of life. During fœtal life the right atrium is heavier than the left; in the first month after birth the two become equal; at the second year the right again begins to preponderate, and it is heavier than the left during the remainder of life. In the latter part of fœtal life the two ventricles are equal; after birth the left grows more rapidly than the right, until, at the end of the second year, a position of stability is gained, when the right is to the left as 1 to 2, and this proportion is maintained until death.

Capacity.—During life the capacity of the ventricles is probably the same, and each is capable of containing from three to four ounces of blood, whilst the atria are a little less capacious. After death the cavity of the right ventricle appears larger than that of the left.

Blood-Supply of Heart.—The walls of the heart are supplied by the **coronary arteries** (p. 1250), the branches of which pass through the interstitial tissue to all parts of the muscular substance and to the subendocardial and subepicardial tissues; the endocardium and the free parts of the valves are devoid of vessels. The capillaries, which are numerous, form a close-meshed network around the muscular fibres. Sometimes the valves contain a few muscular fibres, and in those cases they also receive some minute vessels (p. 1235). Special branches of the coronary arteries supply the conducting system of the heart (Haas, 1911; Gross, 1921). The right coronary supplies the atrio-ventricular node, the main bundle and the posterior branches of its left septal division; the left coronary supplies the anterior branches of the left division and assists the right coronary in the supply of the right septal division by sending a branch from the ventricular septum along the moderator band of the right ventricle.

The majority of the veins of the heart end in the coronary sinus, which opens into the lower part of the right atrium; some few small veins, however, open directly into the right atrium, and others are said to end in the left atrium, and in the cavities of the ventricles.

Lymph-Vessels of Heart.—A subendocardial plexus communicates through the substance of the heart with a superficial network beneath the epicardium. Efferent vessels from the subepicardial network follow the coronary arteries and end in right and left trunks which pass respectively to innominate and tracheo-bronchial glands (p. 1426).

Nerves of Heart.—The heart receives its nerves from the superficial and deep cardiac plexuses. The former lies below the aortic arch and the latter between the arch and the bifurcation of the trachea. Through the plexuses it is connected with the vagus, the accessory (through the vagus) and the sympathetic nerves (see p. 1138). After leaving the cardiac plexuses many of the nerve-fibres enter the walls of the atria and form a subepicardial plexus in which many ganglion-cells are embedded, especially near the terminations of the inferior vena cava and the pulmonary veins. From the subepicardial atrial plexus, nerve-filaments, with which nerve-cells are associated, pass into the substance of the atrial walls.

Other fibres from the cardiac plexuses accompany the coronary arteries to the ventricles, and upon those also nerve-cells are found in the region immediately below the atrio-ventricular sulcus.

The nerve-fibres which issue from the plexuses of the heart are non-medullated. They form fine plexuses around the muscle-fibres, and they end either in fine fibrils on the surfaces of the muscle-fibres, or in nodulated ends which lie in contact with the muscle-cells. Many nerve-fibres accompany the branches of the atrio-ventricular bundle (p. 1236). See also the account of the cardiac plexuses (p. 1138).

Abnormalities of Heart.—The **heart** may be transposed from the left to the right side of the body, a condition which is usually associated with general transposition of the viscera, and with the presence of a right aortic arch instead of a left.

The external form of the heart does not as a rule vary much, but occasionally the apex is slightly bifid, a character it normally possesses at an early stage of its development, and which is retained in the adult in many cetaceans and sirenians. The internal conformation of the heart deviates from the normal much more frequently; more particularly is this the case with regard to the septa which separate the right from the left chambers. The interatrial septum may be entirely absent, as in fishes; it may be fenestrated and incomplete, as in some amphibians; or the foramen ovale may remain patent, as in amphibians and reptiles.

The ventricular septum may be absent, as in fishes and amphibians, or incomplete, as in reptiles; when incomplete, it is usually the membranous part which is deficient, but perforations are occasionally found in the muscular portion.

The communication between the infundibulum of the right ventricle and the body of the ventricle may be constricted or the infundibulum may be entirely cut off from the remainder of the cavity. In such cases of "pulmonary stenosis" there is always an interventricular foramen, and the pulmonary arteries receive their blood from the aorta via a patent ductus arteriosus. Many congenital malformations of the heart are incompatible with life. (See also p. 1371, and consult Keith, 1909; Walmsley, 1929; Abbott, 1936.)

Radiographic Examination of Heart and Blood-Vessels.—The heart, having a solid wall and a cavity filled with blood, absorbs X-rays to such an extent that it causes a dense white shadow in radiographs. With modern apparatus the time of exposure can be reduced to $\frac{1}{25}$ of a second or less; this high speed prevents blurring by movement, and the cardiac outline appears quite sharp.

The general shape of the shadow of the **heart** with the great vessels is seen in Pl. LXV, p. 704. Apart from local modifications according to the phase of heart-action, it is important to note that the shape is greatly altered by the position of the diaphragm (Pls. LXVI, p. 705, LXVII, p. 720). These alterations are easily understood if it is remembered that the pericardium is firmly attached to the diaphragm, and that the arch of the aorta is prevented from descending to any great extent by the passage of its branches out of the thorax and of the left bronchus under it. Thus, with the descent of the diaphragm in full inspiration the mediastinum as a whole is elongated and the shadow of the heart in particular appears long and narrow (Pl. LXVI); at the same time it is more clearly defined, partly because the lungs have become more translucent (p. 721). As the diaphragm ascends the mediastinum shortens, until in full expiration the combined shadow of the heart and great vessels is quite broad (Pl. LXVII).

Screen examination permits direct observation of the alteration of the outline of the heart during systole and diastole, and the alterations produced by respiration may be studied as they take place.

These changes in the normal appearance of the heart are paralleled by permanent differences in persons of different build or who suffer from abnormal conditions in the thorax or the abdomen. Thus, in thin patients with marked emphysema (see p. 721) the air-content of the lungs is so much increased that the diaphragm is pushed much farther down than normal, and the heart may become so narrow that it is scarcely broader than the vertebral column. On the other hand, in stout patients with much intra-abdominal fat the diaphragm is elevated, and the cardiac shadow is broader than the average in all phases of respiration.

In the ordinary anterior radiograph of the chest, the shadows cast by the great vessels merge into that of the heart, but the aorta at least can always be distinguished in two places. The wide curve of the **ascending aorta** is visible to the right of the shadow of the vertebral column, while to the left of it the terminal part of the **arch** forms a rounded prominence known to radiologists as the aortic "knob" or "knuckle". When the heart-shadow is elongated in deep inspiration the shadow of the **pulmonary trunk** also may be seen (Pl. LXVI). The *left* subclavian vessels may sometimes be seen as they cross the apex of the lung. In children, the **superior vena cava** is prominent as it passes upwards to the right of the shadow of the vertebral column; but in adults it is visible only in cases of venous congestion. Low position of the diaphragm may render the **inferior vena cava** visible in the "cardio-hepatic angle" at the junction of the cardiac shadow with the right dome of the diaphragm (Pl. LXVI).

Peripheral blood-vessels are not usually seen in radiographs unless their walls are calcified. They may be shown, however, by the injection of thorium dioxide (thorotrast) by which means radiographs of even the cerebral arteries (Pl. LXXX, Fig. 1, p. 1217) may be produced. Unfortunately, the use of thorotrast is not free from risk as it is radio-active; this method, therefore, has to be restricted to the investigation of certain pathological conditions in which the desired information cannot be obtained in any other way.

PERICARDIUM

The **pericardium** is a fibro-serous sac which surrounds the heart. It lies in the middle mediastinum. It is attached below to the diaphragm, and above and behind to the roots of the great vessels. In front and behind it is in relation with structures in the anterior and posterior mediastina; laterally it is in close apposition with the pleural sacs.

The **fibrous pericardium** is a strong fibrous sac of conical form; its base is attached to the central tendon and to the adjacent part of the muscular substance of the diaphragm, and it is pierced by the inferior vena cava. At its apex and posteriorly it is gradually lost upon the great vessels which enter and emerge from the heart, and it gives sheaths to them—namely, the aorta, the two branches of the pulmonary trunk, the superior vena cava, the four pulmonary veins, and the ligamentum arteriosum. Its anterior surface forms the posterior boundary of the anterior mediastinum, and it is attached, above and below, by the sterno-pericardial

ligaments to the sternum. In the greater part of its extent it is separated from the anterior wall of the thorax by the anterior parts of the lungs and pleural sacs, but it is in direct relation with the left half of the lower portion of the body of the sternum and often with the medial ends of the cartilages of the fourth, fifth, and sixth ribs of the left side and the left sterno-costalis muscle. Its posterior surface forms the anterior boundary of the upper part of the posterior mediastinum; it is in relation with the œsophagus and the descending aorta, both of which it separates from the back of the left atrium (Fig. 1063). Each lateral surface is in close contact

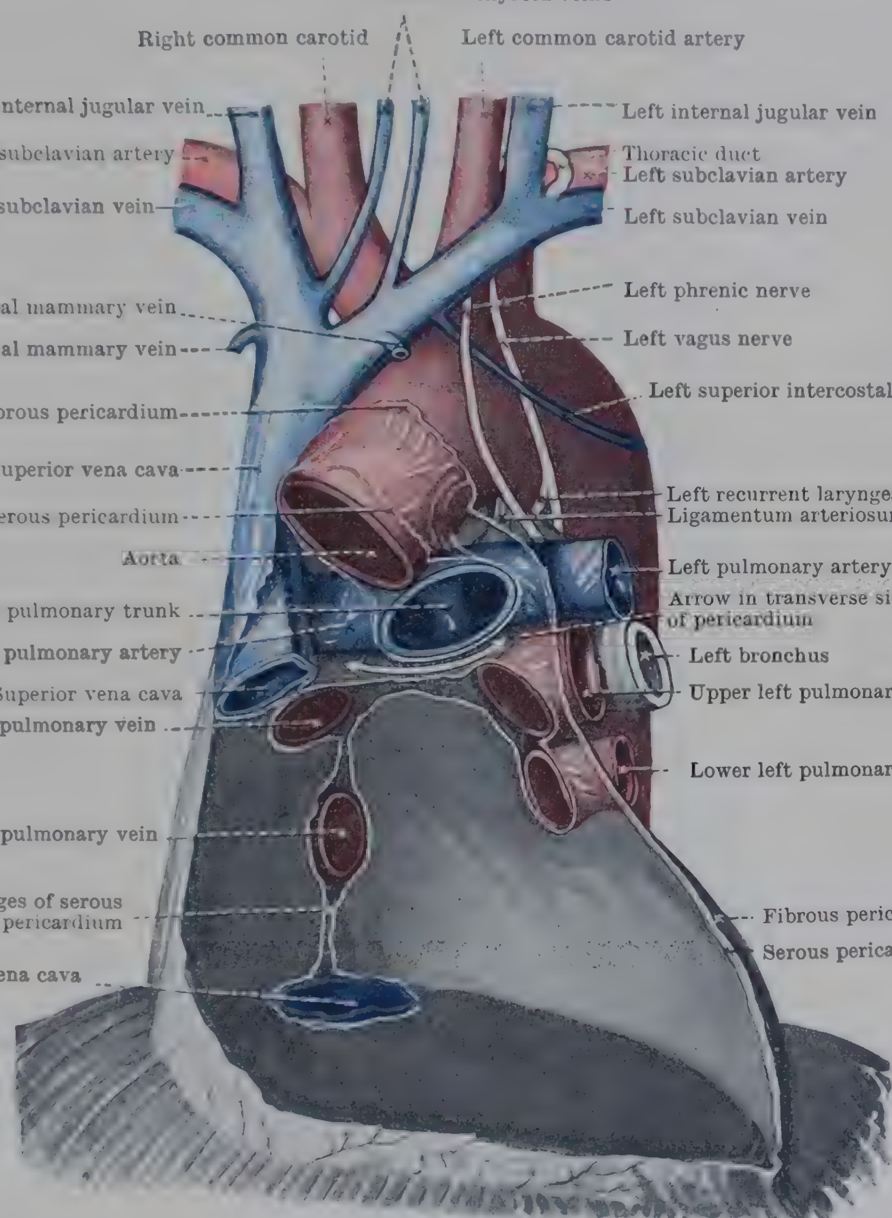

Fig. 1069.—Posterior Wall of Pericardium after Removal of the Heart.
Showing the relation of the serous pericardium to the great vessels.

with the mediastinal portion of the parietal pleura, the phrenic nerve and its accompanying vessels intervening. The inner surface of the fibrous sac is lined with, and is closely attached to, the parietal part of the serous pericardium.

The **serous pericardium** is a closed sac containing a little lubricating fluid. It is surrounded by the fibrous pericardium and invaginated by the heart. It is, therefore, separable into two portions—the parietal, which lines the inner surface of the fibrous sac, and the visceral, which ensheaths, or partially ensheaths, the heart and the great vessels; but the two portions are, of course, continuous with each other where the serous layer is reflected on to the great vessels as they pierce the fibrous layer. The majority of the great vessels receive only partial coverings from the visceral layer: thus, the superior vena cava is covered in front and on each side; the pulmonary veins in front, above, and below; and the inferior vena

cava in front and on each side. The aorta and the pulmonary trunk are enclosed together in a complete sheath of the visceral layer. Therefore, when the pericardial sac is opened from the front, it is possible to pass a finger behind them and in front of the atria, from the right to the left side, through a passage called the **transverse sinus** of the pericardium (Fig. 1069). The spaces or pouches which intervene between the vessels which receive partial coverings from the serous pericardium are also called sinuses; and the largest of them, which is called the **oblique sinus**, is bounded below and on the right by the inferior vena cava, and above and on the left by the lower left pulmonary vein. It passes upwards and to the right behind the left atrium, and lies in front of the œsophagus and the descending thoracic aorta.

A small fold of the serous pericardium, called the **fold of the left vena cava**, passes from the left pulmonary artery to the upper left pulmonary vein, behind the left end of the transverse sinus. It merits special attention because it encloses a fibrous strand—the *ligament of the left vena cava.* That is a remnant of the left superior vena cava, or duct of Cuvier, which atrophied at an early period of fœtal life. From the lower end of the ligament a small vein—*the oblique vein of the left atrium*—passes below the orifice of the lower left pulmonary vein, and descends to the coronary sinus; it represents the continuation of the duct of Cuvier to the heart (see pp. 1329, 1381).

Structure.—The fibrous pericardium is a dense unyielding fibrous membrane. The serous pericardium is covered on its inner aspect by a layer of flat mesothelial cells. The mesothelium rests upon a basis of mixed white and elastic fibres in which run numerous blood-vessels lymph-vessels, and nerves.

PULMONARY CIRCULATION

PULMONARY ARTERIES

The **pulmonary trunk** springs from the infundibulum of the right ventricle, and runs backwards and upwards, towards the concavity of the aortic arch, curving from the front round the left side of the ascending aorta to reach a plane behind it. It is slightly wider at its origin than the aorta, and is slightly dilated, immediately above the cusps of the pulmonary valve, into three shallow pouches or **sinuses**. It ends, by dividing into right and left pulmonary arteries, at the level of the sternal end of the second left costal cartilage. Its length is a little more than two inches.

Relations.—The pulmonary trunk is enclosed within the fibrous pericardium, and is enveloped, along with the ascending aorta, in a common sheath of the visceral layer of the serous pericardium (Fig. 1069). It lies behind the anterior end of the second left intercostal space, from which it is separated by the anterior margins of the left lung and pleural sac.

Its posterior relations are first the ascending aorta, and then the left atrium (Figs. 1058, 1061). To the right it is in relation with the auricle of the right atrium and the ascending aorta, and to the left with the auricle of the left atrium. Immediately above its bifurcation, between it and the aortic arch, is the superficial cardiac plexus of nerves.

Both the coronary arteries are in relation to its root—the right coronary artery on its right, the left at first behind and then on its left.

The **right pulmonary artery** is longer and wider than the left. It passes to the right lung, in its root, enters the hilum and descends, with the main bronchus, to the lower end of the lung (Fig. 1071).

Relations.—Before it enters the lung the right pulmonary artery passes behind the ascending aorta, the superior vena cava, and the upper right pulmonary vein. At first it lies below the arch of the aorta and the right bronchus, in front of the œsophagus, and above the left atrium and the lower right pulmonary vein; then it crosses in front of the right bronchus, immediately below its eparterial branch, and reaches the hilum of the

lung (Fig. 606, p. 719). In the lung the artery descends posterior and lateral to the main bronchus.

Branches.—Before entering the hilum it gives off a large branch which accompanies the eparterial bronchus to the upper lobe of the right lung. In the substance of the lung it gives off numerous branches which accompany the lobar and segmental branches of the right bronchus. (See Respiratory System, p. 720.)

The **left pulmonary artery**, shorter, narrower, and a little higher in position than the right, passes laterally and backwards from the bifurcation of the pulmonary trunk, and runs, in the root, to the hilum of the left lung; it then descends, in company with the main bronchus, to the lower end of the lung.

Relations.—Before it enters the lung it is crossed, *anteriorly*, by the upper left pulmonary vein; *posterior* to it are the left bronchus and the descending aorta; *above*, are

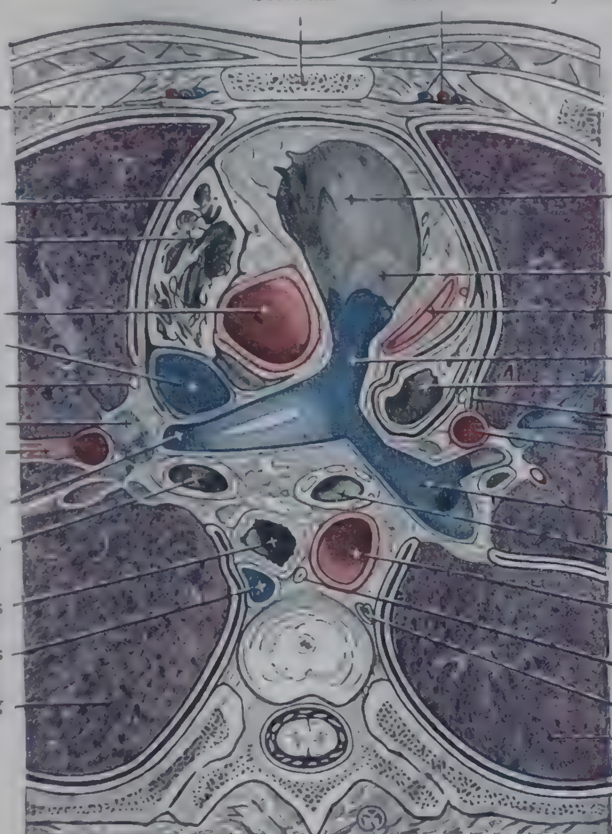

FIG. 1070.—TRANSVERSE SECTION OF THORAX OF YOUNG MAN THROUGH PULMONARY TRUNK AND ARTERIES. The section is in the plane C-C, Fig. 1109, p. 1330, and is seen from below.

the aortic arch (to which it is connected by the ligamentum arteriosum, pp. 1373, 1386) and the left recurrent laryngeal nerve; *below*, it is in relation with the lower left pulmonary vein (Figs. 606, 1071). After entering the lung it descends, like the right pulmonary artery, posterior and lateral to the stem bronchus.

Branches.—Just before it passes through the hilum it gives off a branch to the upper lobe of the left lung, and in the substance of the lung its branches correspond with the lobar and segmental branches of the left bronchus. (See also p. 720.)

Variations.—Abnormal formation of the **pulmonary trunk** is very uncommon and is associated with abnormality of the aorta (p. 1250). Congenital malformation of the right ventricle may cause stenosis (narrowing) of the trunk which may obliterate its lumen (p. 1239).

PULMONARY VEINS

The terminal **pulmonary veins** (Figs. 1057, 1063, and 1069), two on each side, open into the left atrium of the heart. Their tributaries arise in capillary plexuses in the walls of the pulmonary alveoli. By the union of the smaller veins larger vessels are formed which run in front of the bronchial tubes, and unite to form in each lobe a single efferent vessel which passes into the root of the lung. Thus there are

five main pulmonary veins, but, immediately after entering the root of the lung, the vessels from the upper and middle lobes of the right lung usually join together, and so only four terminal pulmonary veins open into the left atrium. Neither the main stems nor their tributaries possess valves.

Relations.—In the root of each lung the upper pulmonary vein lies below and in front

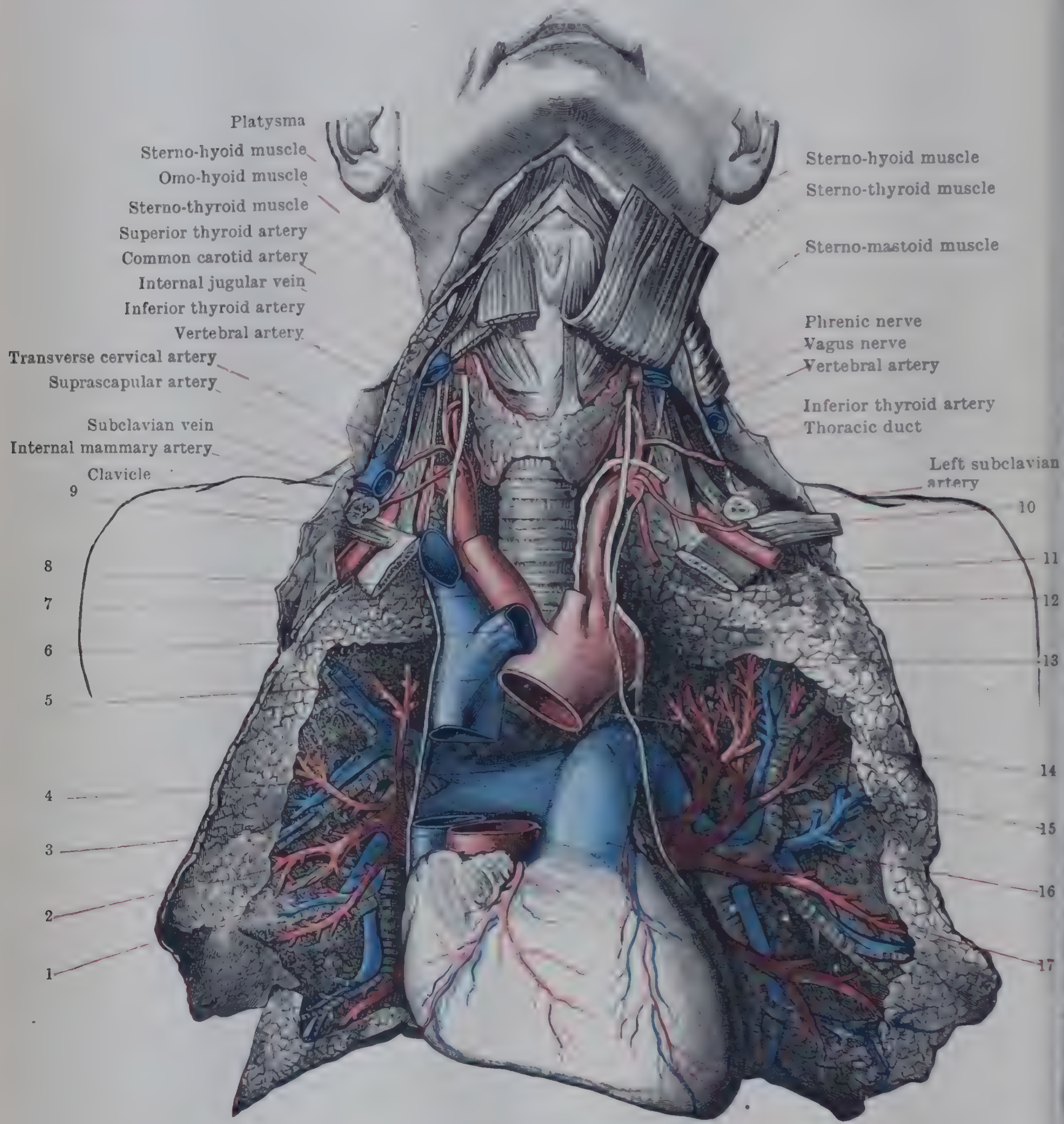

FIG. 1071.—PULMONARY ARTERIES AND VEINS AND THEIR RELATIONS.
The ascending aorta and part of the superior vena cava have been removed. Cf. Fig. 606, p. 719.

1. Ascending aorta.
2. Superior vena cava.
3. Upper right pulmonary vein.
4. Right pulmonary artery.
5. Superior vena cava.
6. Left innominate vein.
7. Innominate artery.
8. Right innominate vein.
9. Subclavius muscle.
10. Subclavius muscle.
11. First rib.
12. Left common carotid artery.
13. Arch of aorta.
14. Ligamentum arteriosum.
15. Left pulmonary artery.
16. Upper left pulmonary vein.
17. Pulmonary trunk.

of the pulmonary artery (Fig. 606, p. 719). The lower pulmonary vein is in the lowest part of the root, and also in a plane posterior to the upper vein.

On the right side the upper pulmonary vein passes behind the superior vena cava, and the lower passes behind the right atrium. They both end in the upper and posterior part of the left atrium close to the atrial septum. *On the left side* both upper and lower pulmonary veins cross in front of the descending aorta, and they end in the upper and posterior part of the left atrium near its left border.

All four pulmonary veins perforate the fibrous layer of the pericardium, and receive partial coverings of the serous layer before they enter the atrium.

Variations.—The openings of the pulmonary veins into the left atrium of the heart may be reduced or increased in number. The commonest variations are the fusion of the left veins into a single trunk, and separate openings for the veins from all three lobes of the right lung.

SYSTEMIC CIRCULATION

ARTERIES

The systemic arteries all spring from the aorta, and the whole system, with reference to its branching and re-branching, is sometimes spoken of as the "arterial tree". The tissues of the body are supplied with blood through the ultimate branches, or *arterioles*, and the capillaries which arise from them; some tissues, however, are devoid of arteries, *e.g.*, the transparent cornea of the eye, articular cartilages, the epidermis of the skin with the nails and the hairs.

The larger arteries are naturally protected from injury by their situation both in the trunk and the limbs. In particular, the main arteries of the limbs emerge from the trunk into the medial side of the limb and run distally on the flexor side so that protection is more effective as the limbs are bent. Most main arteries pursue a more or less straight or evenly curved course, but some, for functional reasons, are very tortuous; for example, the facial artery because of the movements of the mandible, and the uterine artery probably in anticipation of necessary enlargement as the uterus grows during pregnancy. The tortuosity of arteries tends to increase or develop with age as changes occur in their coats.

The mode of division of arteries varies according to their situation and the areas they supply. The usual arrangement is illustrated by the arteries of the limbs, which give off a series of branches in succession yet retain their individuality as main vessels; some arteries end by dividing into two more or less equal branches—the most notable example is the aorta itself; a few arteries represent the combined origin of several branches which spring together from a short trunk, *e.g.*, the thyro-cervical trunk and the cœliac artery. The sectional area of the "arterial tree" increases steadily towards the periphery. When an artery divides into two, each branch is narrower than the parent trunk but the two together have a greater capacity; and the combined sectional area of all the arterioles is much greater than that of the aorta.

Functional Distribution.—The functional distribution of some arteries (pulmonary, renal) is obvious, but Hilton (1863) raised the interesting question whether the distribution of other arteries, not confined to single organs, may have a general functional significance. For example, he named the maxillary artery the "masticatory artery" because of its distribution to the bones, muscles and nerve concerned. The subclavian, apart from its continuation to the upper limb, he considered to be essentially a "respiratory artery", analysing the distribution of its branches including the vertebral artery, which supplies the respiratory nerve-centres. The palate is another example, its multiple blood-supply being related to the part it plays in respiration, mastication and deglutition.

Shellshear (1920) quotes Hilton on this interesting and rather neglected subject, and discusses the functional distribution of the cerebral arteries.

Anastomoses.—There are few arteries in the body that are entirely independent of their neighbours, for the great majority communicate with other arteries through branches that unite to form *anastomoses*. In some regions anastomosis occurs directly between arteries of considerable size, so that there is an even distribution of blood to the parts supplied, *e.g.*, the union of the two vertebral arteries to form the basilar artery which takes part in the remarkable "circulus arteriosus" at the base of the brain (Fig. 1084, p. 1272), and the formation of the "arterial arcades" in the supply of the intestines (Fig. 1094, p. 1300). But the most widespread anastomoses take place between the smaller arteries, and there are usually so many communications between arterioles that extensive networks are formed from which the capillaries arise. In the limbs there are notable anastomoses between medium-sized arteries around the joints (Pls. LXXXI, p. 1296; LXXXIV, p. 1313); these anastomoses are of surgical importance as they are the means by which the blood-supply to the distal part of the limb is maintained by the opening up of a *collateral circulation* after ligature of a main artery. Quiring (1949) provides a convenient, illustrated survey of the chief anastomoses, both arterial and venous, in the body.

Arterio-Venous Anastomoses.—Direct connexions, without the intervention of capillaries, occur between small arteries and veins in many situations in the body. The best known are the anastomoses that form the basis of the 'glomera' found in the skin of the palmar surface of the digits (Fig. 1072). Contraction and relaxation of the arteriole determine the flow of the blood either through the capillaries or direct into the venule, the glomus thus acting as a "by-pass" for the capillaries. Grant & Bland (1930) have obtained evidence that this mechanism is of some importance in the regulation of temperature.

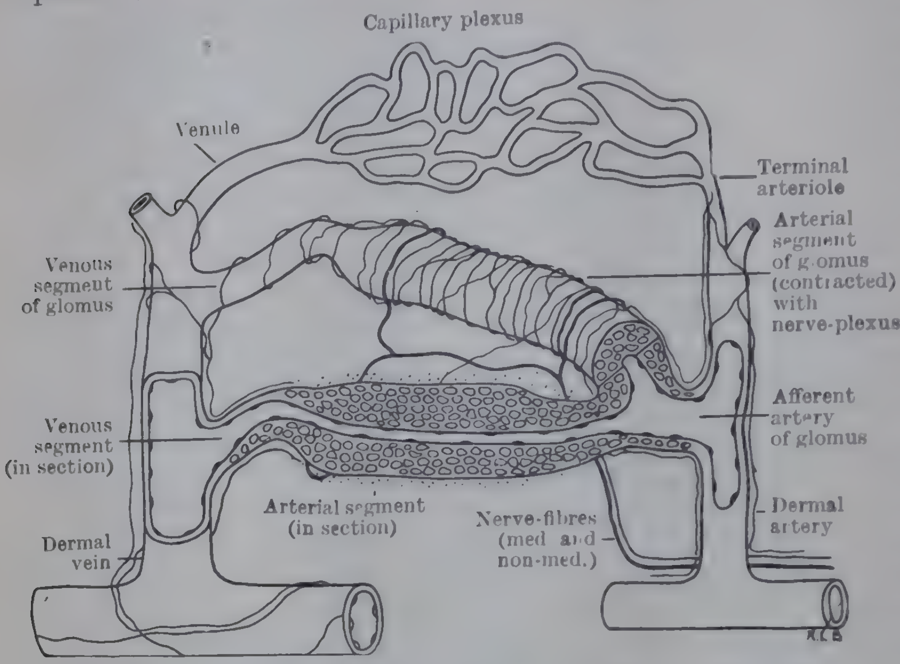

FIG. 1072.—ARTERIO-VENOUS ANASTOMOSIS IN THE SKIN OF THE HAND. (After Masson, 1937.)

The glomus coccygeum (p. 809) contains numerous arterio-venous anastomoses; they are present in the kidney (p. 736), in the spleen (p. 831), in the nasal mucous membrane (p. 1212), in the villi of the small intestine (p. 626), and in the wall of the stomach (Walder, 1950); Hayek (1940) has described them in the lung and Nonidez (1942) in the ganglia of the sympathetic trunk. For a general review of the whole subject consult Clark (1938) and Boyd (1939).

End-Arteries.—Small arteries which do not anastomose with others and therefore (apart from capillary communications) constitute the sole source of blood to the areas they supply are called *end-arteries* ; they are of pathological importance since occlusion of such an artery causes death of the tissues it supplies. End-arteries are found in the distribution of the main vessels to some organs, *e.g.*, kidney (p. 735) and spleen (p. 831) ; and in the case of the blood-supply of the substance of the spinal cord and brain, although communications do exist, there is reason to believe that the smaller vessels act as "functional end-arteries" owing to the difficulty of establishing an effective collateral circulation. One of the most important of the end-arteries is the central artery of the retina (p. 1172), since its occlusion causes blindness.

AORTA

The **aorta** is the main trunk of the general arterial system. It begins at the base of the left ventricle and runs upwards (**ascending aorta**), with an inclination to the right and forwards, to the level of the second right costal cartilage ; continuing upwards it curves first to the left and then backwards and downwards, until it reaches the left side of the lower border of the fourth thoracic vertebra (**arch of aorta**) ; from that level it runs downwards (**descending aorta**) through the thorax into the abdomen, where it ends, on the left of the median plane, on the front of the fourth lumbar vertebra, by bifurcating into the two common iliac arteries. The descending portion of the aorta is, for convenience, divided into the *descending thoracic aorta*, and the *abdominal aorta*.

Ascending Aorta.—The ascending aorta lies in the middle mediastinum. It springs from the base of the left ventricle, behind the left margin of the sternum, opposite the lower border of the third left costal cartilage. From its origin it passes upwards, forwards, and to the right, and it ends by becoming the arch of the aorta behind the right margin of the sternum at the level of the second costal cartilage. Its *length* is from 2 to 2¼ inches (about 55 mm.) and its diameter is a little over 1 inch (about 28 mm.). In the adult it is a little narrower at its origin than the pulmonary artery, but as age advances it enlarges and exceeds that vessel in size. The diameter, however, is not uniform throughout the whole

length of the ascending aorta. Its root is dilated owing to three bulgings in its wall—the **sinuses of the aorta**. The sinuses are immediately opposite the cusps of the aortic valve. One is therefore anterior in position, and two posterior. At a higher level a diffuse bulging of the right wall is sometimes known as the *great sinus of the aorta*.

Relations.—The ascending aorta is completely enclosed within the fibrous pericardium which blends above with the sheath of the vessel, and it is enveloped, together with the pulmonary trunk, in a tube of the serous pericardium. At its origin it has the infundibulum of the right ventricle and the pulmonary trunk in front, the transverse sinus of the pericardium and the left atrium behind, and the right atrium on its right side. In the upper part of its course the ascending aorta is overlapped by the anterior margins of the right lung and right pleural sac, whilst posterior to it are the

FIG. 1073.—TRANSVERSE SECTION THROUGH SUPERIOR MEDIASTINUM AT LEVEL OF FOURTH THORACIC VERTEBRA.

right pulmonary artery, the right bronchus, and the left margin of the superior vena cava. The superior vena cava lies on the right side and partly behind the upper part of the ascending aorta, whilst the pulmonary trunk is at first in front and then, at a higher level, on its left side.

Branches.—Two branches arise from the ascending aorta, viz., the right and the left coronary arteries (p. 1250). The right coronary artery springs from the anterior sinus of the aorta, and the left artery from the left posterior sinus (Fig. 1061).

Arch of Aorta.—The arch of the aorta lies in the superior mediastinum opposite the lower part of the manubrium sterni. It begins behind the right margin of the sternum, at its union with the second costal cartilage, and ends at the left side of the lower border of the fourth thoracic vertebra. The arch makes two curves, one with the convexity upwards (Fig. 1069), and the other with the convexity to the left and slightly forwards. From its origin it runs for a short distance upwards and to the left anterior to the trachea; then it passes backwards, round the left side of the trachea to the left side of the body of the fourth thoracic vertebra (Fig. 1073). Finally it turns downwards to become continuous with the descending aorta.

The arch has at first the same diameter as the ascending aorta, a little more than one inch (28 mm.), but after giving off three large branches, the diameter is reduced to a little less than one inch (23 mm.).

Relations.—*In front* it is related to the remains of the thymus, and is overlapped, almost equally, by the right and left pleuræ and lungs. *On its left* it is very closely related to the left pleura and lung. Under cover of the pleura its left side is crossed vertically by four nerves in the following order from before backwards: the left phrenic, the inferior cervical cardiac branch of the left vagus, the cardiac branch of the left superior cervical ganglion of the sympathetic, and the trunk of the left vagus. The left superior intercostal vein passes obliquely upwards and to the right, across it, superficial to the left vagus nerve and deep to the left phrenic nerve.

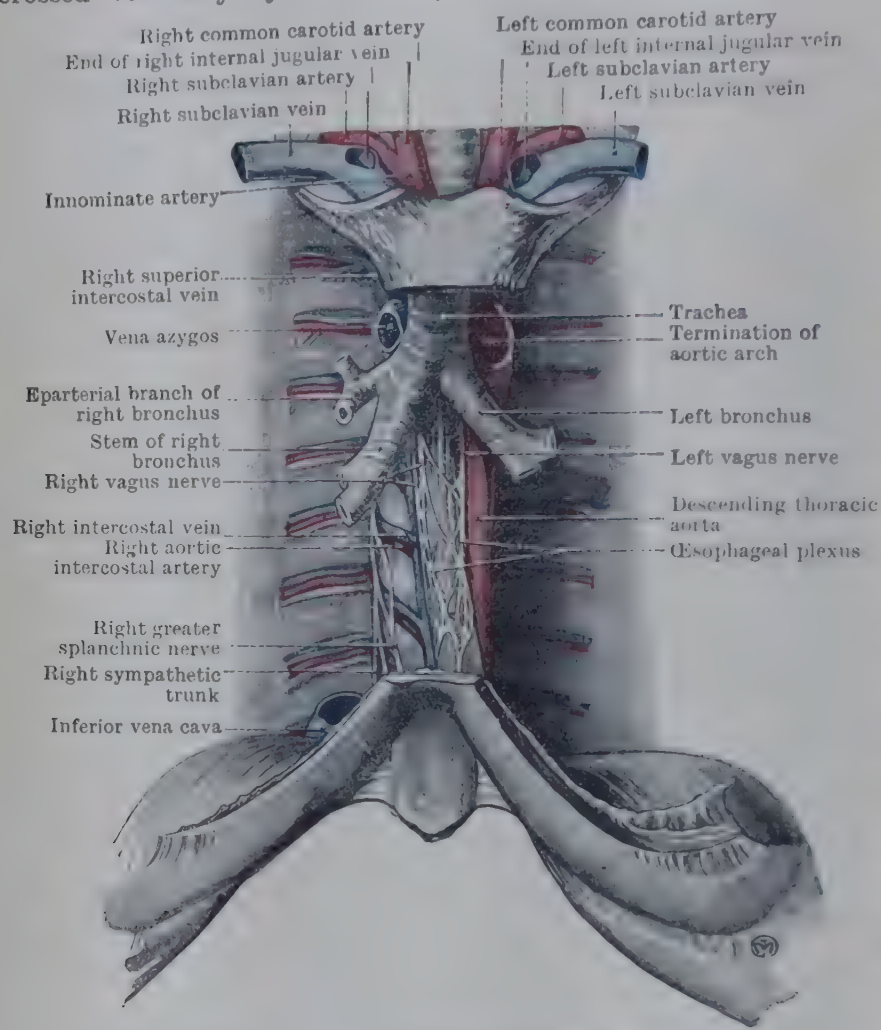

FIG. 1074.—DISSECTION OF POSTERIOR MEDIASTINUM AND POSTERIOR PART OF SUPERIOR MEDIASTINUM, FROM THE FRONT.

Behind, and *on the right* of the arch, are the deep cardiac plexus, the trachea, the left recurrent laryngeal nerve, the left border of the œsophagus and the thoracic duct. *Above* are its three large branches—the innominate, the left common carotid and the left subclavian arteries; and crossing anterior to them is the left innominate vein. *Below* are the bifurcation of the pulmonary trunk and the root of the left lung; the ligamentum arteriosum (p. 1386), which also is below, attaches it to the left pulmonary artery, whilst in front and to the right of the ligament lies the superficial cardiac plexus, and to its left and behind it the left recurrent laryngeal nerve.

Branches.—The three great vessels which supply the head and neck, part of the thoracic wall, and the upper limbs—the innominate, the left common carotid, and the left subclavian arteries—arise from the aortic arch (p. 1251).

Descending Aorta.—The **descending thoracic aorta** lies in the posterior mediastinum; it extends from the end of the arch, at the lower border of the left side of the fourth thoracic vertebra, to the aortic opening in the diaphragm where, opposite the twelfth thoracic vertebra, it becomes continuous with the abdominal aorta. Its length is from seven to eight inches (17·5 to 20 cm.), and its diameter diminishes slightly as it gives off branches.

Relations.—Its *posterior* relations are: the vertebral column and the anterior longitudinal ligament; the superior and inferior hemiazygos veins, which cross behind it; the posterior intercostal arteries, which spring from its posterior surface; and the left pleura and lung, which are behind its left margin—especially in its upper part.

In front it is in relation, from above downwards, with the root of the left lung, the pericardium, which separates it from the back of the left atrium, the œsophagus with the œsophageal plexus of nerves, and the diaphragm, which separates it from the caudate lobe of the liver. On the *left side* are the left lung and pleura. On

he *right side* the thoracic duct and the vena azygos are in relation to it along its whole length. The vertebral bodies and the œsophagus also lie to the right of the upper part of the descending thoracic aorta, whilst the right lung and pleura are in relation below.

Branches.—Nine pairs of posterior intercostal arteries, one pair of subcostal arteries, two left bronchial arteries, four or five œsophageal, some small pericardial, and

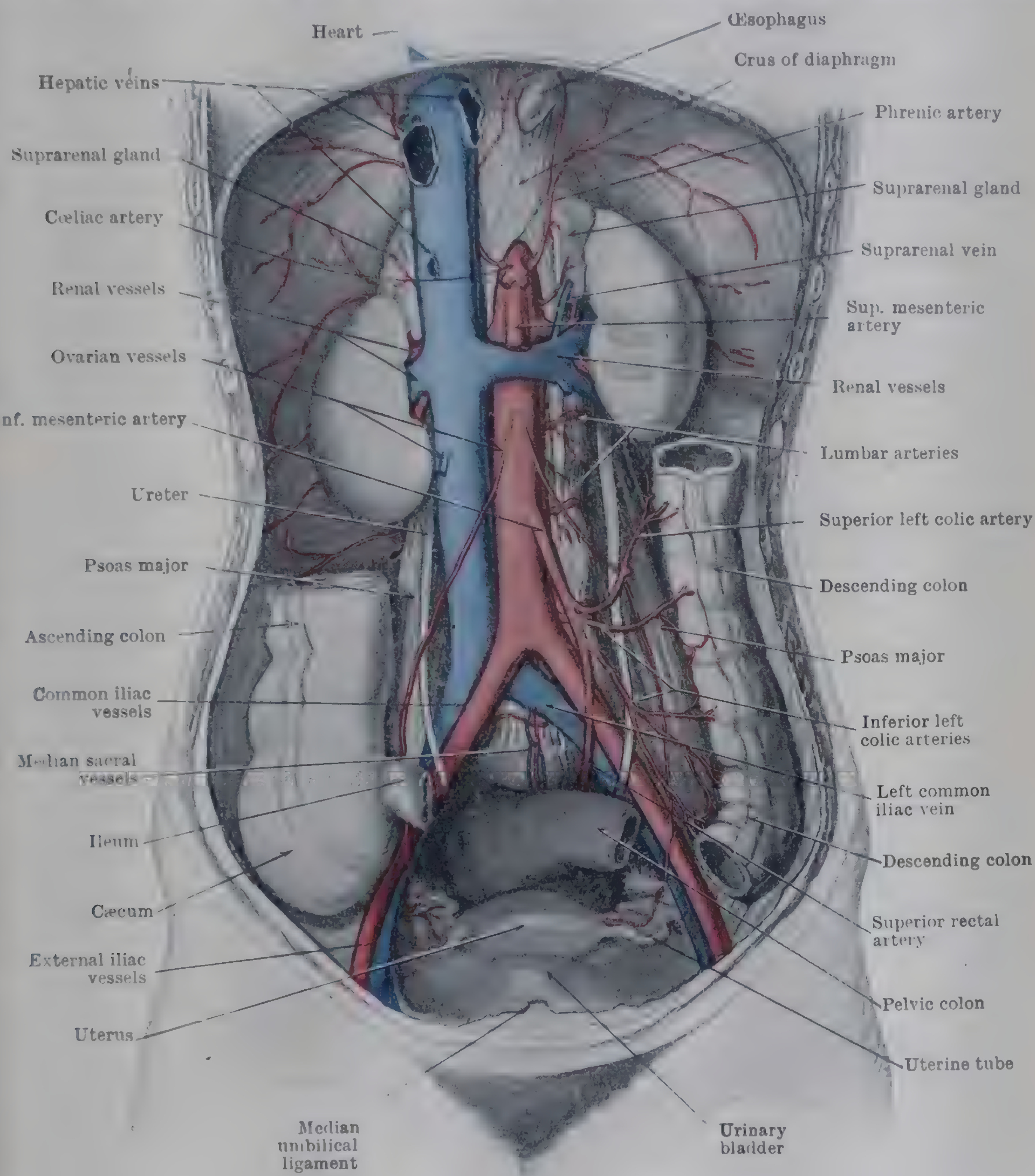

FIG. 1075.—ABDOMINAL AORTA AND ITS BRANCHES.

a few mediastinal and phrenic branches, usually arise from the descending thoracic aorta (p. 1293).

The **abdominal aorta** extends from the middle of the lower border of the last thoracic vertebra to the body of the fourth lumbar vertebra, where, to the left of the median plane, it bifurcates into the right and left common iliac arteries. The point of division is usually a little below and to the left of the umbilicus, opposite a line drawn transversely across the abdomen on a level with the highest points of the iliac crests.

At first it is about 21 mm. in diameter, but after the origin of two large branches—the cœliac and the superior mesenteric arteries—it diminishes considerably, and then retains a fairly uniform diameter to its termination.

Relations.—*Behind*, it is related to the upper four lumbar vertebræ and the intervertebral discs between them, the anterior longitudinal ligament, and the third and fourth left lumbar veins; four pairs of lumbar arteries and a single median sacral artery also spring from the posterior surface of the vessel. *In front* is the aortic plexus of nerves, and also in close relation with it from above downwards are the cœliac artery and cœliac plexus, the pancreas and splenic vein, the superior mesenteric artery, the left renal vein, the third part of the duodenum, the inferior mesenteric artery, the root of the mesentery, and the peritoneum and coils of small intestine. More superficially the stomach, the transverse colon, and the greater and lesser omenta are in front. On the *right side*, in the upper part of its extent, are the thoracic duct and cisterna chyli, the vena azygos, and the right crus of the diaphragm—the latter separating it from the right cœliac ganglion and from the upper part of the inferior vena cava. Its lower part is in direct relation, on the right side, with the inferior vena cava. On the *left side*, the left crus of the diaphragm with the left cœliac ganglion, and the terminal portion of the duodenum, are in close relation with its upper part, whilst in the lower portion of its extent the peritoneum and some coils of the small intestine are in contact with it. Aortic lymph-glands lie in front and on both sides of it.

Branches.—The branches form two groups—visceral and parietal—and each group consists of paired and unpaired vessels, as follows: *Visceral*—Cœliac, superior mesenteric, inferior mesenteric; pairs of suprarenal, renal, and testicular or ovarian; *Parietal*—Median sacral (which is the original continuation of the aorta); one pair of phrenic, four pairs of lumbar, and a terminal pair of common iliac arteries (p. 1295).

Abnormalities of Pulmonary Trunk and Aorta.—The **pulmonary trunk** and the **aorta** may arise by a common stem as in fishes and some amphibians, and the common stem may spring from either the right or the left ventricle, or from both. In those cases the truncus arteriosus has remained undivided, and the normal position of the ventricular septum in relation to the lower orifice of the bulbus cordis (p. 1369) has been altered. Again, owing to malposition of the aortic septum, the pulmonary trunk may spring from the left ventricle and the aorta from the right ventricle.

Occasionally the arch of the aorta is on the right side instead of the left, a condition which is normal in birds. More rarely there are two permanent aortic arches, right and left, as in reptiles; the œsophagus and trachea are then enclosed in a vascular collar, the two arches unite dorsally, and the descending aorta has a double origin. Quite independent of that condition, however, the two primitive dorsal aortæ sometimes fail, either altogether or partially, to unite together, and the descending aorta is accordingly represented, to a corresponding extent, by two tubes. A more common, though still rare, form of double aorta is that due to the persistence, in whole or in part, of the septum formed by the fused walls of the primitive dorsal aortæ from which the descending aorta is developed.

The length of the descending aorta is determined largely by the extent to which fusion of the two primitive aortæ takes place. Accordingly, when that deviates from the normal, the end of the descending aorta is at a correspondingly higher or lower level than usual, and the lengths of the common iliac arteries are almost invariably proportionately modified. The bifurcation of the aorta may be as low as the fifth lumbar vertebra; less frequently it is higher than usual; it is rare, however, to find it as high as the third lumbar vertebra, and still more rare to find it at the level of the second.

The aorta, instead of bifurcating into two common iliac arteries, may end in a common iliac artery on one side and an internal iliac artery on the opposite side, the external iliac artery on the irregular side arising, at a higher level, as a branch of the aortic stem. That arrangement approaches the condition met with in carnivores and many other mammals, in which the aorta bifurcates into two internal iliac arteries, the external iliacs arising from the aorta at a higher level as collateral branches; it is probably due either to a fusion of the secondary roots of the umbilical arteries of opposite sides or to a caudal continuation of the fusion of the primitive dorsal aortæ (see pp. 1373, 1391, and 1393, where references to special works are given).

BRANCHES OF ASCENDING AORTA

Coronary Arteries

The coronary arteries are two in number, a right and a left; they are distributed almost entirely to the heart, but give also some small branches to the roots of the great vessels, and to the pericardium (Figs. 1057, 1058, 1061). The branches of the coronary arteries anastomose freely in the substance of the heart, but form no important anastomoses with any other arteries. Communications do exist, however, between the coronary system and arteries of neighbouring parts by means of the small branches which pass out of the pericardium on the vessels that

iter and leave the heart (p. 1293). For detailed information consult Gross (1921) nd Spalteholz (1924); and, from the physiological point of view, Gregg (1946).

The **right coronary artery** springs from the anterior aortic sinus. It runs orwards, between the root of the pulmonary trunk and the auricle of the right trium, to the atrio-ventricular groove, in which it passes downwards and to the ight to the junction of the right and lower borders of the heart. There it turns ackwards into the inferior part of the groove, together with the small cardiac ein, and runs as far as the posterior end of the inferior interventricular groove, where it gives off its interventricular branch and then ends by anastomosing with the left coronary artery. It is accompanied by branches from the cardiac plexus and lymph-vessels, and in the second part of its course by the small cardiac vein.

Branches.—The **interventricular** branch runs forwards in the inferior interventricular roove; it supplies both ventricles and the ventricular septum, and anastomoses, at the apex of he heart, with the interventricular branch of the left coronary artery.

Twigs are distributed to the roots of the aorta and pulmonary trunk. Branches pass pwards on the anterior surface of the right atrium, and downwards on the anterior surface f the right ventricle; a larger **marginal** branch runs along the lower border of the heart and ives branches to both surfaces of the right ventricle.

The **left coronary artery** arises from the left posterior aortic sinus. Its trunk, horter and often slightly wider than that of the right artery, runs to the left and then forwards, between the root of the pulmonary trunk and the auricle of the left atrium, to the upper end of the anterior interventricular groove, where it gives off an interventricular branch. It then runs round the left surface of the heart, in the left part of the atrio-ventricular groove, where it comes into relation with the coronary sinus and ends by anastomosing with the right coronary artery.

Branches.—The **interventricular branch** passes down the anterior interventricular groove to the lower border of the heart, where it anastomoses with the interventricular branch from the right coronary; it supplies both ventricles and the ventricular septum, and is accompanied by cardiac nerves and lymph-vessels and by the great cardiac vein.

Branches of small size pass to the wall of the left atrium, the left surface of the heart, and the posterior part of the inferior surface of the left ventricle; and small twigs are also given to the roots of the aorta and pulmonary trunk.

Variations.—The two **coronary arteries** may arise by a single stem. When arising separately both may spring from the same aortic sinus; or, again, an interventricular branch may arise as a distinct vessel from the same aortic sinus as the coronary to which it belongs. The variability is not very remarkable, seeing that the arteries in question are equivalent to enlarged "vasa vasorum" raised to a position of special importance by the development of the heart.

BRANCHES OF ARCH OF AORTA

The branches which arise from the arch of the aorta supply the head and neck, the upper limbs, and part of the body-wall.

They are three in number—the **innominate**, the **left common carotid**, and the **left subclavian arteries**. The innominate is a short but wide trunk, from the termination of which the right common carotid and the right subclavian arteries spring (Figs. 1069 and 1071); thus there is, at first, a difference between the stem-vessels of opposite sides, but their branches are distributed to similar areas.

Variations.—The **branches of the arch** may be increased or decreased in number.

The highest number recorded is six—right subclavian, right vertebral, right common carotid, left common carotid, left vertebral, and left subclavian. Apparently that condition is the result of the absorption into the arch of the innominate artery and of the roots of the subclavian arteries, to points beyond the origins of the vertebrals. By variations of that process of absorption other combinations may be produced; thus, instead of the roots of the subclavian arteries being absorbed, the right common carotid and innominate arteries may alone be absorbed, in which case the five following branches spring separately from the arch of the aorta: right subclavian, right external carotid, right internal carotid, left common carotid, and left subclavian. The trunk most commonly absorbed is the initial part of the left subclavian; the number of branches then arising from the arch of the aorta is four, the additional vessel being the left vertebral, which arises between the left common carotid and the left subclavian. Occasionally the usual three branches from the arch are increased to four by the formation of a

new vessel, the "thyroidea ima". That may be placed between the innominate and left caroti trunks, in which case it represents a persistent ventral visceral branch from the ventral root of th fourth left aortic arch; in other cases the thyroidea ima springs from the innominate artery an represents a ventral visceral branch of the ventral root of the fourth *right* arch. Very rarel the right vertebral artery arises separately, and forms a fourth branch of the arch of the aorta the rest of the branches being normal. That condition cannot be accounted for by any modifica tion of the ordinary developmental processes. It may possibly be due to the persistence of a irregular or unimportant anastomosis between the ventral root of an aortic arch and the sevent somatic intersegmental artery.

Decrease in the number of branches from the arch of the aorta is most frequently due t fusion of the ventral roots of the fourth aortic arches, the result being that a stem is forme common to the right subclavian and the right and left common carotid arteries; whilst the lef subclavian, arising separately, is the only other branch which springs from the arch of the aort

If the fusion of the ventral roots proceeds farther and includes those of the third arches, th result, as regards the branches given off from the arch of the aorta, is the same, *i.e.*, there is common stem for the right subclavian and both carotids, and a separate left subclavian trunk; bu the common stem then gives off the right subclavian artery, and afterwards continues for som distance before it divides into the two common carotids, of which the left crosses in front of th trachea. That arrangement is common in many quadrumana and in some other mammals.

When the number of branches from the arch of the aorta is reduced to two, it is onl rarely that they are a right subclavian artery and a single stem common to the tw carotids and the left subclavian artery. In such cases, however, the right common caroti crosses in front of the trachea, and the variation is one of practical importance, but it doe not appear to exist as a normal condition in any mammal. Probably it is due to fusion of th ventral roots of the fourth aortic arches, with absorption of the left fourth arch and the left sub clavian into the stem so formed, whilst the right subclavian is relatively displaced. The tw common carotids may arise by a common stem, and the left subclavian arise separately fro the arch of the aorta, whilst the right subclavian springs from the descending aorta, an passes upwards and to the right behind the œsophagus. That arrangement probably results fro the disappearance of the fourth right arch, the fusion of the ventral roots of the fourth arches o opposite sides and the persistence of the dorsal roots of the right fourth and sixth arches. (Se Development of Vascular System, p. 1373.)

Sometimes two innominate arteries, right and left, replace the usual three branches of th arch of the aorta. That is the normal arrangement in bats, moles, and hedgehogs. It obviously the result of the disappearance of that portion of the arch which intervenes betwee the left carotid and left subclavian arteries, and the consequent fusion of these two vessels.

In a similar way may be explained the rarer condition in which the three ordinar branches of the arch arise by one single stem which divides into right and left innominat arteries. In most ruminants (Pl. LXXXVII, p. 1386), in the horse and in the tapir, that arrang ment is constant.

Other combinations and modifications may be met with in the branches of the arch of th aorta as the result of fusions and absorption. Other arteries also—internal mammary, inferi thyroid, bronchial—may occasionally arise from it. On this subject consult in particular th splendid, classical work of R. Quain (1844).

INNOMINATE ARTERY

The **innominate artery** (Fig. 1071) arises behind the middle of the manu brium sterni as the first branch from the convexity of the arch of the aorta, and i ends behind the upper part of the right sterno-clavicular joint, where it divid into the right subclavian and right common carotid arteries.

Course.—The trunk (from 35 to 50 mm. in length) runs upwards, backward and to the right, out of the superior mediastinum into the root of the neck.

Relations.—*Posterior.*—It is in contact behind, with the trachea below and wit the right pleura above. *Anterior.*—The left innominate vein crosses in front of th lower part of the artery, and the remains of the thymus are in front of that vein; abov that level, the sterno-thyroid muscle separates it from the sterno-hyoid and the righ sterno-clavicular joint. *Right Side.*—The right innominate vein and the upper part of th superior vena cava are on the right side of the artery. *Left Side.*—On its left side is th origin of the left common carotid artery, whilst at a higher level the trachea is in conta with it.

Branches.—As a rule the innominate artery does not give off any branches excep its two terminals, but occasionally it furnishes an additional branch—the thyroidea ima.

Variations.—The innominate artery may be absent. On the other hand there may two innominate arteries, a right and a left, each ending in corresponding common carotid an subclavian trunks, and the two vessels may themselves arise by a common stem. The branch of the innominate artery may be increased in number; or the innominate may vary from th

ormal only in length. As a consequence of such modifications in length, the origins of the ight common carotid and right subclavian arteries may be at a higher or lower level than sual, whilst, in the absence of the innominate artery, both these arteries may arise directly from he aorta.

The **thyroidea ima** is an inconstant and slender vessel. When present it nay arise from the arch of the aorta between the innominate and left common arotid arteries, but it springs usually from the lower part of the innominate. It passes upwards, on the front of the trachea, and is distributed to the thyroid gland and the trachea.

ARTERIES OF HEAD AND NECK

The vessels distributed to the Head and Neck are derived chiefly from the carotid trunks; there are, however, in addition, other vessels which arise from the main arterial stems of the Upper Limbs, and it will be advantageous to describe the most important of those, namely, the vertebral arteries, with the carotid system. The smaller additional branches will be considered along with the remaining branches of the subclavian arteries.

The **carotid system of arteries** consists, on each side, of a **common carotid** trunk, which divides into **internal** and **external carotid arteries**, from which numerous branches are given off (Figs. 1069, 1076, 1078, 1079).

The internal carotid arteries are distributed, almost entirely, to the contents of the cranial cavity that lie internal to the dura mater, and to the structures in the cavity of the orbit. The external carotid arteries, on the other hand, supply structures of the head and neck more externally situated.

It is to be noted, however, that the vascular supply of the brain is not wholly derived from the internal carotid vessels, but that the vertebral arteries also make an important contribution to it.

COMMON CAROTID ARTERIES

The two **common carotid arteries** are of unequal length. The *right common carotid artery* begins at the bifurcation of the innominate artery behind the right sterno-clavicular joint; the *left common carotid* arises, in the superior mediastinum, from the arch of the aorta; but each terminates at the level of the upper border of the thyroid cartilage. The left artery has thus a short intrathoracic course, and, so far, its relations call for separate consideration; whilst in the rest of its course it passes upwards in the neck, like the right common carotid, and has almost similar relations.

Left Common Carotid Artery.—The **left common carotid artery** springs from the upper aspect of the aortic arch immediately behind and to the left of the origin of the innominate artery, and its *thoracic portion* extends to the left sterno-clavicular joint, where the cervical portion begins. It is from 1 to $1\frac{1}{2}$ inches (25–37 mm.) in length, and it runs upwards and slightly laterally through the upper part of the superior mediastinum.

Relations.—*Posterior.*—The vessel is in contact behind, and from below upwards, with the trachea, the left recurrent laryngeal nerve, the œsophagus, and the thoracic duct; and the thoracic part of the left subclavian artery is a postero-lateral relation. *Anterior.*—The left innominate vein runs obliquely across the artery, and cardiac branches from the left vagus and sympathetic descend vertically in front of it. Those structures, together with the remains of the thymus and the anterior margins of the left lung and pleura, separate the artery from the manubrium sterni and from the origins of the sterno-hyoid and sterno-thyroid muscles. *Medial.*—The innominate artery below, and the trachea above, are on the right side. *Lateral.*—The left pleura, and, on a posterior plane, the left phrenic and vagus nerves and the left subclavian artery are on its left side.

The *cervical portion* of the **left common carotid artery** is about $3\frac{1}{2}$ inches (85 mm.) long; it extends from the left sterno-clavicular joint to the level of the upper border of the thyroid cartilage and the lower border of the third

cervical vertebra, where it ends by dividing into external and internal carotid arteries.

Course.—It runs upwards, laterally, and backwards, through the anterior triangle of the neck. Below it is separated from its fellow of the opposite side by the trachea and the œsophagus, and above by the relatively wide larynx and pharynx.

Relations.—It is enclosed, together with the internal jugular vein and the vagus nerve, in a sheath of cervical fascia—the **carotid sheath.**

Posterior.—The longus cervicis, below, and the longus capitis, above, are separated from the artery by the prevertebral fascia with the sympathetic trunk intervening. The

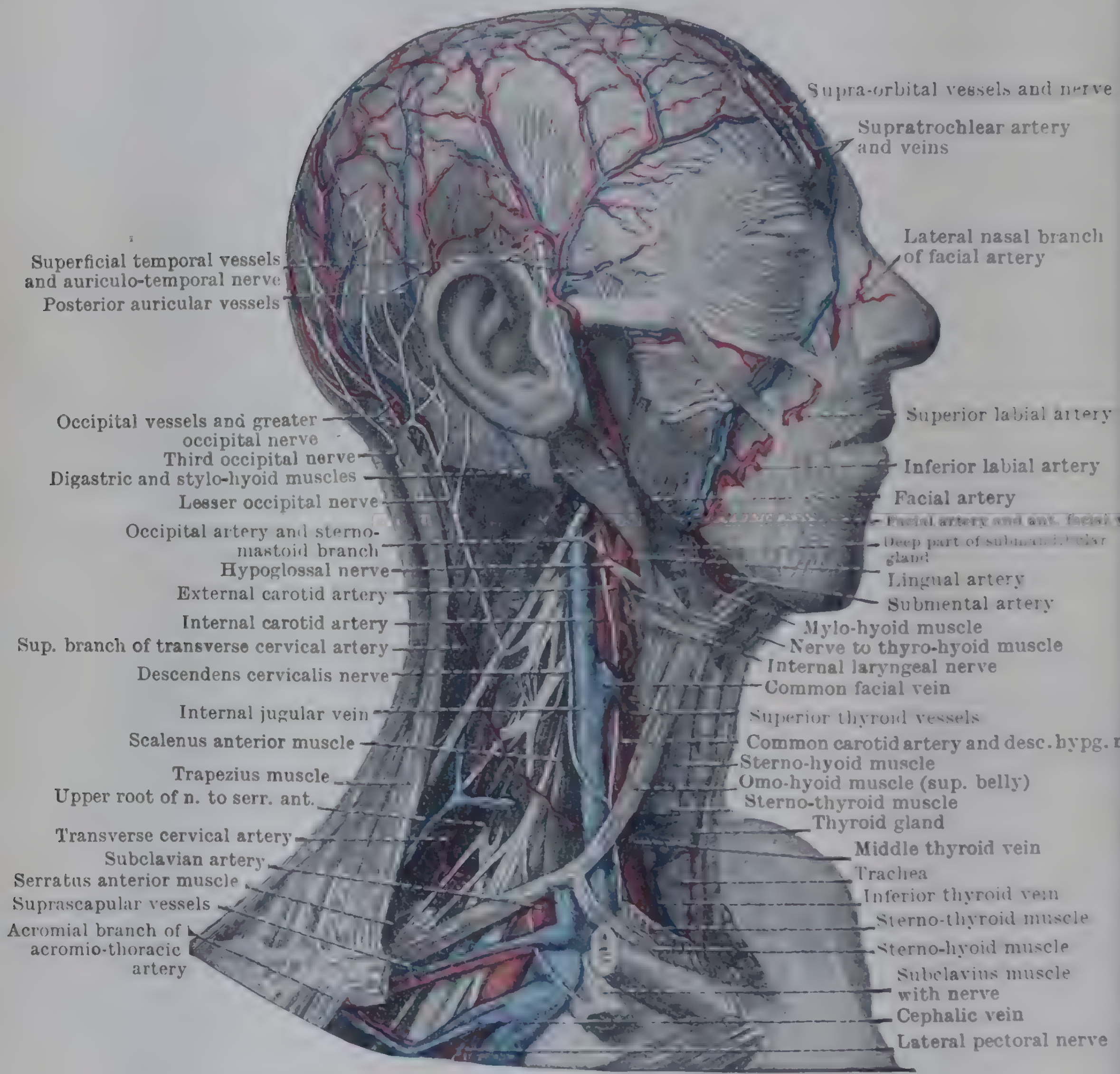

Fig. 1076.—Dissection of Head and Neck showing the Carotid Arteries.

vertebral artery and the thoracic duct are posterior to it at the level of the seventh cervical vertebra; the inferior thyroid artery crosses behind it, between it and either the vertebral artery or the transverse process of the sixth cervical vertebra; and the vagus nerve lies postero-lateral to it.

Superficial.—The descending branch of the hypoglossal nerve lies superficial to the artery, usually outside the sheath, but sometimes enclosed in it (Fig. 1076). Opposite the sixth cervical vertebra the omo-hyoid muscle and the sterno-mastoid branch of the superior thyroid artery cross superficial to the common carotid artery, which is overlapped, above the omo-hyoid muscle, by the anterior border of the sterno-mastoid and by deep cervical lymph-glands. It is frequently crossed, in that part of its extent, by the superior thyroid vein. Below the omo-hyoid the artery is covered by the sterno-thyroid, the sterno-hyoid, and the sterno-mastoid muscles, and it may be overlapped by the lobe of the thyroid gland; it is also crossed, deep to the muscles, by the middle thyroid

ein, whilst occasionally a communication between the common facial and anterior ugular veins descends in front of the artery along the anterior border of the sterno-nastoid. Just above the sternum the anterior jugular vein is in front of the artery, but eparated from it by the sterno-hyoid muscles.

Medial.—The trachea and œsophagus, with the recurrent laryngeal nerve in the angle between them, are medial to the lower part of the artery; the larynx and pharynx are medial to its upper part. The carotid body lies on the medial side of the termination of the artery.

Lateral.—The internal jugular vein occupies the lateral part of the carotid sheath. The vein lies not only to the lateral side of the artery, but also slightly in front of it, especially in the lower part of the neck.

Branches.—As a rule no branches are given off from either of the common carotid arteries, except the terminal branches and some minute twigs to the carotid sheath and carotid body. But occasionally one or more of the branches usually given off by the external carotid may arise from the common carotid; the most frequent is the superior thyroid artery.

Right Common Carotid Artery.—The **right common carotid artery**, as already stated, differs as regards origin from the left common carotid. In length and general position it corresponds with the cervical portion of the left common carotid, and its relations also are very similar. Such differences as exist may be briefly summarized as follows:—The internal jugular vein lies lateral to the artery on each side; on the left side in the lower part of the neck it is also anterior to the artery whilst on the right side the vein is separated from the lateral surface of the artery at its lower end, by a well-marked interval in which the vagus nerve appears The thoracic duct does not come into relation with the right common carotid. There is also a difference in the relations of the recurrent laryngeal nerves to the arteries on the two sides. The left nerve is posterior to the mediastinal part of the left artery, and lies medial to its cervical part, whilst the right nerve passes posterior to the lower part of the corresponding artery in the neck to reach its medial side. The œsophagus has a less intimate relation with the right common carotid artery than with the left.

Carotid Sinus.—The terminal portion of the common carotid artery and the root of its internal carotid branch are dilated to form the *carotid sinus.* This sinus is part of the mechanism that regulates blood-pressure; its walls are more elastic than adjacent parts of the arteries, and it is specially innervated by the glosso-pharyngeal nerve, which supplies the carotid body also (see Fig. 689, p. 808).

Variations.—The right common carotid artery may arise separately from the arch of the aorta; then it may be the first, or, much more rarely, the second branch. In the former case the fourth right aortic arch has been obliterated, and the right subclavian artery springs from the descending aorta; in the latter case either the innominate stem has been absorbed into the arch of the aorta, or the ventral root of the fourth right aortic arch has fused with part of an elongated fourth left arch.

Whether the artery arises as the first or second branch, the origin may be to the left of the median plane, and the trunk may pass in front of the trachea, or behind the œsophagus, before it ascends into the neck.

The left common carotid artery varies, as regards its origin, much more frequently than the right vessel; not uncommonly, and apparently because of the fusion of the ventral roots of the fourth aortic arches, it arises from a stem common to it and to the right common carotid and right subclavian arteries.

Both common carotids may vary as regards their termination. They may divide at a higher or lower level than usual, the former more commonly than the latter; whilst in a few exceptional cases the common carotid does not divide, but is continued directly into the internal carotid; then the branches usually given off by the external carotid spring from it. That arrangement is probably due to obliteration of the ventral roots of the first and second aortic arches, the arches persisting and being divided into the branches which generally arise from their ventral extremities.

EXTERNAL CAROTID ARTERY

The **external carotid artery** (Figs. 1076, 1078) is the smaller of the two terminal branches of the common carotid; its length is about 2½ inches (62 mm.). It extends from the upper border of the thyroid cartilage to the back of the neck of the mandible, where it ends by dividing into the superficial temporal and maxillary arteries.

Course.—It begins in the carotid triangle, passes upwards, medial to the posterior belly of the digastric and the stylo-hyoid muscles and the lower part of the parotid gland; then it grooves the medial border of the gland, and passes through its substance to the upper part of its antero-medial surface behind the neck of the mandible, where it ends.

At first it lies anterior and medial to the internal carotid artery, but it inclines backwards as it ascends, and thus becomes superficial to the internal carotid. Its course is indicated by a line drawn from the tip of the greater horn of the hyoid bone to the lobule of the ear.

Relations.—*Deep.*—At first the inferior constrictor muscle is in relation with its medial side, but at a higher level the structures which intervene between it and the internal carotid—the stylo-pharyngeus muscle, the styloid process (or the stylo-glossus muscle), the glosso-pharyngeal nerve, the pharyngeal branch of the vagus and a portion of the parotid gland—separate it from the wall of the pharynx; whilst medial both to it and to the internal carotid artery are the external and internal laryngeal branches of the superior laryngeal nerve.

Superficial.—In the carotid triangle it is overlapped by the anterior border of the sterno-mastoid. Immediately below the level of its occipital branch it is crossed by the hypoglossal nerve; and it is crossed by the lingual and common facial veins also, and sometimes by the superior thyroid vein. At the level of the angle of the mandible it passes under cover of the posterior belly of the digastric and the stylo-hyoid muscles, which separate it from the parotid gland. As it emerges from under cover of the stylo-hyoid, it grooves the parotid gland, and, as it passes through the gland, the posterior facial vein descends superficial to the artery, and both the artery and the vein are crossed, usually superficially, by the branches of the facial nerve.

Branches.—Eight branches arise from the external carotid artery; of those, three—the superior thyroid, the lingual, and the facial—spring from the front of the artery in the carotid triangle; two arise from the back of the artery, namely, the occipital and the posterior auricular, the former below the posterior belly of the digastric and the latter above it; one from its medial side, namely, the ascending pharyngeal, which arises in the carotid triangle. Its terminal branches are the superficial temporal and maxillary arteries.

Variations.—The external carotid artery may be absent, or it may, in rare cases, arise directly from the arch of the aorta. The number of its branches may be diminished either by fusion of their roots or by transference to the internal or common carotid arteries. On the other hand, the number of its branches may be increased; thus, the sterno-mastoid artery, or the infrahyoid branch usually given off by the superior thyroid artery, or the ascending palatine branch of the facial artery, may arise directly from the external carotid.

Branches of External Carotid Artery

(1) The **superior thyroid artery** (Figs. 1071 and 1076) springs from the front of the lower part of the external carotid artery, just below the tip of the greater horn of the hyoid bone, and it ends at the apex of the corresponding lobe of the thyroid gland by dividing into glandular branches.

Course.—From its origin, in the carotid triangle, the artery runs downwards and forwards to its termination.

Relations.—*Medially* it is in relation with the inferior constrictor muscle and the external laryngeal branch of the superior laryngeal nerve.

Superficially it is covered, at its origin, by the anterior border of the sterno-mastoid; afterwards, for a short distance, by fascia, platysma, and skin, and in the lower part of its extent by the omo-hyoid, the sterno-hyoid, and the sterno-thyroid muscles, and it is overlapped by an accompanying vein.

Branches.—*In the carotid triangle.*—A small **infrahyoid artery** runs along the lower border of the hyoid bone, under cover of the thyro-hyoid muscle, to anastomose with its fellow of the opposite side and with the suprahyoid branch of the lingual artery. It supplies the thyro-hyoid muscle and membrane.

The **superior laryngeal artery** runs forwards, deep to the thyro-hyoid muscle. It pierces the thyro-hyoid membrane and enters the lateral wall of the piriform fossa, in company with the internal laryngeal nerve, supplies the muscles, ligaments, and mucous

membrane of the larynx, and anastomoses with its fellow of the opposite side, with the crico-thyroid branch, and with the inferior thyroid artery.

The **sterno-mastoid branch** passes downwards and backwards, along the upper border of the superior belly of the omo-hyoid muscle and across the common carotid artery, to the deep surface of the sterno-mastoid muscle. It anastomoses, in the sterno-mastoid, with branches of the occipital and suprascapular arteries.

In the muscular triangle.—A **crico-thyroid branch** passes forwards, either superficial or deep to the sterno-thyroid. It crosses the crico-thyroid muscle to anastomose, in front of the crico-thyroid ligament, with its fellow of the opposite side, and, by branches which perforate the ligament, with laryngeal branches of the superior and inferior thyroid arteries. It supplies the adjacent muscles and membrane.

The terminal **glandular branches** are anterior, medial, and lateral. The *anterior glandular branch* descends along the anterior border of the lobe of the thyroid gland, and runs along the upper border of the isthmus to anastomose with its fellow of the opposite side. The *medial glandular branch* is the largest; it is distributed to the medial surface of the lobe. The *lateral glandular branch*, which ramifies in the lateral surface of the lobe, is the smallest. All three branches anastomose with one another and with branches from the inferior thyroid artery.

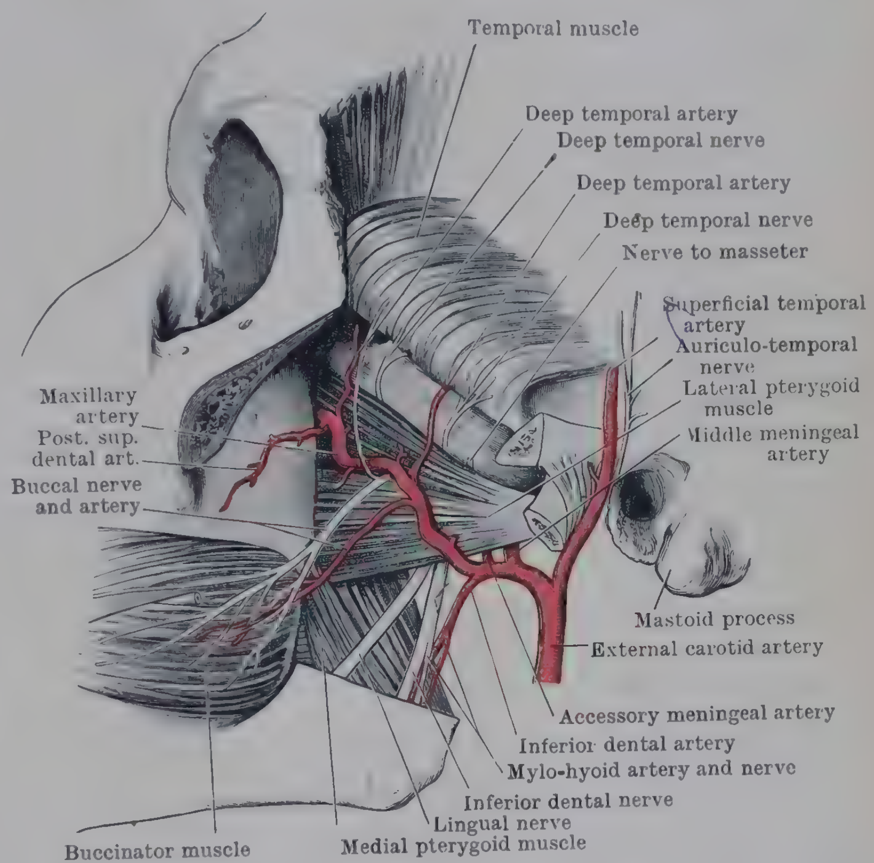

FIG. 1077.—DISSECTION SHOWING TERMINATION OF EXTERNAL CAROTID ARTERY AND FIRST AND SECOND PARTS OF MAXILLARY ARTERY.

(2) The **lingual artery** (Figs. 1076 and 1078) springs from the front of the external carotid, opposite the tip of the greater horn of the hyoid bone, and, becoming the *arteria profunda linguæ*, it ends beneath the tip of the tongue, where it anastomoses with its fellow of the opposite side.

Course.—Whilst in the carotid triangle, the *first part of the artery* forms a loop with the convexity upwards. The *second part* passes forwards, medial to the hyo-glossus muscle immediately above the greater horn of the hyoid bone, to the anterior border of the hyo-glossus, where it becomes the *third part*, which ascends along the anterior border of the hyo-glossus, and, having given off a sublingual branch, ends as the profunda artery of the tongue. The **profunda artery of the tongue** takes a tortuous course forwards on the under surface of the tongue to the tip.

Relations.—The *first part* of the lingual artery is crossed superficially by the hypoglossal nerve, and is covered by skin, fascia, and the platysma; it rests medially against the middle constrictor of the pharynx. The *second part* is deeper. It lies between the middle constrictor medially and the hyo-glossus laterally, and is separated by the latter from the hypoglossal nerve and its vena comitans, and the lower part of the submandibular gland. The *third part* ascends between the genio-glossus and the anterior border of the hyo-glossus, which is covered by the mylo-hyoid. The profunda artery runs forwards between the inferior longitudinal muscle and the genio-glossus, and is covered, on its lower surface, by the mucous membrane of the tongue. Thus, at its termination, near the frenulum of the tongue, the artery is comparatively superficial.

Branches.—The **suprahyoid artery** is a small branch which arises in the caroti triangle and runs along the upper border of the greater horn of the hyoid bon superficial to the hyo-glossus. It anastomoses with its fellow of the opposite side an with the infrahyoid artery.

The **dorsales linguæ branches**—usually two—arise from the second part of the arter and are of moderate size. They ascend, between the hyo-glossus and the genio-glossus to the dorsum of the tongue, where they branch and anastomose with their fellows c the opposite side around the foramen cæcum. They supply the posterior part of th tongue as far back as the epiglottis, and send branches backwards to the tonsil whic anastomose with the tonsillar artery and tonsillar twigs of the ascending palatine branc of the facial and with the ascending pharyngeal artery.

A **sublingual branch** arises at the anterior border of the hyo-glossus muscle an runs forwards and upwards, between the mylo-hyoid and the genio-glossus, to the sub lingual gland, which it supplies: it supplies also the mylo-hyoid, the genio-glossus, an the genio-hyoid muscles. It anastomoses with its fellow of the opposite side, with th profunda artery by a branch which it sends along the frenulum of the tongue, and, throug the mylo-hyoid muscle, with the submental branch of the facial artery.

(3) The **facial artery** (Fig. 1076) arises from the front of the external caroti immediately above the lingual. It ends at the medial angle of the eye, where i anastomoses with the dorsal nasal and palpebral branches of the ophthalmic artery.

Course.—The course of the facial artery is very tortuous. It begins in th carotid triangle and passes *upwards* to the angle of the mandible, on the later surface of the middle constrictor muscle. Still ascending, it lies between th posterior belly of the digastric and the stylo-hyoid muscles laterally and th superior constrictor medially. When it reaches the upper border of the stylo hyoid it enters a groove in the posterior part of the submandibular gland an runs *downwards* and *forwards*, between the lateral surface of the gland and th medial pterygoid muscle, to the lower border of the mandible. There it pierce the deep cervical fascia, turns round the inferior border of the mandible a the anterior border of the masseter, enters the face, and continues *upwards* an *forwards* in a tortuous manner to its termination.

Relations.—In the carotid triangle the artery is comparatively superficial, excep just at its origin, which is overlapped by the anterior fibres of the sterno-mastoid muscl As it ascends it is in relation, on the medial side, with the middle and superior constricto muscles, and the superior constrictor separates it from the tonsil. Its relations betwee the point where it passes medial to the posterior belly of the digastric and the poin where it turns round the lower border of the mandible have been given in the descriptio of its course.

After turning round the lower border of the body of the mandible, which it groove slightly, the artery becomes more superficial than in any other part of its course, bein covered only by platysma, fascia, and skin. At that point the anterior facial vein i immediately posterior to the artery, lying on the surface of the masseter. As it passe upwards in the face the artery is deep to the platysma, the risorius, the zygomaticu major, the levator labii superioris, and the fascia and skin, and superficial to the mandibl the buccinator and the levator anguli oris: it then enters the substance of the levator lab superioris alæque nasi.

The anterior facial vein is posterior to the artery in the face, is situated at som little distance from it, and runs a straighter course.

Branches.—Four named branches are given off in the neck and several in the face.

In the Neck.—The **ascending palatine artery** (Fig. 1083) is a small branch whic arises under cover of the posterior belly of the digastric. It ascends between the stylo glossus and the stylo-pharyngeus muscles towards the base of the skull, and turns dow wards over the upper border of the superior constrictor of the pharynx, accompanyin the levator palati muscle, and enters the soft palate (Fig. 1079).

It supplies the lateral wall of the upper part of the pharynx, the soft palate, th tonsil, and the pharyngo-tympanic tube. It anastomoses with the tonsillar branc of the facial, the dorsales linguæ, the greater palatine branch of the maxillary, and wit the ascending pharyngeal artery, which sometimes replaces it.

The **tonsillar artery** is a small branch which arises close to the ascending palatine It passes upwards between the medial pterygoid and the stylo-glossus, pierces the superio

ıstrictor, and ends in the tonsil. It supplies the middle and superior constrictor ıscles, and it anastomoses with the dorsales linguæ, with the ascending palatine and e ascending pharyngeal arteries.

The **glandular branches** are two or three small twigs which pass directly into the ıbmandibular gland.

The **submental artery** arises from the facial near the lower border of the mandible. is the largest branch given off in the neck; it runs forwards, on the lateral surface the mylo-hyoid muscle, and medial to the upper part of the submandibular gland, to ıe symphysis menti; there it turns upwards, round the margin of the mandible, and it ıds by anastomosing with branches of the mental and inferior labial arteries. In the eck the submental artery supplies the mylo-hyoid muscle, and the submandibular and ıblingual glands, the latter by a branch which perforates the mylo-hyoid muscle. It ıastomoses with the mylo-hyoid branch of the inferior dental and with the sublingual ranch of the lingual artery.

In the Face.—The **inferior labial arteries** arise from the front of the facial below ıe level of the angle of the mouth. There are usually two, the lower arising below ıe level of the alveolar border of the mandible. They run medially, under cover of the ıuscles of the lower lip, supply the skin, muscles, mucous membrane, and glands of the ıp, and anastomose with each other, with the mental artery, and with their fellows of ıe opposite side. The upper of the two arteries pierces the orbicularis oris and runs ıose to the mucous membrane near the margin of the lip.

The **superior labial artery** springs from the front of the facial about the level of ıe angle of the mouth. It runs medially, between the orbicularis oris and the mucous ıembrane of the upper lip, to the median plane, supplying the skin, muscles, mucous ıembrane and glands of the upper lip, and, by a *septal branch*, the lower and anterior part f the nasal septum. It anastomoses with its fellow of the opposite side, with the *lateral asal* branch of the facial, and with the septal branch of the spheno-palatine artery.

The *lateral nasal* is a constant branch that ramifies on the side of the nose (Fig. 1052).

Numerous other small branches arise from the facial artery in the face; through these t anastomoses also with the transverse facial artery, and with the buccal and infra-rbital branches of the maxillary artery.

(4) The **occipital artery** (Figs. 1076, 1078) arises from the back of the external arotid artery, below the posterior belly of the digastric muscle, and ends, near he medial end of the superior nuchal line of the occipital bone, by dividing into medial and lateral terminal branches.

Course.—It begins in the carotid triangle and runs upwards and backwards, parallel with and under cover of the posterior belly of the digastric, to the interval between the transverse process of the atlas and the base of the skull; there it turns backwards, in a groove on the lower surface of the mastoid portion of the temporal bone; as it leaves the groove it alters its direction and runs upwards and medially, on the superior oblique muscle, to the junction of the medial and intermediate thirds of the superior nuchal line of the occipital bone, where it pierces the deep fascia of the neck and enters the superficial fascia of the scalp.

Relations.—In the first part of its course the occipital artery crosses successively the internal carotid artery, the hypoglossal nerve (which hooks round it), the vagus nerve, the internal jugular vein, and the accessory nerve; it is covered by the lower fibres of the posterior belly of the digastric and the anterior part of the sterno-mastoid muscle. In the second and more horizontal part of its course it is still under cover of the sterno-mastoid and digastric, and lies, medially, against the rectus capitis lateralis, which separates it from the vertebral artery. In the third part of its course it rests upon the superior oblique and semispinalis capitis, under cover of the sterno-mastoid and the splenius capitis muscles, and either superficial or deep to the longissimus capitis. Near its termination it is crossed by the greater occipital nerve, and it passes either through the trapezius or between the trapezius and the sterno-mastoid.

Branches.—**Muscular branches** go to the surrounding muscles. There are usually two **sterno-mastoid branches**; one springs from the occipital near its origin, is looped downwards across the hypoglossal nerve, and is continued downwards and backwards, below and anterior to the accessory nerve, into the sterno-mastoid muscle, where it anastomoses with the sterno-mastoid branch of the superior thyroid artery. The other arises higher up and accompanies the accessory nerve into the muscle.

The **descending branch** is given off from the occipital upon the surface of the superior

oblique and supplies the muscles of the back of the neck. It passes medially, and divides at the lateral border of the semispinalis capitis into superficial and deep branches. The superficial branch runs between the semispinalis and the splenius capitis, and anastomoses with the superficial branch of the transverse cervical artery. The deep branch descends between the semispinalis capitis and the semispinalis cervicis, and anastomoses with branches of the deep cervical artery.

The **meningeal** are irregular branches which enter the skull through the condylar canals and the jugular foramen; they supply the dura mater in the posterior fossa of the skull and anastomose with branches of the middle meningeal and ascending pharyngeal arteries.

The **mastoid** is a small and inconstant branch which arises behind the mastoid process. It enters the posterior fossa of the skull through the mastoid foramen, supplies the mastoid air-cells on its way to the dura mater, and anastomoses with branches of the middle meningeal artery.

The **auricular** is an inconstant branch which is given off from the occipital, as a rule only when the posterior auricular artery is absent. It ramifies over the mastoid process, and supplies the medial surface of the auricle.

The terminal **occipital branches** are medial and lateral. They ramify in the superficial fascia of the posterior part of the scalp, where they anastomose with the posterior auricular and superficial temporal arteries. Both branches are accompanied by branches of the greater occipital nerve. The medial branch gives off a *meningeal* twig which passes into the skull through the parietal foramen to supply the walls of the superior sagittal sinus and to anastomose with the middle meningeal artery.

(5) The **posterior auricular artery** (Figs. 1076, 1078, 1083) springs from the back of the external carotid immediately above the posterior belly of the digastric muscle, and it ends between the mastoid process and the back of the auricle by dividing into occipital and auricular branches.

Course and Relations.—From its origin it runs upwards and backwards superficial to the styloid process under cover of the parotid gland, to the interval between the mastoid process and the auricle. It is accompanied in the terminal part of its course by the posterior auricular branch of the facial nerve.

Branches.—In addition to twigs of supply to the parotid gland and *muscular* branches to the sterno-mastoid, the digastric, and the styloid group of muscles, there are three named branches.

The **stylo-mastoid artery** is given off at the lower border of the external auditory meatus, runs upwards by the side of the facial nerve, and enters the stylo-mastoid foramen. It accompanies the facial nerve in its canal to the upper part of the medial wall of the tympanum, where it ends by anastomosing with the superficial petrosal branch of the middle meningeal artery; other branches anastomose with tympanic branches from the internal carotid and the ascending pharyngeal arteries, and with the internal auditory branch of the basilar. It supplies the tympanic cavity and antrum, the vestibule, and semicircular canals, *mastoid* branches to the mastoid air-cells and a *stapedial* to the stapedius muscle; and it gives off a *posterior tympanic branch*, which anastomoses with the anterior tympanic branch of the maxillary artery, forming, in young subjects, a vascular circle around the tympanic membrane.

The **auricular branch** ascends medial to the posterior auricular muscle. It gives branches to the auricle and to the scalp in the posterior part of the temporal region, which anastomose with the superficial temporal and occipital arteries. The auricular branches supply both surfaces of the auricle, piercing or turning round the margins of the cartilage to gain the lateral surface; and they anastomose with the auricular branches of the superficial temporal artery.

The **occipital branch** runs upwards and backwards along the insertion of the sterno-mastoid muscle. It supplies the sterno-mastoid muscle, the occipital belly of the occipito-frontalis, and the skin; and it anastomoses with the occipital artery.

(6) The **ascending pharyngeal artery** (Fig. 1083) arises from the medial surface of the lower part of the external carotid, and its terminal branches are distributed to the wall of the pharynx and in the soft palate.

Course.—It begins in the carotid triangle, usually as the first or second branch of the external carotid, and it ascends on the wall of the pharynx to the apex of the petrous portion of the temporal bone.

Relations.—*Medially* it is in relation with the constrictor muscles of the pharynx. *Posterior* to it is the longus capitis. *Laterally* it is in relation with the internal carotid artery, and it is crossed by the stylo-pharyngeus muscle, the glosso-pharyngeal nerve, and the pharyngeal branch of the vagus.

Branches.—The branches of this artery are very irregular and inconstant; in addition to those named, small branches are distributed to the prevertebral muscles and fascia, the deep cervical lymph-glands, and the large nerve-trunks. They anastomose with branches of the ascending cervical and vertebral arteries.

Small **pharyngeal branches** ramify on the walls of the pharynx and supply the middle and superior constrictor muscles, the tonsil, and the lower part of the pharyngo-tympanic

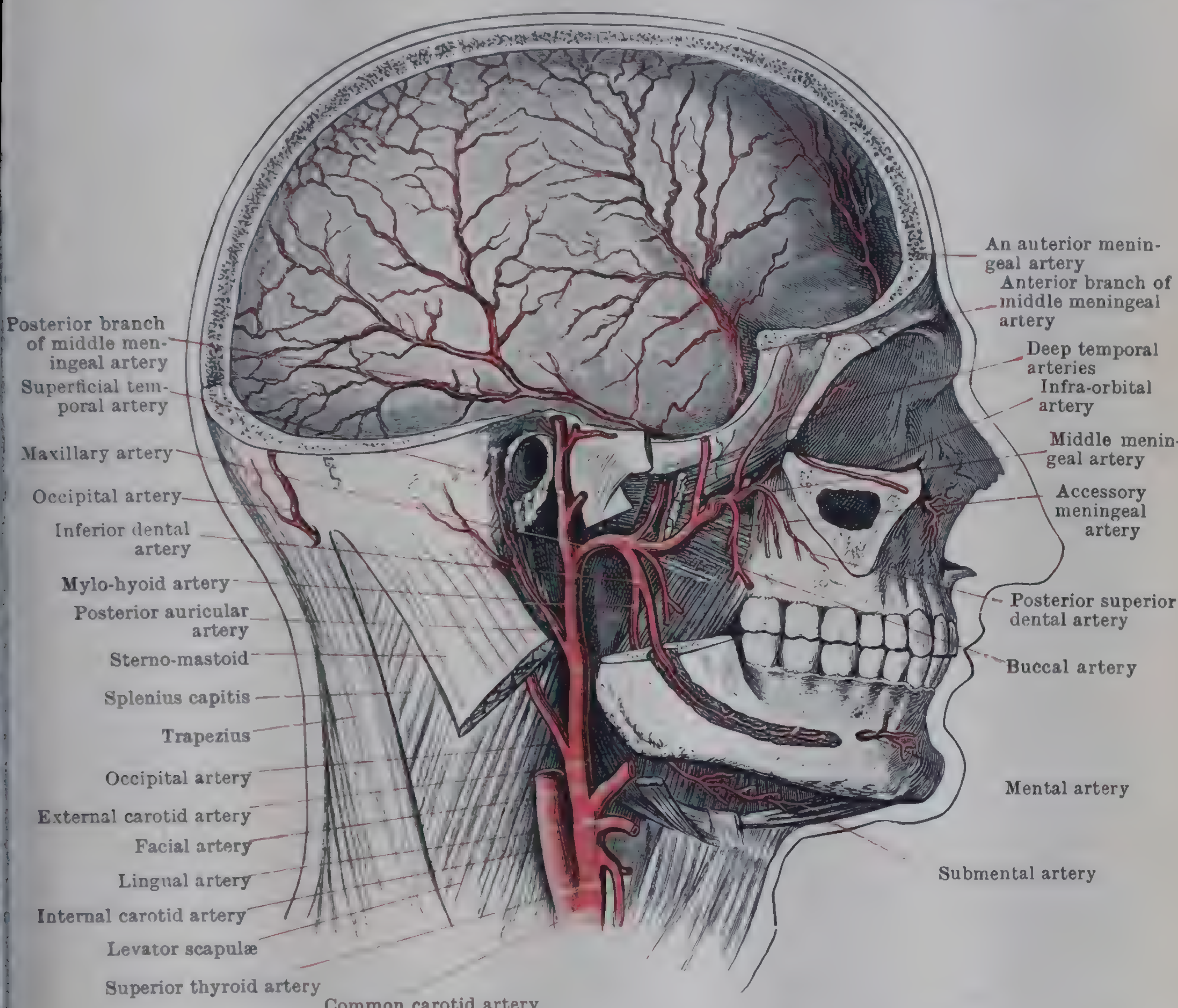

FIG. 1078.—EXTERNAL CAROTID, MAXILLARY, AND MENINGEAL ARTERIES.

tube. They anastomose with branches of the superior thyroid, lingual, and facial arteries. A small inconstant branch sometimes replaces the ascending palatine branch of the facial artery. When present, it springs from the upper part of the ascending pharyngeal artery, pierces the pharyngo-basilar fascia above the superior constrictor muscle, and descends into the soft palate with the levator palati muscle.

One or more small **meningeal** branches enter the cranium by the anterior condylar canal, the jugular foramen, or the foramen lacerum, and supply the dura mater. They anastomose with branches of the middle meningeal and vertebral arteries.

The **inferior tympanic** is a small artery which accompanies the tympanic branch of the glosso-pharyngeal nerve to the tympanic cavity, where it anastomoses with the other tympanic arteries.

(7) The **superficial temporal artery** (Fig. 1076), one of the terminal branches of the external carotid, begins between the upper part of the parotid gland and the back of the neck of the mandible, and ends in the scalp, from 1 to 2 inches (25 to 50 mm.) above the zygomatic arch, by dividing into anterior and posterior branches.

Course.—The artery pierces the deep fascia, ascends over the posterior root of the zygoma, and enters the superficial fascia of the temporal region. It is accompanied by the auriculo-temporal nerve, which is behind it, and by the superficial temporal vein, which is usually superficial to it. As it crosses the zygoma it is covered by the skin alone, and it may easily be compressed against the subjacent bone.

Branches.—Small **parotid** branches supply the upper part of the gland, and some twigs go to the *mandibular joint*.

Small **auricular** branches ramify on the lateral surface of the auricle and supply the external auditory meatus.

The **transverse facial artery** is a branch of moderate size which emerges from under cover of the upper part of the anterior border of the parotid gland. It runs forwards across the masseter, below the zygomatic arch and above the parotid duct, accompanied by zygomatic branches of the facial nerve, which may lie either above or below it. It supplies the parotid gland, the masseter, parotid duct, and the skin, and it ends in branches which anastomose with the infra-orbital and buccal branches of the maxillary artery and with muscular branches of the facial artery.

The **middle temporal artery** usually arises below the zygomatic arch, and runs upwards over it; it then pierces the temporal fascia, passes behind or through the posterior fibres of the temporal muscle, and ascends in the temporal fossa, grooving the skull-wall and anastomosing with the deep temporal branches of the maxillary artery.

The **zygomatic** branch may spring directly from the superficial temporal, but it is frequently a branch of the middle temporal. It runs forwards, above the zygomatic arch between the two layers of the temporal fascia. It supplies branches to the orbicularis oculi, and anastomoses, through the zygomatic bone and round the lateral orbital margin, with the lacrimal and palpebral branches of the ophthalmic artery.

The **anterior branch** runs forwards and upwards, in a tortuous course, through the superficial fascia of the scalp towards the frontal eminence, lying at first upon the temporal fascia, and then upon the epicranial aponeurosis. It supplies the frontal belly of the occipito-frontalis and the orbicularis oculi, and anastomoses with the lacrimal and supra-orbital branches of the ophthalmic artery, with the posterior terminal branch of the superficial temporal, and with its fellow of the opposite side.

The **posterior branch**, less tortuous than the anterior, runs upwards and backwards in the superficial fascia of the scalp. It anastomoses in front with the anterior terminal branch, behind with the posterior auricular and occipital arteries, and across the median line with its fellow of the opposite side. It supplies the skin and fascia, and the anterior and superior muscles of the auricle.

(8) The **maxillary artery** begins between the upper part of the parotid gland and the back of the neck of the mandible and ends in the pterygo-palatine fossa (Figs. 1078, 1079).

Course and Relations.—The maxillary artery has many important relations, in the consideration of which it is convenient to divide the vessel into three parts. The **first part** extends from the back of the neck of the mandible into the infratemporal fossa, as far as the lower border of the lateral pterygoid muscle. It lies between the spheno-mandibular ligament and the neck of the mandible, along with the auriculo-temporal nerve and the maxillary vein. The **second part** is in the infratemporal fossa, and runs upwards and forwards. It may lie on the lateral or the medial side of the lower head of the lateral pterygoid muscle either between the temporal and lateral pterygoid muscles or between the lateral pterygoid and the branches of the mandibular nerve. The **third part** passes between the upper and the lower heads of the lateral pterygoid, and through the pterygo-maxillary fissure into the pterygo-palatine fossa.

Branches.—*From the first part.*—The **deep auricular artery** passes upwards in the parotid gland to the external auditory meatus. It supplies also the mandibular joint and the superficial surface of the tympanic membrane. It anastomoses with branches of the superficial temporal and posterior auricular arteries.

The **anterior tympanic artery** is a variable and small branch. It runs upwards and backwards, traverses the squamo-tympanic fissure, and enters the tympanum near its lateral wall. In the tympanic cavity it anastomoses with tympanic branches from the internal carotid and ascending pharyngeal arteries, and with the posterior

ympanic branch of the stylo-mastoid artery, forming with the latter, in young subjects circular anastomosis around the tympanic membrane.

Middle Meningeal Artery.—This is the largest of the meningeal arteries; it is also y far the most important branch of the maxillary artery as it is a frequent source of æmorrhage after injury to the skull. It ascends between the lateral pterygoid muscle and the spheno-mandibular ligament and lies on the lateral surface of the tensor palati, which separates it from the pharyngo-tympanic tube; it passes between the two roots of the auriculo-temporal nerve and through the foramen spinosum, and enters the middle cranial fossa. Before it enters the skull it lies behind the mandibular nerve, nd is accompanied by a vein which descends through the foramen spinosum. In the middle cranial fossa it passes for a short distance forwards, in a groove on the greater wing f the sphenoid, in the outer layer of the dura mater, and divides into anterior and posterior terminal branches.

Branches.—A small **superficial petrosal** branch arises from the middle meningeal soon after it nters the cranium. It passes through the hiatus for the greater superficial petrosal nerve and anastomoses with the stylo-mastoid branch of the posterior auricular artery; it gives branches to he facial nerve and the wall of the tympanic cavity.

Minute branches supply the ganglion and the roots of the trigeminal nerve.

A small **superior tympanic artery** reaches the tympanic cavity through the canal for the tensor tympani, which muscle it supplies, or through the petro-squamous suture.

The **anterior terminal branch**, the larger and more important of the two, passes upwards along the greater wing of the sphenoid to the antero-inferior angle of the parietal bone, where it is often enclosed in a bony canal; it is continued upwards, a short distance behind the anterior border of the parietal bone, almost to the vertex of the skull, sending branches forwards and backwards. An occasional branch from the anterior terminal branch enters the orbit through the superior orbital fissure and anastomoses with the lacrimal artery.

The **posterior terminal branch** passes backwards from the greater wing of the sphenoid to the squamous part of the temporal bone, whence it sends branches upwards to the vertex and backwards to the occiput.

The anterior and posterior branches of the middle meningeal artery and their ramifications are separated from the bone by corresponding veins (p. 1341).

By means of its various branches the middle meningeal artery anastomoses—with its fellow of the opposite side; with the accessory meningeal artery; with meningeal branches from the occipital, ascending pharyngeal, ophthalmic, and lacrimal arteries; with the stylo-mastoid branch of the posterior auricular, in the temporal bone; and, through the skull-wall, with the middle and deep temporal arteries.

An **accessory meningeal artery** may arise either directly from the first part of the maxillary or from the middle meningeal artery. It enters the middle fossa of the skull through the foramen ovale, and supplies the trigeminal ganglion and the dura mater.

The **inferior dental artery** is a branch of moderate size which passes downwards, between the spheno-mandibular ligament and the ramus of the mandible, to the mandibular foramen. It is accompanied by the inferior dental nerve, which lies in front of it. Entering the foramen it descends with the nerve in the mandibular canal and, after giving off the mental artery, is continued in the bone to the median plane, where it anastomoses with its fellow of the opposite side.

Branches.—Before it enters the mandibular foramen it gives off a small **lingual** twig, which accompanies the lingual nerve and supplies the buccal mucous membrane. The **mylo-hyoid artery** is a small branch which arises immediately above the foramen. It pierces the spheno-mandibular ligament, and descends, with the mylo-hyoid nerve, in the mylo-hyoid groove to the floor of the mouth, where it anastomoses, on the superficial surface of the mylo-hyoid muscle, with the submental branch of the facial artery.

In the mandibular canal branches are given off to the molar teeth, to the premolar teeth, and, beyond the point of origin of the mental artery, to the canine and incisor teeth. The **mental artery**, which passes through the mental foramen, emerges beneath the depressor labii inferioris and anastomoses with its fellow of the opposite side, and with the inferior labial and submental arteries.

From the second part.—The **masseteric artery** is a small branch which passes laterally, through the mandibular notch, to the deep surface of the masseter muscle. It anastomoses in the substance of the muscle with branches of the facial and transverse facial arteries.

There are two **deep temporal arteries**—anterior and posterior. They ascend, in the temporal fossa, between the temporal muscle and the squamous part of the temporal bone, supplying the muscle and anastomosing with the middle temporal and lacrimal arteries, and, through the substance of the temporal bone, with the middle meningeal artery.

Small **pterygoid branches** supply the medial and lateral pterygoid muscles.

The **buccal artery** is a long, slender branch which passes obliquely forwards and downwards with the buccal nerve. It supplies the buccinator muscle, the skin and mucous membrane of the cheek, and it anastomoses with branches of the facial artery.

From the third part.—One or more **posterior superior dental arteries** descend, in the infratemporal fossa, on the posterior surface of the maxilla, and end in branches which supply the molar and premolar teeth and the mucous lining of the maxillary sinus; they also give twigs to the gums and to the buccinator muscle.

An **infra-orbital artery** arises in the pterygo-palatine fossa. It enters the orbit through the inferior orbital fissure and runs forwards, in the infra-orbital groove and canal, to the infra-orbital foramen, through which it emerges on the face, deep to the levator labii superioris. In the infra-orbital groove it gives branches to the inferior rectus and inferior oblique muscles of the orbit and to the lacrimal gland. In the infra-orbital canal it gives small twigs to the canine and incisor teeth (*ant. sup. dental arteries*) and to the walls of the maxillary sinus. In the face it sends branches upwards to the lower eyelid, to the lacrimal sac, and to the frontal process of the maxilla ; those anastomose with branches of the ophthalmic and facial arteries ; other branches run downwards to the upper lip, where they anastomose with the superior labial artery, and laterally into the cheek to unite with the transverse facial and the buccal arteries.

The **greater palatine artery** runs downwards, through the pterygo-palatine fossa and the greater palatine canal, to the roof of the mouth. As it descends it gives off the artery of the pterygoid canal and several small twigs (*lesser palatine arteries*) which pass through the lesser palatine canals to supply the soft palate, and to anastomose with the ascending palatine and tonsillar branches of the facial and with the ascending pharyngeal artery. The greater palatine artery runs forwards in the roof of the mouth, medial to the alveolar process and lateral to the accompanying nerve. Its delicate terminal portion ascends through the incisive canal and anastomoses in the nasal septum with a branch of the spheno-palatine artery. In its course forwards in the roof of the mouth the greater palatine artery supplies the gums and the mucous membrane of the hard palate, and also the palatine and maxillary bones.

The **artery of the pterygoid canal** is a long, slender branch, usually given off from the greater palatine ; it runs backwards through the pterygoid canal with the corresponding nerve and supplies branches to the upper part of the pharynx, to the levator and tensor palati muscles, and to the pharyngo-tympanic tube. One of the latter branches passes along the wall of the tube to the tympanic cavity, where it anastomoses with the other tympanic arteries.

The **pharyngeal branch** is a small artery which runs backwards, with the pharyngeal branch of the spheno-palatine ganglion, through the palatino-vaginal canal to the roof of the pharynx. It supplies the mucous lining of the upper and posterior part of the roof of the nose, the roof of the pharynx, the sphenoidal sinus, and the lower part of the pharyngo-tympanic tube.

The **spheno-palatine artery** is the continuation of the maxillary artery. It passes medially, through the spheno-palatine foramen, into the nose, where it gives off (*a*) a branch to the sphenoidal sinus, and (*b*) a branch which may replace the pharyngeal artery. Then it divides into nasal branches. The *posterior lateral nasal* branches supply the lateral wall of the nasal cavity and the sinuses which open through it, and they anastomose with the posterior and anterior ethmoidal arteries and the lateral nasal branch of the facial. The *posterior septal nasal* branch accompanies the long spheno-palatine nerve across the roof of the nasal cavity and downwards and forwards in the groove on the vomer. It anastomoses with the greater palatine artery and the septal branch of the superior labial.

INTERNAL CAROTID ARTERY

The **internal carotid artery** (Figs. 1076, 1078–1080) springs from the common carotid opposite the upper border of the thyroid cartilage, and ends in the middle fossa of the skull, in the vallecula of the cerebrum below the anterior perforated substance, where it divides into the anterior and middle cerebral arteries (Fig. 1079).

Course.—From its origin in the carotid triangle it ascends to the base of the skull, lying first medial to the sterno-mastoid, and then medial to the posterior belly of the digastric and the styloid process and its muscles. At first it lies postero-lateral to the external carotid, but as it ascends it gradually passes to the

medial side of that artery, from which it is separated by the styloid process, the stylo-pharyngeus muscle, the glosso-pharyngeal nerve, the pharyngeal branch of the vagus and a portion of the parotid gland.

At the base of the skull it enters the carotid canal, in which it ascends, anterior to the tympanum and the cochlea; then it turns antero-medially to the apex of

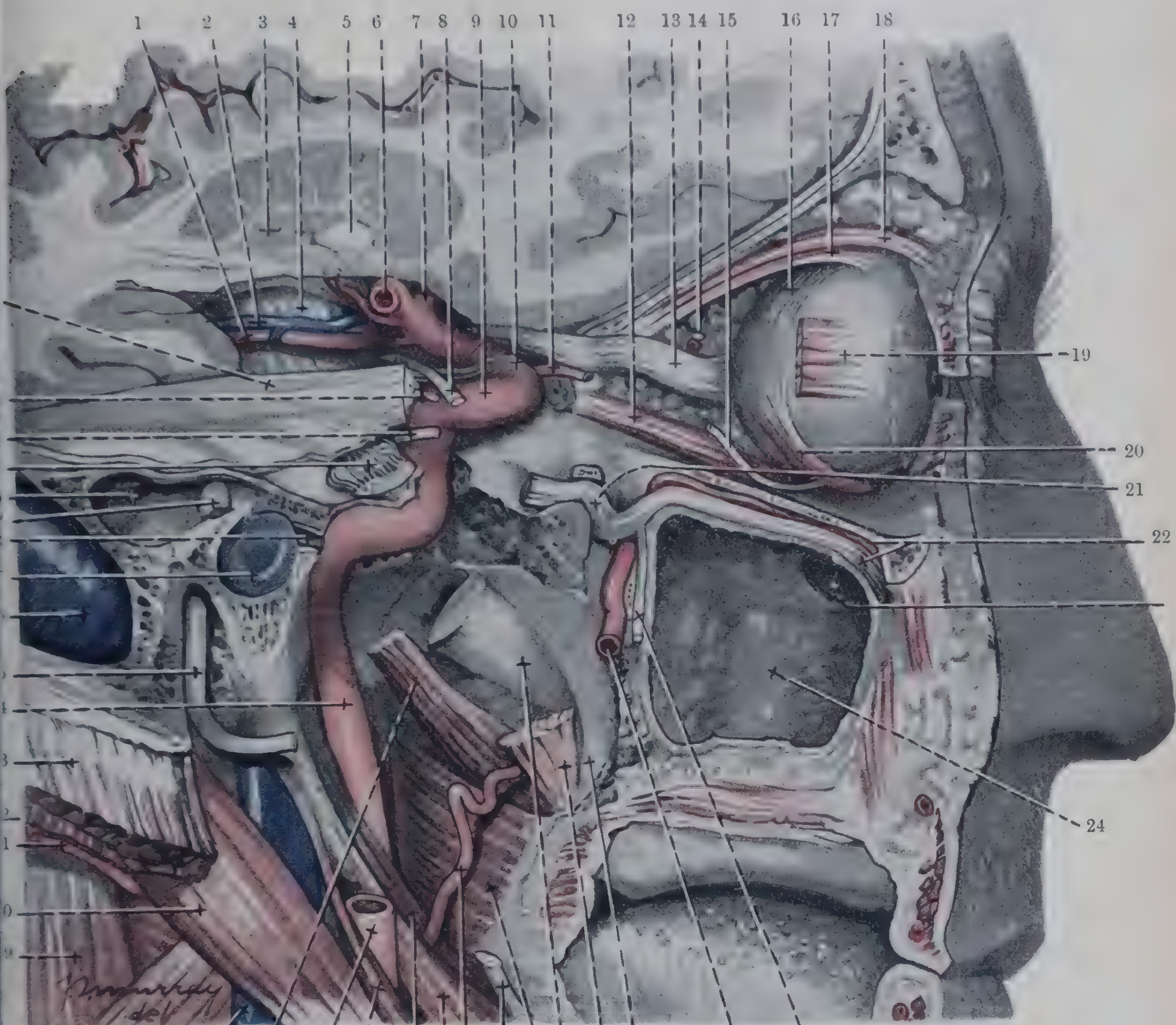

Fig. 1079.—Dissection showing Course and Relations of Upper Part of Internal Carotid Artery.

1. Posterior cerebral artery.
2. Basal vein.
3. Lentiform nucleus.
4. Cerebral peduncle.
5. Anterior commissure.
6. Middle cerebral artery.
7. Anterior cerebral artery.
8. Oculo-motor nerve.
9. Internal carotid artery.
10. Interclinoid ligament.
11. Ophthalmic artery.
12. Inferior rectus muscle.
13. Optic nerve.
14. Naso-ciliary nerve (cut).
15. Nerve to inf. oblique muscle.
16. Tendon of sup. oblique muscle.
17. Superior rectus muscle.
18. Levator palpebræ muscle.
19. Lateral rectus muscle.
20. Inferior oblique muscle.
21. Maxillary nerve.
22. Infra-orbital nerve and artery.
23. Opening from maxillary sinus into nose.
24. Maxillary sinus.
25. Posterior superior dental nerve.
26. Maxillary artery.
27. Medial pterygoid lamina.
28. Tensor palati muscle.
29. Pharyngo-tympanic tube.
30. Superior constrictor muscle.
31. Lingual nerve.
32. Ascending palatine branch of facial artery.
33. Stylo-glossus muscle.
34. Stylo-pharyngeus muscle.
35. Stylo-hyoid muscle.
36. External carotid artery.
37. Levator palati muscle.
38. Internal jugular vein.
39. Longissimus capitis muscle.
40. Posterior belly of digastric muscle.
41. Occipital artery.
42. Splenius capitis muscle.
43. Sterno-mastoid muscle.
44. Internal carotid artery.
45. Facial nerve.
46. Sigmoid sinus.
47. Tympanic membrane.
48. Pharyngo-tympanic tube (osseous part).
49. Head of malleus.
50. Tympanic antrum.
51. Trigeminal ganglion.
52. Abducent nerve.
53. Trochlear nerve.
54. Tentorium cerebelli.

the petrous temporal bone, where it enters the foramen lacerum, through which it ascends, along the side of the body of the sphenoid, into the middle cranial fossa.

In the middle fossa it runs forwards, in the lateral wall of the cavernous sinus, to the lesser wing of the sphenoid; there it turns backwards along the medial border of the anterior clinoid process, which it grooves. At the tip of the process it turns upwards and laterally to the point where it divides below the anterior perforated substance of the cerebrum (Fig. 1079).

Relations.—Three main parts of the artery require separate consideration.

In the Neck.—Posterior to the artery are the longus capitis, the prevertebral fascia and the sympathetic trunk, which separate it from the transverse processes of the cervica vertebræ. *Postero-lateral* to it are the internal jugular vein and the vagus nerve; th accessory and glosso-pharyngeal nerves also are postero-lateral to the artery for short distance in the upper part of the neck, where they intervene between it and th internal jugular vein. *Medial* or deep to the internal carotid is the external carotid artery for a short distance below, and afterwards the wall of the pharynx, the ascendin

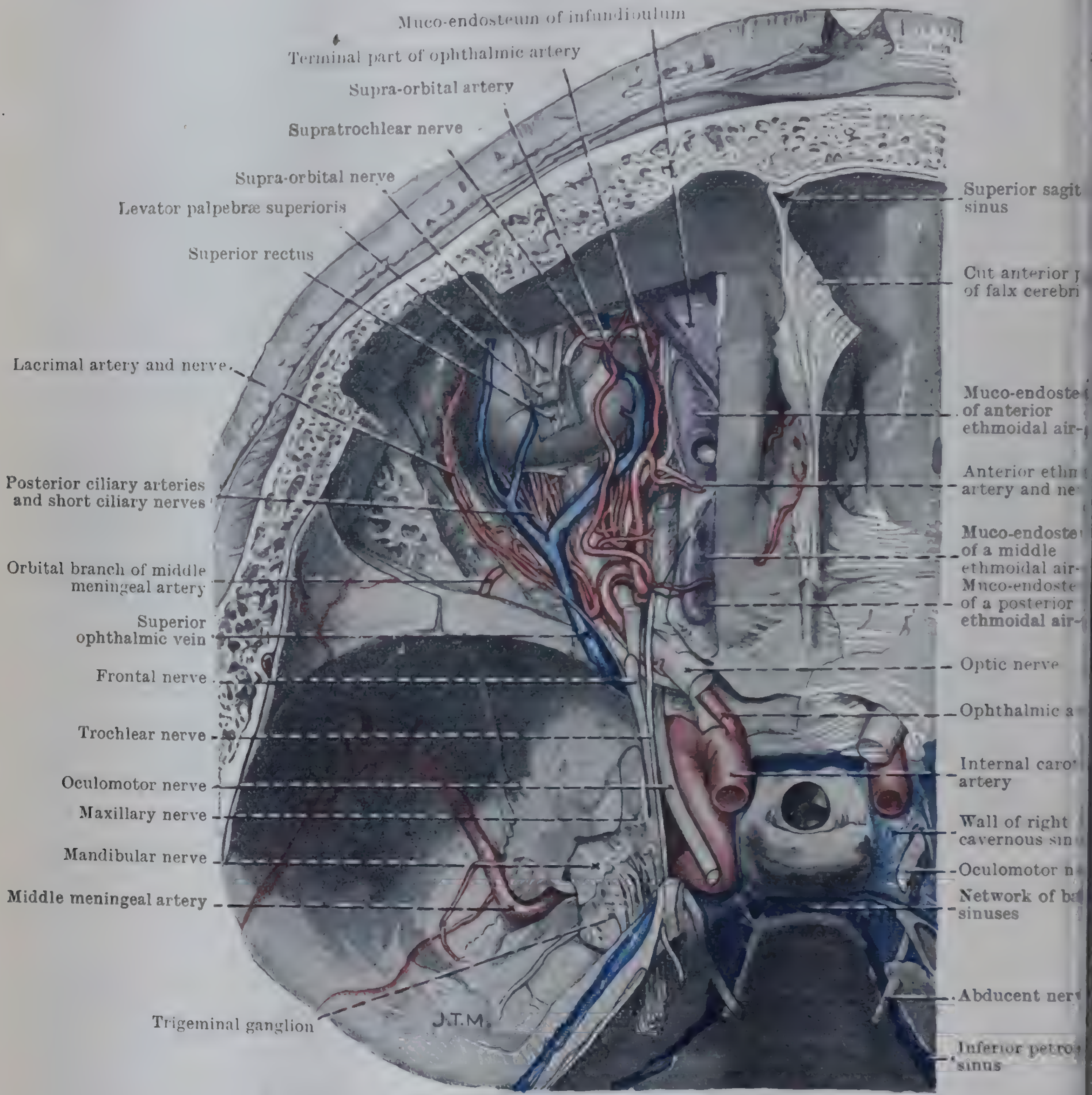

FIG. 1080.—DISSECTION OF ORBIT AND MIDDLE CRANIAL FOSSA.

On the right side the trochlear nerve has been removed, and in the left orbit portions of the structures above the ophthalmic artery have been taken away.

pharyngeal artery, the pharyngeal plexus of veins, and the external and internal laryngea nerves. Just before it enters the temporal bone the levator palati muscle is anter medial to it. *Lateral* or superficial to it are the sterno-mastoid, skin, and fasciæ, an it is crossed under cover of the sterno-mastoid, from below upwards, by the hypoglossa nerve, the occipital artery, and the posterior auricular artery. It is also crosse superficially, between the last-mentioned arteries, by the digastric and stylo-hyoid muscles which separate it from the parotid gland, and below the digastric it is covered by th lower part of the gland. Passing obliquely across its antero-lateral surface, an separating it from the external carotid artery, are the following structures—the styl pharyngeus, the styloid process (or the stylo-glossus muscle), and the glosso-pharyngea nerve, the pharyngeal branch of the vagus, and some sympathetic twigs.

In the Carotid Canal.—The artery, as it passes upwards, is antero-inferior to the cochlea nd the tympanum, postero-medial to the pharyngo-tympanic tube and the canal for ne tensor tympani, and below the trigeminal ganglion. The thin lamina of bone which eparates it from the tympanum is frequently perforated, and the lamina between it nd the trigeminal ganglion is often absent. In its course through the canal it is ccompanied by small veins and sympathetic nerves. The veins receive tributaries rom the tympanum, and communicate above with the cavernous sinus and below with he internal jugular vein. The nerves are branches of the superior cervical ganglion nd constitute the internal carotid plexus.

As it enters the cranial cavity the internal carotid artery pierces the external layer f the dura mater and passes between the lingula and the sixth cranial nerve laterally, nd the petrosal process of the body of the sphenoid medially.

In the Cranial Cavity.—The artery runs forwards, in the lateral wall of the cavernous inus, in relation with the oculomotor, trochlear, the ophthalmic division of the trigeminal, nd the abducent nerves laterally, and with the endothelial wall of the sinus medially. When it reaches the lower root of the lesser wing of the sphenoid it turns upwards to the nedial side of the anterior clinoid process, pierces the inner layer of the dura mater and he arachnoid, and comes into close relation with the inferior surface of the optic nerve, mmediately behind the optic foramen. It then runs backwards below the optic nerve, nd on the medial side of the anterior clinoid process which it frequently grooves; nclining laterally, it passes between the optic and oculomotor nerves, and finally urns upwards, a short distance from the corresponding lateral border of the optic hiasma, to end in the vallecula below the anterior perforated substance by dividing into ts two terminal branches—the anterior and middle cerebral arteries.

Carotid sinus.—The carotid sinus includes the root of the internal carotid artery, and may be limited to it (see p. 1255).

Variations.—The internal carotid artery is rarely absent, but its absence has been noted on one side (more commonly the left) and on both sides. Occasionally it springs from the arch of the aorta, and in its course through the neck it may vary in length and in tortuosity. One or more of the branches usually derived from the external carotid artery may arise from it, and it sometimes gives off a large meningeal branch to the posterior fossa of the skull. Its posterior communicating branch may replace the posterior cerebral artery; on the other hand, the upper part of the internal carotid may be absent, and the posterior communicating artery, springing from the posterior cerebral, may become the middle cerebral artery.

Branches of Internal Carotid Artery

Branches are given off from the internal carotid in the temporal bone and in the cranium, but no constant branches are given off in the neck.

In the Temporal Bone.—(1) A **carotico-tympanic branch**, very small, perforates the posterior wall of the carotid canal, and anastomoses in the tympanum with the tympanic branches of the stylo-mastoid, maxillary, and ascending pharyngeal arteries.

A small, inconstant branch accompanies the nerve of the pterygoid canal and anastomoses with the artery of the canal.

In the Cranium.—Small branches are distributed to the walls of the cavernous sinus, to the oculomotor, trochlear, trigeminal, and abducent nerves, to the trigeminal ganglion and to the dura mater of the middle cranial fossa.

One or two small branches supply the *hypophysis cerebri* (see p. 824).

(2) The **ophthalmic artery** (Figs. 1079, 1080) springs from the antero-medial side of the internal carotid immediately after it has pierced the dura and arachnoid on the medial side of the anterior clinoid process. It passes forwards and laterally, below the optic nerve, through the optic foramen into the orbital cavity. In the orbit it runs forwards, for a short distance, on the lateral side of the optic nerve, and it is in relation laterally with the ciliary ganglion and the lateral rectus muscle; turning upwards and medially, it crosses, between the optic nerve and the superior rectus, to the medial wall of the orbit, where it turns forwards to end near the front of the orbit by dividing into the supratrochlear and dorsal nasal arteries. It is accompanied at first by the naso-ciliary nerve and then by the infratrochlear nerve.

Variations.—The ophthalmic artery, as it traverses the orbit, may pass either above or below the optic nerve. It (or its lacrimal branch) is occasionally replaced by a branch of the middle meningeal artery.

Branches.—The branches of the ophthalmic artery are numerous. The **posterior cilia** arteries, usually six to eight in number, run forwards at the sides of the optic nerve; they so divide into numerous branches which pierce the fascial sheath of the eyeball and the posteri part of the sclera; the majority terminate in the choroid coat of the eye as the *short posteri ciliary arteries*, but two of larger size—the *long posterior ciliary arteries*—run forwards, one each side of the eyeball almost in the horizontal plane, between the sclera and the choroi to the periphery of the iris, where they divide. The resulting branches anastomose wi anterior ciliary arteries to form the *greater arterial circle* at the periphery of the iris, fr which secondary branches run inwards and anastomose together in a *lesser arterial circle* near t pupillary border of the iris.

The **central artery of the retina** arises in, or close to, the optic foramen and enters t dural sheath of the optic nerve. It pierces the infero-medial aspect of the nerve about half-w along its intra-orbital course, and runs with its companion vein in its centre to the retina whe it breaks up into terminal branches (see p. 1172). It is an 'end-artery' and the most importa branch of the ophthalmic.

Small **meningeal branches**, of which one arises from the lacrimal artery, pass backwar through the superior orbital fissure into the middle fossa of the cranium, where they anastomc with the middle and accessory meningeal arteries and with meningeal branches of the intern carotid artery.

The **lacrimal artery** arises from the ophthalmic on the lateral side of the optic nerv It runs forwards with the lacrimal nerve, along the upper border of the lateral rectus, to t upper lateral corner of the orbit, where it gives off branches to the lacrimal gland. In course it gives off *muscular branches* to the lateral and superior recti, and twigs whi accompany the zygomatico-temporal and zygomatico-facial branches of the zygomatic ner to the temporal fossa and the face respectively. The lacrimal artery gives off also *anter ciliary arteries* to the eyeball, and it ends in the *lateral palpebral arteries* which supply t conjunctiva and the eyelids.

The **muscular** branches are arranged in two sets: one supplies the upper and lateral orbi muscles, the other the lower and medial muscles. They anastomose with muscular branches fr the lacrimal and the supra-orbital arteries, and they give off *anterior ciliary arteries*.

The **anterior ciliary arteries** arise from muscular branches of the ophthalmic and from t lacrimal artery. They pierce the sclera behind the corneo-scleral junction and join the grea arterial circle of the iris. They give off small *episcleral arteries*, which pass forwards on t surface of the sclera to the corneo-scleral junction and give off in turn minute *anter conjunctival arteries*, which loop back in the conjunctiva to anastomose with posterior co junctival branches of the palpebral arteries. (For the circulation in the Eye and its access organs, see the Section on Organs of the Senses and Fig. 984, p. 1165.)

The **supra-orbital artery** is given off as the ophthalmic artery crosses above the optic ner It passes round the medial borders of the superior rectus and levator palpebræ muscles, and ru forwards, between the levator and the periosteum, to the supra-orbital notch or foram accompanying the frontal nerve and its supra-orbital branch. Passing through the notch reaches the scalp, and, after it has perforated the frontalis muscle, it anastomoses with the sup trochlear and superficial temporal arteries.

Anterior and **posterior ethmoidal arteries** arise from the ophthalmic as it runs forwa along the medial wall of the orbit. They pass medially, between the superior oblique a the medial rectus. The posterior, which is much the smaller of the two, traverses the poster ethmoidal canal and supplies the posterior ethmoidal sinuses and the posterior and upper part the lateral wall of the nasal cavity. The anterior ethmoidal artery passes through the anter ethmoidal canal with the anterior ethmoidal nerve, enters the anterior fossa of the skull a crosses the cribriform plate of the ethmoid to the nasal slit, passes through an aperture at t lateral side of that slit into the nasal cavity, where it descends, with the nasal continuation the anterior ethmoidal nerve, in a groove on the inner surface of the nasal bone, and, final passes between the lateral cartilage and the lower border of the nasal bone to the tip the nose. It gives off meningeal branches in the anterior cranial fossa and supplies anterior and middle ethmoidal cells, the frontal sinus, the nasal muco-periosteum, and the sk on the dorsum of the nose.

Medial palpebral arteries, upper and lower, are given off near the termination of ophthalmic. They are distributed to the upper and lower eyelids, and they anastomose with supra-orbital and infra-orbital arteries, and with the **lateral palpebral arteries**, which arise fr the lacrimal, to form the *superior* and *inferior palpebral arches*. The palpebral arteries give *posterior conjunctival arteries*, which anastomose with the anterior conjunctival branches of anterior ciliary arteries.

The **dorsal nasal artery** passes out of the orbit above the medial palpebral ligament pierces the palpebral fascia and ends on the side of the nose by anastomosing with the termi part of the facial artery.

The supratrochlear artery pierces the palpebral fascia at the upper and medial part of orbit, and ascends, with the supratrochlear nerve, in the superficial fascia of the anterior a medial part of the scalp, anastomosing with its fellow of the opposite side and with the sup orbital artery.

(3) The **posterior communicating artery** arises from the internal carotid near termination, and forms part of the *circulus arteriosus* (p. 1275). It runs backwar below the optic tract and anterior to the cerebral peduncle, and, passing above the ocu

tor nerve, joins the posterior cerebral artery. It gives branches to the optic chiasma, optic tract, the cerebral peduncle, the interpeduncular region, the internal capsule, l the thalamus. The posterior communicating artery varies much in size; it may be all on one or both sides, and sometimes it is very large on one side. Occasionally it laces the origin of the posterior cerebral artery from the basilar; and it sometimes ses from the middle cerebral artery.

(4) The **anterior choroid artery** is a small branch which also arises near the termina- n of the internal carotid; it passes backwards and laterally, between the cerebral luncle and the uncus, to the lower and anterior part of the choroid fissure, which it ers; and it ends in the choroid plexus of the inferior horn of the lateral ventricle. supplies the optic tract, the cerebral peduncle, the uncus, the posterior part of the ernal capsule, the tail of the caudate nucleus, part of the lentiform nucleus, and the ygdaloid nucleus. It anastomoses with the posterior choroid artery on the surface, the lateral geniculate body and helps to supply it (Abbie, 1933).

(5) The **anterior cerebral artery** is the smaller of the two terminal branches the internal carotid. It passes forwards and medially, above the optic iasma and in front of the lamina terminalis, to enter the longitudinal fissure of

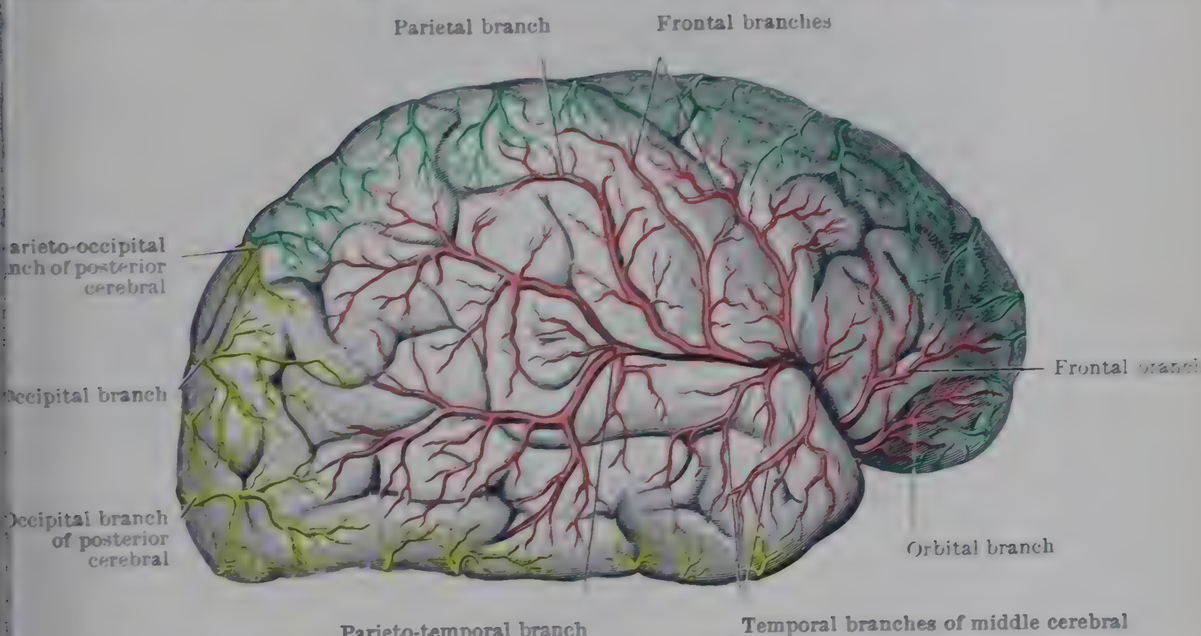

Fig. 1081.—Distribution of Cerebral Arteries on Supero-Lateral Surface of Right Cerebral Hemisphere.

The anterior cerebral artery is coloured *green*, the middle cerebral *red*, and the posterior cerebral *yellow*.

e cerebrum; it continues upwards and forwards along the rostrum of the rpus callosum, turns round the genu, and runs backwards in the longitudinal sure on the upper surface of the corpus callosum or in the sulcus cinguli; and ends by turning upwards on the medial surface of the hemisphere in front of e parieto-occipital sulcus and dividing into branches which pass over the supero- edial margin of the hemisphere. As it enters the longitudinal fissure it is closely nnected with its fellow of the opposite side by a wide but short **anterior com- unicating artery**, and from that point the two arteries run side by side, though parated by the arachnoid mater and, in the posterior part of their course, by the lge of the falx cerebri.

Branches.—Branches of all the cerebral arteries are distributed both to the interior the cerebrum and to the cerebral cortex; they therefore form two distinct groups which not communicate with one another—(*a*) **central**, (*b*) **cortical**.

The branches of the anterior cerebral are as follows:

Central Branches.—These are a small group of slender arteries which pass upwards to the base of the brain, in front of the optic chiasma; they pierce the lamina rminalis and the rostrum of the corpus callosum, and supply the head of the caudate ucleus, the anterior part of the lentiform nucleus and internal capsule, the anterior lumns of the fornix, the septum lucidum, and the anterior commissure. These branches re known as the **antero-medial central arteries**.

Cortical Branches.—The area supplied by these is seen in Figs. 1081, 1082; it

includes the corpus callosum. One or more small **orbital branches** supply the media half of the orbital surface and the olfactory lobe.

Several **frontal branches** are distributed to the medial surface of the frontal lobe, to the gyrus cinguli, to the superior and middle frontal gyri on the supero-lateral surface of the hemisphere, and to the upper part of the pre-central gyrus.

Parietal branches supply the precuneus, and the upper parts of the post-centra gyrus and the superior parietal lobule.

Branches of the anterior cerebral artery thus supply the upper parts of the motor and sensory areas of the cortex.

Variations.—The anterior cerebral may arise from the corresponding artery of the opposite side by enlargement of the anterior communicating artery; or there may be an additiona anterior cerebral artery, the third vessel arising from the anterior communicating artery.

(6) The **middle cerebral artery** is the larger of the two terminal branches of the internal carotid artery and is in more direct continuation with it. It passes

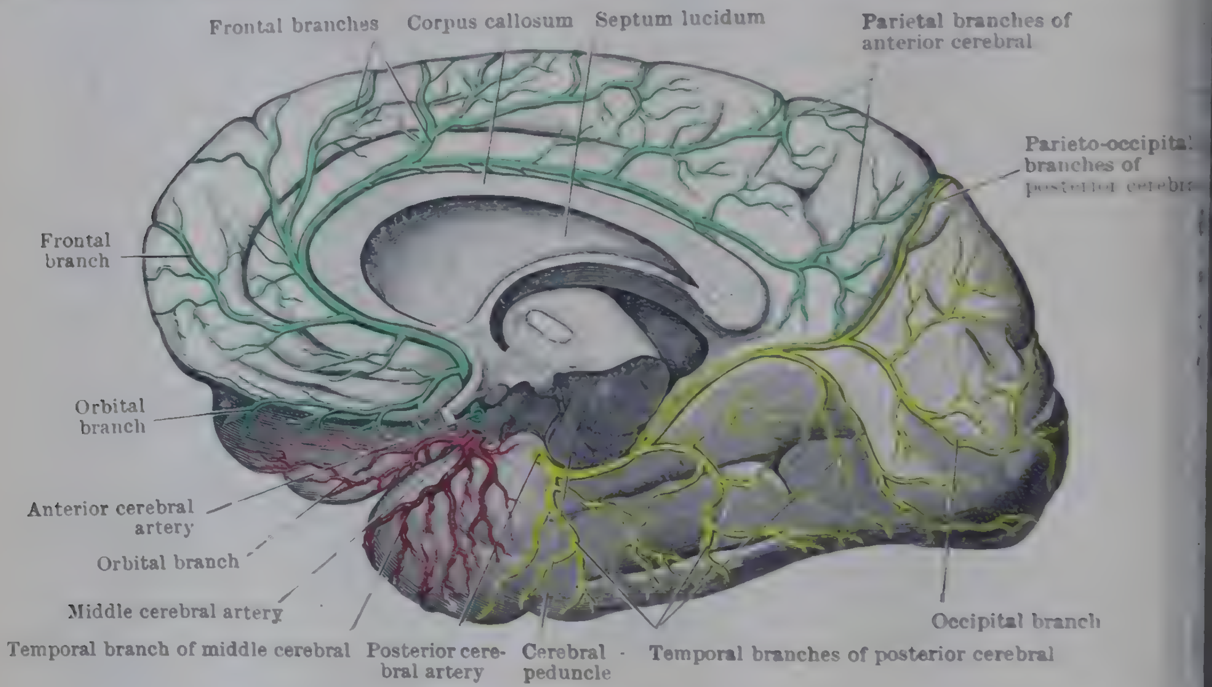

FIG. 1082.—DISTRIBUTION OF CEREBRAL ARTERIES ON MEDIAL AND TENTORIAL SURFACES OF RIGHT CEREBRAL HEMISPHERE.

The anterior cerebral artery is coloured *green*, the middle cerebral *red*, and the posterior cerebral *yellow*.

laterally, in the stem of the lateral sulcus, to the surface of the insula, where i divides into numerous parietal and temporal cortical branches.

Branches.—*Central branches* are numerous and very variable in size. They aris at the base of the brain and pierce the anterior perforated substance. They constitut the **antero-lateral central arteries**, and are arranged in two sets, known as the media and the lateral striate arteries.

The **medial striate arteries** pass upwards through the globus pallidus of the lentiforn nucleus and the internal capsule to end in the caudate nucleus. They supply th anterior parts of the lentiform and caudate nuclei and of the internal capsule.

The **lateral striate arteries** pass upwards through the putamen of the lentiforn nucleus, and between it and the external capsule, and they form two sets—an anteric and a posterior; both sets traverse the lentiform nucleus and the internal capsule, bu the anterior arteries terminate in the caudate nucleus, and the posterior in the thalamu One of the anterior set, which passes in the first instance round the lateral side of th lentiform nucleus and afterwards through its substance, is larger than its companions; is said to be the one that most frequently ruptures, and is known as the "artery c cerebral hæmorrhage".

Cortical branches are given off as the middle cerebral artery passes over the surface c the insula at the bottom of the lateral sulcus. They supply the gyri of the insula, tl deep surfaces of its opercula, and a considerable area of the frontal, parietal an temporal lobes (Figs. 1081, 1082).

One or two **orbital branches** run forwards and laterally, and are distributed to the ateral part of the orbital surface of the frontal lobe and to the inferior frontal gyrus.

Several **frontal branches** turn round the upper margin of the lateral sulcus, and re distributed to the inferior and middle frontal gyri, and to the greater part of the re-central gyrus.

Two main **parietal branches** emerge from the lateral sulcus and pass upwards and ackwards, supplying the post-central gyrus and the superior and inferior parietal lobules.

The **temporal branches** pass out of the lateral sulcus, and turn downwards to supply he greater part of the lateral surface of the temporal lobe.

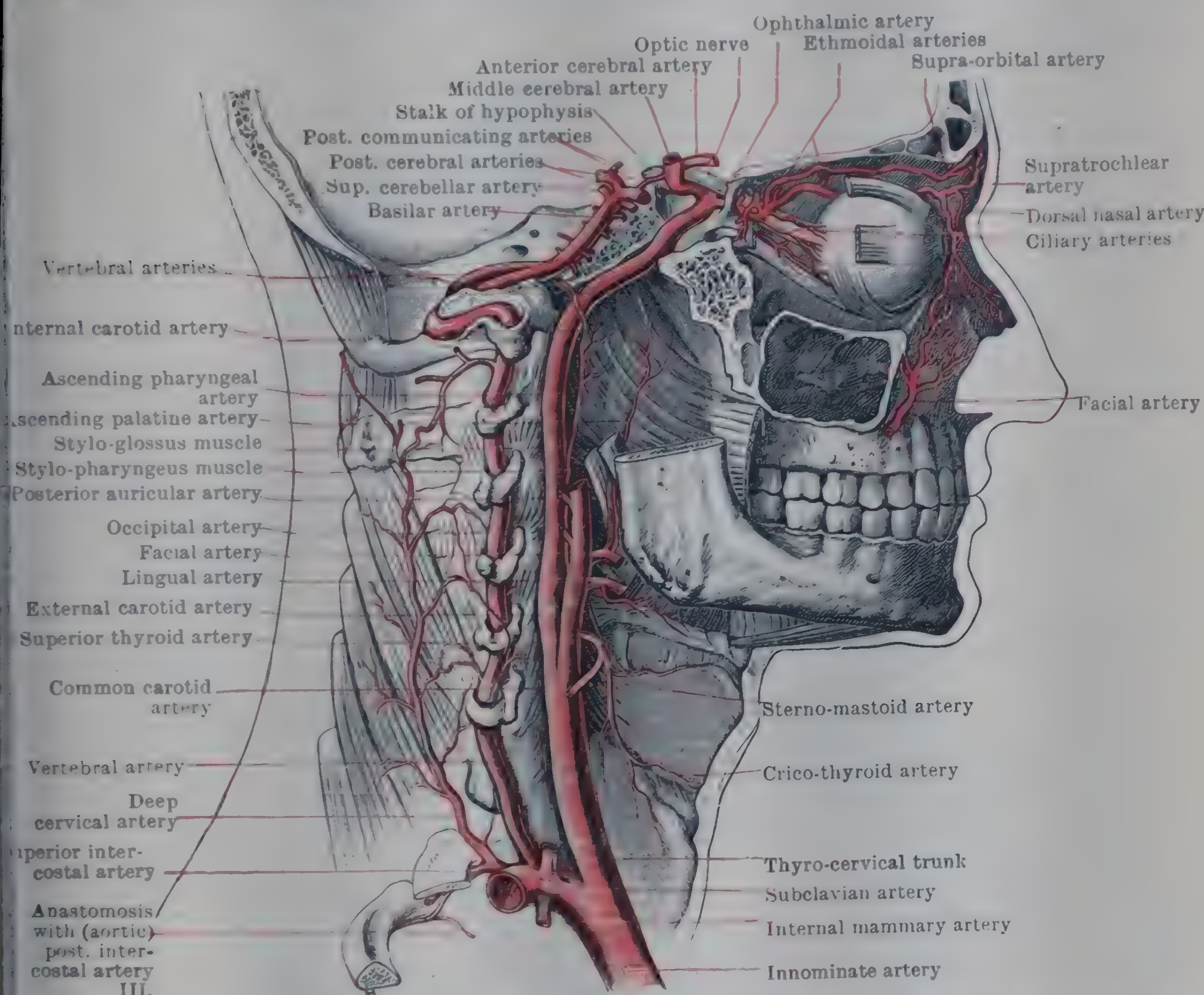

Fig. 1083.—Carotid, Subclavian, and Vertebral Arteries and their Main Branches.

A common parieto-temporal branch, continuing the main stem of the middle cerebral artery, emerges, as a rule, from the posterior end of the lateral sulcus; and divides into parietal and temporal branches (Fig. 1081).

VERTEBRAL ARTERY

The **vertebral artery** (Figs. 1083 and 1084) is the first branch given off from the subclavian trunk; it arises from the upper and posterior part of the parent stem, opposite the interval between the scalenus anterior and the longus cervicis muscles, and terminates at the lower border of the pons by uniting with its fellow of the opposite side to form the basilar artery.

Course and Relations.—The vertebral artery is divisible into four parts.

The **first part** runs upwards and backwards, between the scalenus anterior and the longus cervicis, to the foramen in the transverse process of the sixth cervical vertebra. Behind it are the transverse process of the seventh cervical vertebra, the anterior primary rami of the seventh and eighth cervical nerves, and also, a little to its medial side near its origin, the inferior cervical ganglion of the sympathetic trunk. Numerous sympathetic nerve-fibres are closely related to it, including communicating cords between the middle and inferior cervical ganglia

which pass in front and behind it. It is covered by the vertebral and internal jugular veins, and it may be crossed in front by the inferior thyroid artery. On the left side the terminal part of the thoracic duct also passes anterior to it.

The **second part** runs upwards through the foramina in the transverse processes of the upper six cervical vertebræ. As far as the second cervical vertebra its course is almost vertical; as it passes through the transverse process of the axis, however, it is directed obliquely upwards and laterally to the atlas. It is surrounded by a plexus of sympathetic nerve-fibres, and also by a plexus of veins. The artery lies anterior to the trunks of the cervical nerves, and medial to the intertransverse

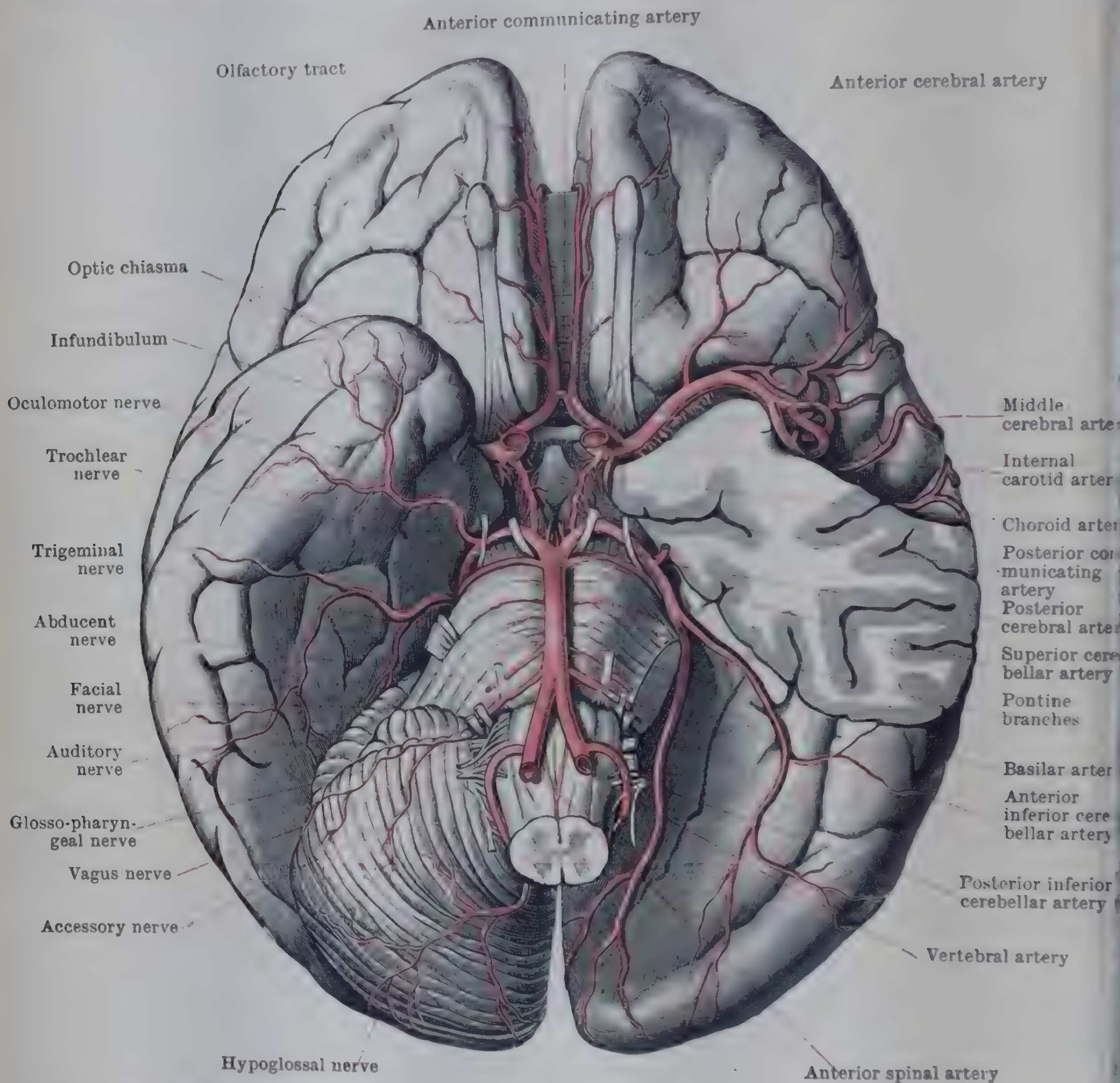

FIG. 1084.—ARTERIES OF BASE OF BRAIN SHOWING THE CIRCULUS ARTERIOSUS.

muscles. The **third part** emerges from the foramen transversarium of the atlas, between the anterior primary ramus of the first cervical nerve medially and the rectus capitis lateralis laterally, and runs almost horizontally backwards and medially, behind the lateral mass of the atlas. In that part of its course it enters the suboccipital triangle, where it lies in the groove on the upper surface of the posterior arch of the atlas. It is separated from the bone by the first cervical nerve, and is overlapped superficially by the superior and inferior oblique muscles. It leaves the triangle by passing anterior to the thickened (sometimes ossified) edge of the posterior atlanto-occipital membrane and enters the vertebral canal.

The **fourth part** pierces the spinal dura mater and the arachnoid mater immediately below the skull and then runs upwards in front of the first dentation of the ligamentum denticulatum into the cranial cavity through the foramen magnum.

it passes in front of the roots of the hypoglossal nerve, and, inclining to the front of the medulla oblongata, reaches the lower border of the pons, where it unites with its fellow of the opposite side to form the basilar artery (Fig. 1084).

Variations.—The vertebral artery may have a double origin—one from the subclavian, and one from the inferior thyroid artery or from the aorta.

The right vertebral may arise from the common carotid or from the arch of the aorta. Occasionally it springs from the descending aorta, an arrangement associated with the persistence of the dorsal roots of the fourth and fifth right arches.

The left vertebral artery not infrequently springs from the arch of the aorta, arising between the left common carotid and left subclavian arteries; that is evidently due to the absorption of the stem of the seventh intersegmental artery into the aortic arch. Very exceptionally the left vertebral is a branch of an intercostal artery.

In its course upwards either vertebral artery may enter the foramen transversarium of any of the lower six cervical vertebræ. If it does not enter one of the lowest of those foramina, it has probably been formed in part from the precostal instead of from the postcostal anastomosing channels.

The artery may enter the vertebral canal with the second cervical nerve instead of with the first, or, after leaving the foramen transversarium of the third vertebra, it may divide into two branches, one of which accompanies the second and the other the first cervical nerve; the two branches unite together again in the vertebral canal to form a single trunk.

Sometimes, though rarely, it gives off superior intercostal and inferior thyroid branches. The upper end of one of the vertebrals is sometimes very small, or it may end in small terminal branches; in the latter case the basilar artery is formed by the direct continuation of the opposite vertebral.

Branches.—**Muscular branches** which vary in number and size arise from the vertebral artery in the cervical part of its course. They supply the deep muscles of the neck and the suboccipital muscles, and anastomose with the deep and ascending cervical arteries and with the descending branch of the occipital artery.

Spinal branches pass from the *second part* of the vertebral artery through the intervertebral foramina into the vertebral canal, where they give off twigs which run along the roots of the spinal nerves to reinforce the anterior and posterior spinal arteries; they supply the bodies of the vertebræ and the intervertebral discs and anastomose with corresponding arteries above and below.

One or two small **meningeal branches** are given off before the vertebral artery pierces the dura mater. They ascend into the posterior fossa of the skull, where they anastomose with meningeal branches of the occipital and ascending pharyngeal arteries, and occasionally with branches of the middle meningeal artery.

The **posterior spinal artery** springs most commonly from the posterior inferior cerebellar branch of the vertebral (Stopford, 1916), but occasionally it arises from the vertebral directly. It runs downwards over the side of the medulla oblongata, giving branches to the fasciculi cuneatus and gracilis, and then on the spinal cord, along the line of the posterior nerve-roots. It is a slender artery, but is continued to the lower part of the spinal cord by means of reinforcements from the spinal branches of the vertebral and posterior intercostal arteries. These anastomose to form two more or less continuous longitudinal vessels, one in front of and the other behind the posterior nerve-roots, which finally end by joining the anterior spinal artery. Branches are given off to the posterior grey horn and others which anastomose in the pia mater before entering the lateral and posterior white columns.

The **anterior spinal artery** arises near the termination of the vertebral. It runs obliquely downwards and medially on the front of the medulla oblongata, and unites with its fellow of the opposite side in front of the decussation of the pyramids to form a single median trunk, which descends in the pia mater of the spinal cord under the linea splendens, and is continued as a fine vessel along the filum terminale. As it descends it is reinforced by anastomosing twigs from the spinal branches of the vertebral, posterior intercostal, and lumbar arteries, and it gives off branches which pass into the anterior median fissure of the spinal cord and divide to supply the grey matter, including the base of the posterior horn, of both sides. Branches from the right and left arteries and from the median vessel supply the anterior and medial parts of the medulla oblongata, including the hypoglossal nucleus and the hypoglossal triangle on the floor of the fourth ventricle (Stopford, 1916; Shellshear, 1927).

The **posterior inferior cerebellar artery** is the largest branch of the vertebral. It arises near the lower end of the olive and pursues a very tortuous course backwards round the medulla oblongata, at first between the rootlets of the hypoglossal nerve, and then upwards behind the rootlets of the vagus and glosso-pharyngeal nerves, loops backwards

and downwards from the lower border of the pons along the infero-lateral boundary o the fourth ventricle, and then turns outwards into the vallecula of the cerebellum, wher it divides into lateral and medial terminal branches. The trunk of the artery give branches to the medulla oblongata and to the choroid plexus of the fourth ventricle. Som of these branches supply the nuclei of the glosso-pharyngeal, vagus, and accessor nerves, the spino-thalamic, spino-cerebellar, rubro-spinal, and olivo-cerebellar tracts, an possibly also the vestibular root of the auditory and the spinal tract of the fifth nerv (Bury & Stopford, 1913). A special branch goes to supply the dentate nucleus of th cerebellum (Shellshear, 1922). The medial terminal branch runs backwards between th inferior vermis and the hemisphere of the cerebellum: it supplies the vermis, and anasto moses with its fellow of the opposite side. The lateral terminal branch passes to the lowe surface of the hemisphere and anastomoses with the superior cerebellar artery.

Basilar Artery.—The basilar artery is formed by the junction of the tw vertebral arteries; it begins at the lower border of the pons and ends a its upper border by bifurcating into the two posterior cerebral arteries.

Course and Relations.—It runs upwards, in the median part of the cistern pontis, in a shallow groove on the front of the pons, behind the sphenoidal sectio of the basi-cranial axis and between the two abducent nerves.

Variations.—The basilar artery may be double in part of its extent, or its lumen may b divided by a more or less complete septum. It may end in one instead of two posterior cerebr arteries, the missing vessel being supplied by the enlargement of the posterior communicatin branch of the internal carotid.

Branches.—A series of pairs of small **pontine branches** supply the pons, the midd cerebellar peduncles, and the roots of the trigeminal nerves.

The **internal auditory arteries** are a pair of long slender branches. Each intern auditory may spring either from the basilar or from the anterior inferior cerebellar arter of the same side (Stopford, 1916). It enters the corresponding internal auditory meat with the facial and auditory nerves, and is distributed to the internal ear.

The **anterior inferior cerebellar arteries** arise, one on each side, from the middle o the basilar artery. They pass backwards, on the anterior parts of the lower surfac of the hemispheres of the cerebellum, and anastomose with the posterior inferior cerebell arteries.

The **superior cerebellar arteries** arise near the termination of the basilar. Each pass laterally, at the upper border of the pons, directly below the oculomotor nerve of th same side, and, after turning round the lateral side of the cerebral peduncle, belo the trochlear nerve, it reaches the upper surface of the cerebellum, where it divide into a medial and a lateral branch. The medial branch supplies the upper part of th vermis, and the superior medullary velum. The lateral branch is distributed over th upper surface of the cerebellar hemisphere; it anastomoses with the inferior cerebell arteries.

The **posterior cerebral arteries** (Figs. 1079 and 1084) are the two termin branches of the basilar. Each runs backwards and upwards between the cerebr peduncle and the uncus and parallel to the superior cerebellar artery, fro which it is separated by the oculomotor and trochlear nerves. It is connecte with the internal carotid by the posterior communicating artery; it gives branche to the inferior surface of the cerebrum, and is continued backwards beneath th splenium of the corpus callosum to the calcarine sulcus, where it divides int occipital and parieto-occipital branches. It supplies the tentorial surface of th hemisphere, the medial and lateral surfaces of the occipital lobe, and the inferi temporal gyrus (Figs. 1081, 1082).

Variations.—The size of the posterior cerebral artery and the size of the posterior commun cating artery vary inversely, and the posterior cerebral may arise entirely from the intern carotid. It may be double, the extra vessel arising from either the basilar or the posteri communicating artery.

Branches.—*Central.*—A set of small **postero-medial central arteries** pass, on th medial side of the corresponding cerebral peduncle, to the posterior perforated substanc They supply the peduncle, the posterior part of the thalamus, the mamillary bodies, an the walls of the third ventricle.

A set of small **postero-lateral central arteries** pass round the lateral side of th

duncle. They supply the quadrigeminal and medial geniculate bodies, the pineal body, e peduncle, and the posterior part of the thalamus.

A set of small **posterior choroid branches** pass through the upper part of the choroid sure; they enter the posterior part of the tela choroidea of the third ventricle, and end the choroid plexus. They supply also the lateral geniculate body and the adjacent arts of the fornix and the thalamus.

Cortical.—Several **temporal branches** supply the uncus, the hippocampal gyrus, the edial and lateral occipito-temporal gyri, and the lingual gyrus.

The **occipital branches**, one of which continues the line of the main artery along the lcarine sulcus, supply the cuneus, the lingual gyrus, and the occipital pole; they are pecially associated with the supply of the visual area of the cortex of the brain.

The **parieto-occipital branch** passes along the corresponding sulcus and supplies he cuneus and precuneus.

Circle Of Willis

Circulus Arteriosus (Fig. 1084).—The cerebral arteries of opposite sides are itimately connected together at the base of the brain by anastomosing channels. hus, the two anterior cerebral arteries are connected with each other by the anterior ommunicating artery, whilst the two posterior cerebral arteries are in continuity rough the basilar artery, from which they arise. There is also a free anastomosis n each side between the carotid system of cerebral arteries and the vertebral ystem by means of the posterior communicating arteries, which connect the nternal carotid trunks and posterior cerebral arteries. It is probable that this free nastomosis equalizes the flow of blood to the various parts of the cerebrum, and rovides for the continuation of a regular blood-supply if one or more of the main runks should be obstructed.

These vessels form the so-called **circulus arteriosus**, described by Willis (1664) in classical work on the brain and therefore long known as the "circle of Willis". It s situated at the base of the brain in the interpeduncular cistern and encloses the ollowing structures: the posterior perforated substance, the mamillary bodies, the uber cinereum, the infundibulum, and the optic chiasma. The "circle" is irregu-arly polygonal in outline, and is formed behind by the termination of the basilar and y the two posterior cerebral arteries, postero-laterally by the posterior communicat-ng arteries and the internal carotids, antero-laterally by the anterior cerebral rteries, and in front by the anterior communicating artery.

Variations.—The posterior communicating artery is the most variable part of the "circle". It may be absent on one side or it may be larger than usual, so that the posterior cerebral artery arises mainly or even entirely from the internal carotid. The anterior communicating artery (which may be double or triple) also varies in size, and there may be corresponding reduction in size of the origin of one of the anterior cerebral arteries from the internal carotid.

ARTERIES OF UPPER LIMB

The main arterial stem of the Upper Limb passes through the root of the neck, traverses the axilla, and is continued through the upper arm to the forearm. In the forearm its extent is short, for it ends opposite the neck of the radius by bifurcating into the radial and ulnar arteries, which run through the forearm to the hand. That portion of the common trunk which lies in the root of the neck is known as the **subclavian artery**, the part in the axilla is termed the **axillary artery**, whilst the remaining part is called the **brachial artery**.

SUBCLAVIAN ARTERIES

The right subclavian artery (Figs. 1062, 1069, 1071, and 1076) is one of the two branches of the innominate artery, and it begins behind the sterno-clavicular joint; the left artery arises from the arch of the aorta opposite the left margin of the manubrium sterni.

The right artery is about 3 inches (75 mm.) long; it lies in the root of the neck. The left artery is about 4 inches (100 mm.) long; it is situated first in the superior mediastinum of the thorax and then in the root of the neck. In the root of the neck each artery arches laterally across the front of the cervical pleura and behind the scalenus anterior muscle; it is divided into three parts, which lie

respectively to the medial side, behind, and to the lateral side of the muscle. Th extent to which the arch rises above the level of the clavicle varies from half a inch to an inch. The first parts of the subclavian arteries differ from each othe both in extent and relations. The relations of the second and third parts ar similar on the two sides.

The **first part of the left subclavian artery** springs from the arch of th aorta, half an inch behind the origin of the left common carotid and on the lef side of the trachea. It ascends almost vertically, in the superior mediastinum, t the root of the neck, where it arches upwards and laterally to the medial borde of the scalenus anterior muscle.

Relations.—(A) **As it ascends.**—*Posterior.*—Left pleura and lung, laterally medially, first the œsophagus and the thoracic duct, and then fatty tissue and the longu

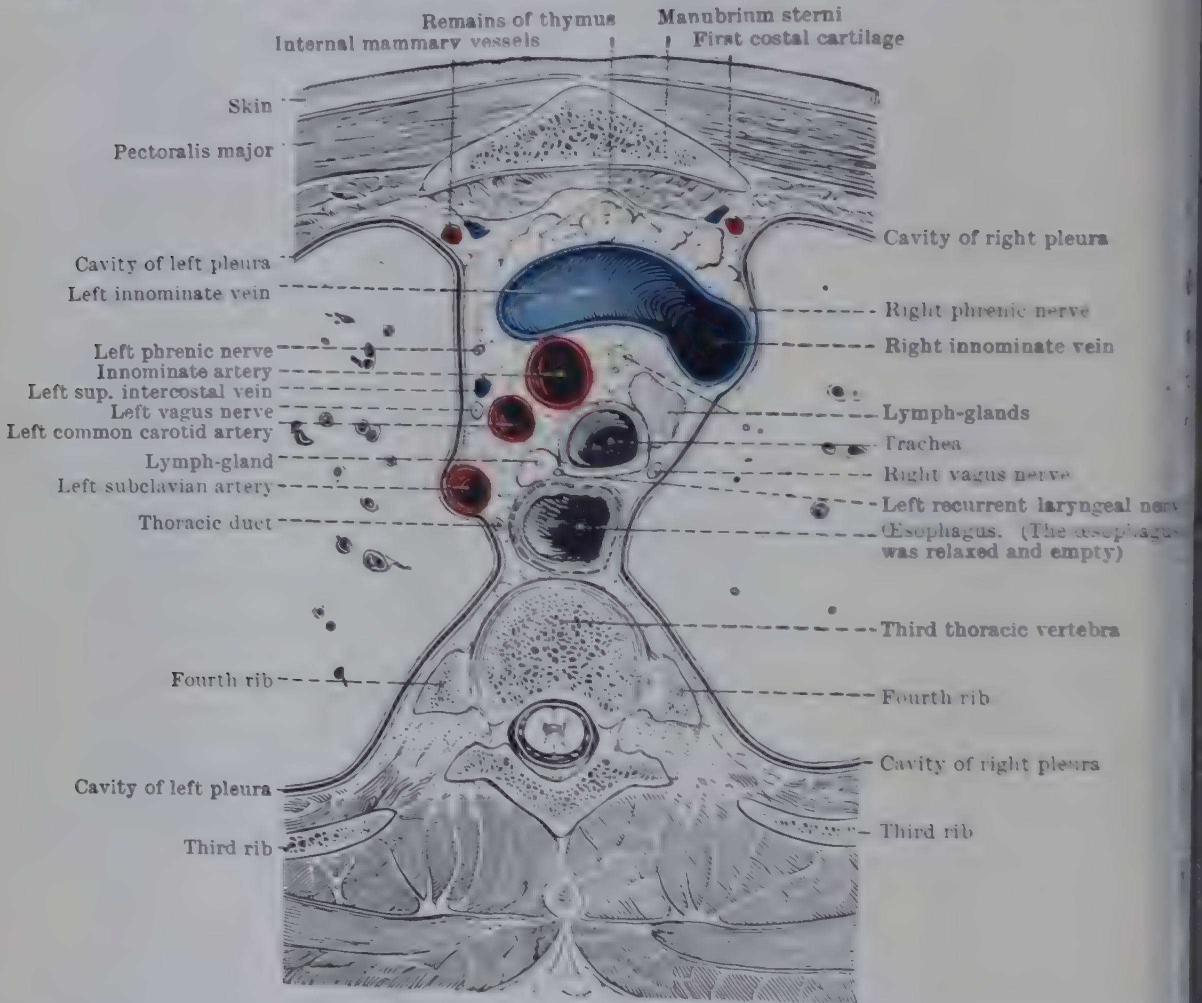

FIG. 1085.—TRANSVERSE SECTION OF THORAX OF YOUNG MAN THROUGH JUNCTION OF INNOMINATE VEINS. The section is in the Plane A-A, FIG. 1109, p. 1330.

cervicis muscle. *Anterior.*—The left vagus, the cardiac branch of the left superic cervical sympathetic ganglion, the inferior cardiac branch of the left vagus, the lef phrenic nerve, and the left common carotid artery, in front of which some distance awa is the left innominate vein. It is overlapped by the left lung and pleura. *Medial.*— From below upwards, the trachea, and, some fatty areolar tissue and perhaps a lympl gland intervening, the left recurrent laryngeal nerve, the œsophagus and the thoraci duct. *Lateral.*—The left pleura and lung, the lung being grooved by it.

(B) **As it runs laterally.**—*Posterior.*—The apex of the left lung and the cervica pleura covered by the suprapleural membrane. *Anterior.*—The vertebral and interna jugular veins; the phrenic nerve and the thoracic duct: the sterno-thyroid and stern hyoid muscles; the anterior jugular vein; and the sterno-mastoid.

The **first part of the right subclavian artery** (Fig. 1071) extends from th back of the right sterno-clavicular joint to the medial border of the scalenu anterior. Thus, it is limited to the root of the neck.

Relations.—*Posterior.*—Behind that part of the artery are the recurrent laryngeal rve, the posterior part of the ansa subclavia, and the apex of the right lung covered the cervical pleura and suprapleural membrane. *Inferior.*—The recurrent laryngeal rve curves backwards *below* it and intervenes between it and the pleural sac. *Anterior.*— front it is in relation with the right vagus, the cardiac branches of the vagus and the mpathetic, the anterior portion of the ansa subclavia, the internal jugular and vertebral ins, and more superficially the sterno-hyoid and sterno-thyroid muscles, the anterior gular vein, and the sterno-mastoid muscle. The right common carotid artery also is in ont of it at its origin.

The **second part of the subclavian artery**, on *each side*, extends from the edial to the lateral border of the scalenus anterior, behind which it lies.

Relations.—*Posteriorly* and *below* it is in relation with the pleural sac and supra- eural membrane. *Anteriorly* it is covered by the scalenus anterior and the sterno- astoid muscles. The scalenus anterior separates it from the subclavian vein, which lies a slightly lower level, from the transverse cervical and suprascapular arteries, from e anterior jugular vein, and, on the right side, from the phrenic nerve.

The **third part of the subclavian artery** is the most superficial portion. extends downwards and laterally from the lateral border of the scalenus anterior the outer border of the first rib, lying partly in the posterior triangle of the eck and partly behind the clavicle and the subclavius muscle.

Relations.—It rests upon the upper surface of the first rib. Immediately *posterior* it is the lowest trunk of the brachial plexus, which separates it from the scalenus edius muscle. *Anterior* to it, and at a slightly lower level, lies the subclavian vein. The ternal jugular vein crosses the medial part of that portion of the artery, and receives e transverse cervical and suprascapular veins; those vessels also pass in front of the rtery, which is thus covered superficially by venous trunks; it is also crossed vertically, ehind the veins, by the nerve to the subclavius muscle. The lateral section of that part f the artery lies behind the clavicle and the subclavius muscle. It is crossed in ont by the suprascapular artery, but the layer of deep cervical fascia which binds the ferior belly of the omo-hyoid to the posterior border of the subclavian groove tervenes between the two vessels. More superficially the third part of the artery is overed by the superficial layer of the deep fascia, the superficial fascia (containing the upraclavicular nerves and the platysma), and the skin.

Variations.—The variations in origin of the subclavian arteries have already been entioned (pp. 1251-1252). Other interesting modifications are met with in respect of its position nd branches.

The subclavian artery may reach as high as 1½ inches (4 cm.) above the clavicle, though as a ule it does not reach more than half that distance. On the other hand, it may not rise even o the level of the upper border of the clavicle. The differences appear to be associated with lescent of the clavicle and sternum, which occurs as age increases.

The artery may pass in front of or through the scalenus anterior instead of behind it, or he vein may accompany it behind the muscle.

The branches of the subclavian artery may be modified with reference to their points of origin; hus, those of the first part may be farther medial or lateral than usual, the suprascapular r some other branch of the thyro-cervical trunk may arise separately from the third part f the subclavian, and not uncommonly the deep branch of the transverse cervical artery s a branch of that part. The variations of the vertebral artery have already been described; hose of the thyro-cervical trunk and its branches are numerous but not important.

Branches of Subclavian Artery

(1) The **vertebral artery** is distributed almost entirely to the head and neck, and its chief function is to supply the posterior part of the brain. Its description has therefore been given with that of the other cerebral arteries (see p. 1271).

(2) The **thyro-cervical trunk** (Figs. 1071 and 1083) arises close to the medial border of the scalenus anterior, from the upper and front part of the subclavian artery. After a very short upward course, it ends, under cover of the internal jugular vein, by dividing into three branches—the inferior thyroid, the transverse cervical, and the suprascapular.

(A) The **inferior thyroid artery** (Fig. 1071) ascends along the anterior border of the scalenus anterior, and turns medially, opposite the cricoid cartilage,

to the middle of the posterior border of the corresponding lobe of the thyroid gland; it then curves medially and downwards, and descends to the lower end of the lobe, where it divides into ascending and inferior terminal branches.

Relations.—*Posterior* are the vertebral artery and the longus cervicis muscle; the recurrent laryngeal nerve passes either in front of or behind the vessel, behind the thyroid gland. It is covered *anteriorly* by the carotid sheath, which contains the common carotid artery, the internal jugular vein, and the vagus nerve; the middle cervical ganglion of the sympathetic lies in front of the artery, which often passes through a loop of the sympathetic trunk as it runs medially; and on the left side the thoracic duct also passes in front of it.

Branches.—Numerous small **muscular** branches pass to adjacent muscles.

The **ascending cervical artery** usually springs from the inferior thyroid as it turns medially, but it may arise separately from the thyro-cervical trunk. It ascends, parallel with and medial to the phrenic nerve, in the groove between the longus capitis and the scalenus anterior, to both of which it gives *muscular branches.* It also gives off *spinal branches* which pass through the intervertebral foramina to the vertebral canal. It anastomoses with branches of the vertebral, occipital, ascending pharyngeal, and deep cervical arteries.

Small **pharyngeal branches** supply the lower part of the pharynx; small **œsophageal branches** anastomose with the œsophageal branches of the thoracic aorta; and **tracheal branches** anastomose on the trachea with branches of the superior thyroid and with the bronchial arteries.

An **inferior laryngeal artery** accompanies the recurrent laryngeal nerve to the lower part of the larynx. It enters the larynx at the lower border of the inferior constrictor, gives branches to the laryngeal muscles and mucous membrane, and anastomoses with the laryngeal branch of the superior thyroid artery.

Inferior and ascending terminal **glandular branches** supply the posterior and lower parts of the thyroid gland, and anastomose with branches of the superior thyroid artery and with their fellows of the opposite side. Small branches are given to the parathyroid glands.

(B) The **transverse cervical artery** (Figs. 1076 and 1087) arises from the thyro-cervical trunk and runs upwards and backwards across the posterior triangle of the neck to the anterior border of the trapezius; there it divides into a superficial and a deep branch. It is very variable in size.

Immediately after its origin, under cover of the internal jugular vein, it crosses the scalenus anterior, lying superficial to the phrenic nerve and under cover of the sterno-mastoid muscle; on the left side it is also crossed, superficially, by the terminal part of the thoracic duct. Passing from beneath the sterno-mastoid, it enters the lower part of the posterior triangle of the neck, where it lies upon the trunks of the brachial plexus, and as it runs upwards and backwards to its termination it passes deep to the inferior belly of the omo-hyoid.

The superficial branch may be a separate vessel which springs from the thyro-cervical trunk and takes the course described, whilst the deep branch arises from the third part of the subclavian artery and lies at a lower level. In such cases the upper of the two vessels is called the *superficial cervical artery* and the lower the *descending scapular artery.*

Branches.—The **superficial branch**, usually a slender artery, passes beneath the trapezius; it sends branches upwards and downwards on the deep surface of the muscle where they anastomose with twigs from the descending branch of the occipital artery.

The **deep branch** runs downwards, deep to the levator scapulæ and the rhomboid muscles, close to the medial border of the scapula. It runs parallel with and a short distance lateral to the nerve of the rhomboids, and it sends branches into the supraspinous, infraspinous, and subscapular fossæ, which anastomose with branches of the suprascapular and subscapular arteries. It also sends branches backwards, through and between the rhomboid muscles, which anastomose with the posterior branches of posterior intercostal arteries.

(C) The **suprascapular artery** springs from the thyro-cervical trunk and ends in the infraspinous fossa of the scapula.

It begins behind the internal jugular vein, crosses the scalenus anterior

nd the phrenic nerve, and is covered superficially by the sterno-mastoid; on he left side it lies behind the thoracic duct also. Continuing laterally behind the lavicle and crossing superficial to the third part of the subclavian artery and the ords of the brachial plexus, it reaches the suprascapular notch and passes over he suprascapular ligament. It then descends, with the suprascapular nerve,

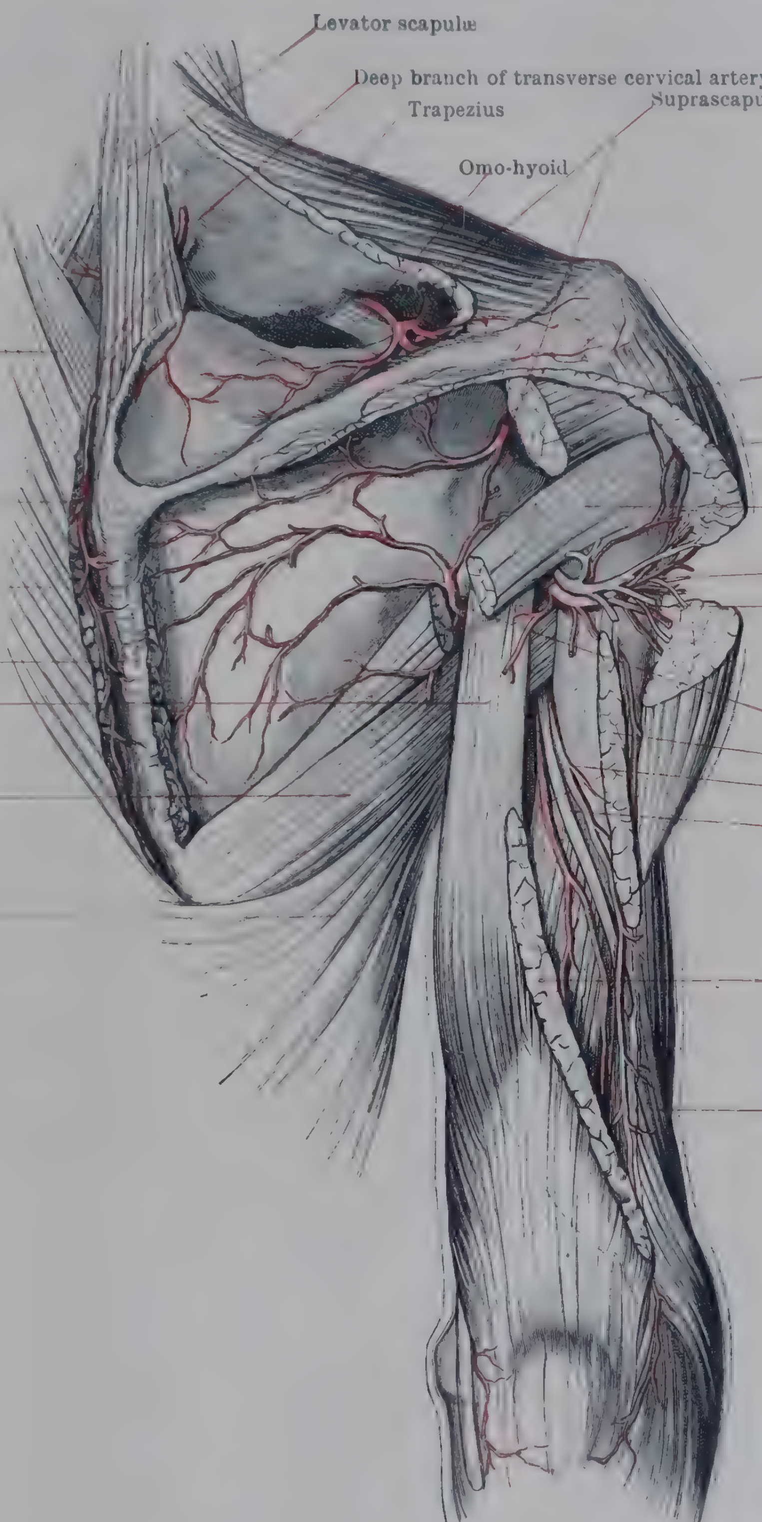

Fig. 1086.—Anastomosing Arteries on Dorsum of Scapula and Posterior Humeral Circumflex and Profunda Brachii Arteries.

through the supraspinous fossa and deep to the supraspinatus muscle, and after passing through the spino-glenoid notch, deep to the spino-glenoid ligament, it ends in the infraspinous fossa.

Branches.—The trunk of the artery gives branches to the adjacent muscles, a branch that passes superficial to the sternal end of the clavicle and an **acromial branch**, which ramifies over the acromion, anastomosing with the acromial branches of the acromio-thoracic and the posterior circumflex arteries.

As the artery passes over the suprascapular ligament, it gives off a branch into t subscapular fossa, which anastomoses with the branches of the subscapular artery a the deep branch of the transverse cervical artery.

In the supraspinous and infraspinous fossæ its branches anastomose also with the de branch of the transverse cervical; and in the infraspinous fossa they anastomose addition with the circumflex scapular artery.

The chief **muscular branches** of the suprascapular artery supply the supraspinat infraspinatus, and subscapularis muscles. The artery also supplies branches to the stern clavicular, acromio-clavicular, and shoulder joints, and nutrient arteries to the clavi and the scapula.

(3) The **internal mammary artery** (Figs. 1071, 1083) arises from the lower a anterior part of the subclavian, at the medial border of the scalenus anterior a usually immediately below the origin of the thyro-cervical trunk. It terminat behind the sternal end of the sixth intercostal space by dividing into t musculo-phrenic and superior epigastric arteries.

The artery passes at first downwards, forwards, and medially, lying upon t pleura, and behind the innominate vein, the sternal end of the clavicle, and t cartilage of the first rib; the right artery is crossed obliquely, from the lateral the medial side, by the phrenic nerve, which usually passes in front of it. Fro the cartilage of the first rib it descends vertically, about half an inch from t border of the sternum, and lies, in the upper part of its course, in front of the pleu and, in the lower part, in front of the sterno-costalis muscle. It is cover in front by the cartilages of the upper six ribs, the intervening anterior intercos membrane and internal intercostal muscles, and is crossed by the terminal portio of the intercostal nerves. It is accompanied by lymph-vessels and lymph-glan, and by two venæ comitantes, which unite at the level of the third costal cartila to form a single trunk which runs on the medial side of the artery to end in t innominate vein in the thorax.

Variations.—The internal mammary artery, though usually a branch of the first part of t subclavian, is very variable in origin. It may arise from the second or third part, or fr the thyro-cervical trunk, or it may spring from the aorta, or from the innominate or axill arteries. All these variations are due to obliteration of the normal origin and the openi up of anastomoses. The internal mammary artery sometimes descends in front of the cartila of one or more of the lower true ribs; and occasionally it gives off a *lateral costal branch* wh descends on the inner side of the chest-wall, close to the mid-axillary line—a point of importa in the operation of paracentesis. Occasionally a bronchial artery may arise from the inter mammary, and one or several small branches may pass to the lower end of the trachea.

Branches.—The **pericardiaco-phrenic artery** is a long slender branch which is giv off from the upper part of the internal mammary. It accompanies the phrenic ner to the diaphragm, where it anastomoses with the phrenic and musculo-phrenic arteri In its course downwards this artery gives off numerous small branches to the ple and pericardium, which anastomose with offsets of the mediastinal and pericard branches of the aorta and internal mammary arteries, and also with the bronch arteries, forming a wide-meshed *subpleural plexus* (Turner. 1865).

Numerous small **mediastinal branches** pass into the mediastinum and supply the ba of the sternum, the areolar tissue and lymph-glands, the thymus and the pericardiu The *thymic branches* are larger and more important in the child.

The **anterior intercostal arteries** are two in number in each of the upper six int costal spaces. They pass laterally and lie for a short distance between the ple (or the sterno-costalis) and the internal intercostal muscles; they then pass between t internal intercostal muscles and the innermost intercostals (see p. 428), and end anastomosing with the posterior intercostal arteries and their collateral branches.

The **perforating branches**, one in each of the upper six intercostal spaces, are sm vessels which pass forwards, with the anterior cutaneous branches of the intercos nerves, piercing the internal intercostal muscle, the anterior intercostal membrane, a the pectoralis major. They end in the skin and subcutaneous tissue. They supply tw to the sternum, and those in the second, third, and fourth spaces, usually the largest the series, give off *mammary branches* which are of special importance in the female arteries of supply to the mammary gland.

The **musculo-phrenic artery**, the lateral terminal branch of the internal mamma runs downwards and laterally, from the sixth intercostal space to the tenth cos

ilage. In the upper part of its course it lies upon the thoracic surface of the hragm, but it pierces the diaphragm about the level of the eighth costal cartilage, and on its abdominal surface. It gives off *muscular branches* to the diaphragm which tomose with phrenic branches of the thoracic aorta and with the phrenic arteries; it supplies two **anterior intercostal arteries** to each of the seventh, eighth, and h intercostal spaces. These are distributed in the same manner as the corresponding nches of the internal mammary artery, and end by anastomosing with the posterior rcostal arteries and their collateral branches.

The **superior epigastric artery**, the medial terminal branch of the internal mammary, ends into the anterior wall of the abdomen. It leaves the thorax, between the sternal costal origins of the diaphragm, and enters the sheath of the rectus abdominis scle, lying first behind the muscle and then in its substance. It ends by anasto-sing with branches of the inferior epigastric artery. It gives *muscular branches* the rectus, to the other muscles of the abdominal wall, and to the diaphragm. ll cutaneous branches pierce the rectus and the anterior wall of its sheath; these mpany the anterior terminal branches of the lower intercostal nerves and end in the cutaneous tissues and skin of the middle portion of the anterior abdominal wall. mall branch which supplies adjacent muscle and skin crosses the front of the xiphoid cess to anastomose with its fellow of the opposite side, and branches of small size pass kwards in the falciform ligament to the liver, where they anastomose with branches he hepatic artery.

(4) The **costo-cervical trunk** (Fig. 1083) springs from the back of the second rt of the subclavian artery on the right side and from the first part on the left e. It runs upwards and backwards, over the cervical pleura and the apex of e lung, to the neck of the first rib, where it divides into the deep cervical and perior intercostal arteries.

Branches.—The **deep cervical artery** runs backwards into the back of the neck, sing below the eighth cervical nerve, and between the transverse process of the seventh vical vertebra and the neck of the first rib. In the back of the neck it ascends ween the semispinalis capitis and semispinalis cervicis muscles, and it ends by astomosing with the descending branch of the occipital artery; it anastomoses also h branches of the ascending cervical and vertebral arteries. It supplies the adjacent iscles; and it sends a *spinal* branch into the vertebral canal through the intervertebral amen between the last cervical and the first thoracic vertebræ; this branch anasto-ses with the spinal branches of the vertebral and posterior intercostal arteries.

The **superior intercostal artery** descends, in front of the neck of the first rib, between e first thoracic nerve laterally and the sympathetic trunk medially. At the lower rder of the neck of the rib, it gives off the posterior intercostal artery of the first ace; then, after crossing in front of the neck of the second rib, it becomes the posterior ercostal artery of the second intercostal space. The **first two posterior intercostal teries** run laterally, each in its own space, lying first between the pleura and the sterior intercostal membrane, and then between the innermost intercostal and the internal ercostal muscle (see p. 448). They end by anastomosing with anterior intercostal anches of the internal mammary artery, and their branches are distributed in the same anner as those of the other posterior intercostal arteries (p. 1294).

Variations.—The **deep cervical artery** may arise directly from the subclavian trunk, and e **superior intercostal artery** may be absent, its place being taken by branches from the aorta. e superior intercostal is sometimes formed from a postcostal instead of a precostal primitive annel; in such cases it passes between the necks of the ribs and the transverse processes of e vertebræ instead of, as usual, in front of the necks of the ribs.

AXILLARY ARTERY

The **axillary artery** is the direct continuation of the subclavian artery, and it comes the brachial artery.

It begins at the outer border of the first rib, at the apex of the axilla. It asses downwards along the lateral wall of the space, *i.e.*, along the medial side of the houlder joint and the humerus, to the lower border of the teres major, where it ecomes the brachial artery. A line drawn from the middle of the clavicle to e medial border of the prominence of the coraco-brachialis muscle, when the

arm is abducted until it is at right angles with the side, indicates the positic and direction of the artery.

The position and direction, and to a certain extent the relations of th axillary artery, are modified, however, by changes in the position of the upp limb. With the arm hanging by the side the axillary artery describes curve with the concavity directed downwards and medially, and the vein lies alor its medial side. When the arm is at right angles with the side, the axillary arte

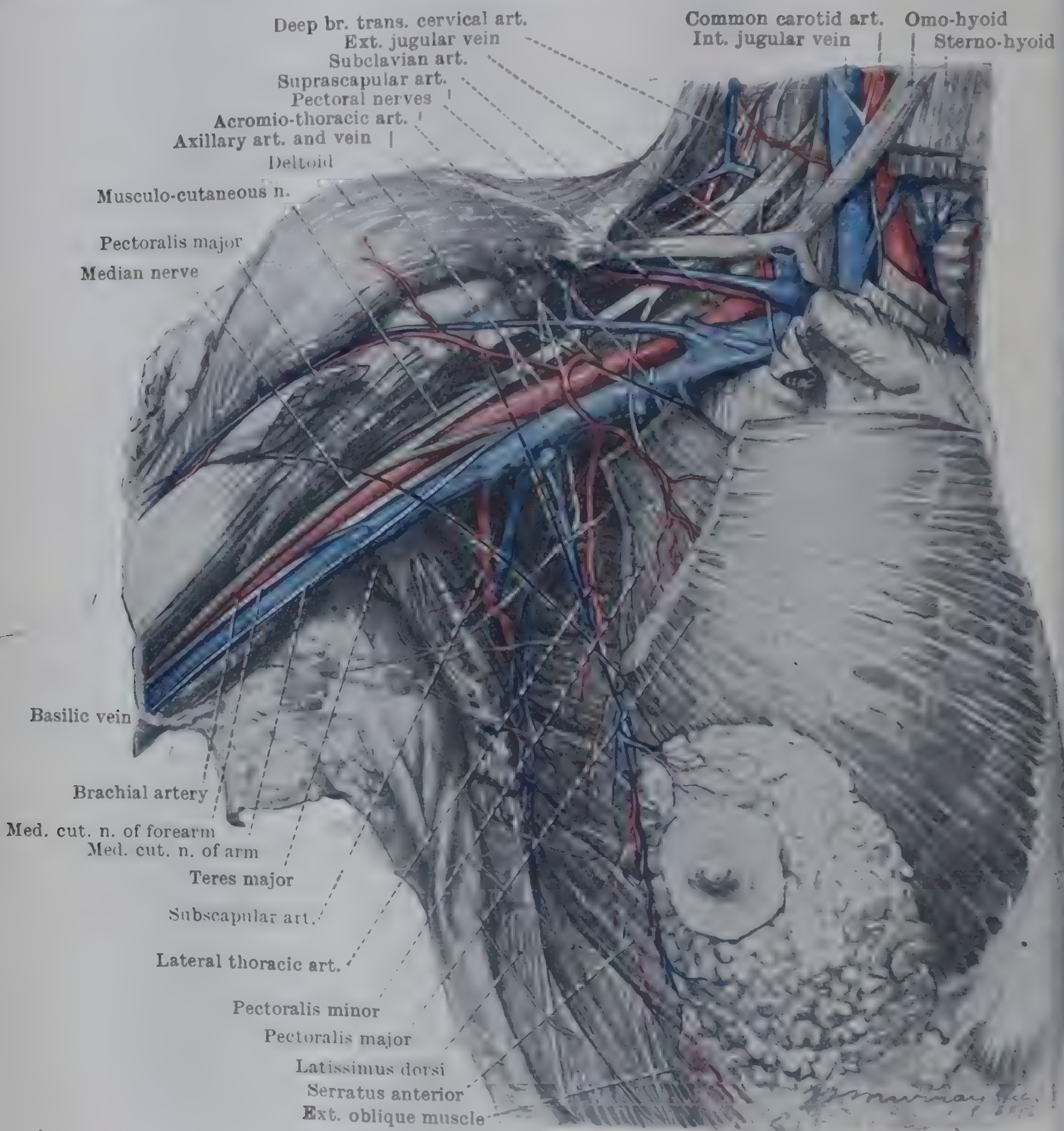

Fig. 1087.—Axillary Artery and its Branches.

The middle third of the clavicle has been removed, and the arm has been slightly abducted and rota laterally. Parts of the pectoralis major and minor have been removed; the positions of the low border of the pectoralis major and both borders of the pectoralis minor are indicated by broken bl lines.

is almost straight; it lies closer to the lateral wall of the axilla, and the ve overlaps it antero-medially. When the arm is raised above the level of t shoulder the axillary artery is curved over the head of the humerus, with t convexity of the curve below, and the vein lies still more in front of it.

For descriptive purposes the artery is divided into three parts: the fir part lies above the pectoralis minor, the second behind, and the third pa below it.

Though it is the usual custom to describe three parts of the axillary arte —a division which is of practical interest in so far as it emphasizes the fact th the axillary artery is surgically accessible above the pectoralis minor—it is to noted that the upper border of the pectoralis minor may be so nearly in line wi

e outer border of the first rib, at the point where the axillary artery begins, at the first part of the artery is exceedingly short.

Relations of First Part.—The first part of the artery is enclosed, together with e vein and the cords of the brachial plexus, in a prolongation of the cervical fascia iown as the *axillary sheath*. *Posterior.*—Behind the sheath are the upper serraon of the serratus anterior, the contents of the first intercostal space, and the nerve serratus anterior, which descends vertically between the artery and the muscle; ithin the sheath, the medial pectoral nerve and the medial cord of the brachial plexus e behind the artery. *Anterior.*—It is covered in front by the clavi-pectoral fascia. his fascia intervenes between the artery and the cephalic vein, the branches of the teral pectoral nerve, the branches of the acromio-thoracic artery with their accomınying veins, and the clavicular part of the pectoralis major muscle, superficial to hich are the deep fascia, the supraclavicular nerves descending from the cervical lexus, the platysma in the superficial fascia, and the skin. Posterior to the claviectoral fascia the artery is crossed by a loop of communication between the lateral nd medial pectoral nerves. *Lateral.*—Above and to the lateral side are the lateral nd posterior cords of the brachial plexus and the lateral pectoral nerve. *Medial.*—elow and to the medial side is the axillary vein, the medial pectoral nerve intervening.

Relations of Second Part.—*Posterior.*—Behind the second part of the artery are ne posterior cord of the brachial plexus and the fatty areolar tissue which separates it from ne subscapularis muscle. *Anterior.*—In front is the pectoralis minor, and, more supercially, the pectoralis major, the fasciæ and skin. *Lateral.*—To the lateral side lies the lateral ord of the brachial plexus. *Medial.*—On the medial side the medial cord of the plexus es in close relation to the artery, and intervenes between it and the axillary vein.

Relations of Third Part.—*Posterior.*—The third part of the artery rests upon ne lower part of the subscapularis, the latissimus dorsi, and the teres major. It is eparated from the subscapularis by the circumflex and radial nerves, and from the atissimus dorsi and teres major by the radial nerve alone. *Anterior.*—It is crossed in ront by the medial ~~head~~ of the median nerve. In its upper half it lies under cover f the lower part of the pectoralis major, the fasciæ and skin, whilst its lower part, hich is superficial, is covered by skin and fasciæ only. *Lateral.*—To the lateral side e the median and musculo-cutaneous nerves and the coraco-brachialis muscle. *Medial.*—o the medial side is the axillary vein. The two vessels are, however, separated by two f the chief branches of the medial cord of the brachial plexus—the medial cutaneous erve of the forearm in front and the ulnar nerve behind. The medial cutaneous erve of the arm lies medial to the vein, and the venæ comitantes of the brachial rtery ascend along the medial side to end in the axillary vein at the lower border of the ubscapularis muscle.

Variations.—The **axillary artery** does not vary much in its origin or course. Its relaions may be modified by the existence of a muscular or tendinous "axillary arch", which, assing from the latissimus dorsi to the pectoralis major, crosses the distal part of the artery uperficially; and there may be an anomalous arrangement of its branches. Occasionally the ubscapular, circumflex humeral, profunda brachii and ulnar collateral arteries arise from the xillary by a common stem. In those cases the chief branches of the brachial plexus are grouped ound the common stem instead of round the axillary artery. The arrangement is due to the ersistence of a different part of the original vascular plexus.

Sometimes the axillary artery divides into the radial and ulnar arteries, and more rarely the common interosseous artery may spring from it. Obviously there is no brachial artery when the adial and ulnar arteries are formed by the division of the axillary; its place is taken by he two abnormal vessels which, as a rule, are separated by the median nerve as they run hrough the arm; the radial is usually more superficial than the ulnar, and crosses laterally in front of it at the bend of the elbow.

Branches of Axillary Artery

(1) The **superior thoracic artery** is a small branch which arises from the first part of the axillary at the lower border of the subclavius. It runs downwards and medially, across the first intercostal space, and pierces the medial part of the clavi-pectoral fascia. It supplies branches to the adjacent muscles; and it anastomoses with branches of the suprascapular, the internal mammary, and the acromio-thoracic arteries.

(2) The **acromio-thoracic artery** (Fig. 1087) arises near the upper border of

the pectoralis minor, from the second part of the axillary artery. It is a very s
trunk, of considerable width, which passes forwards, pierces the clavi-pectoral fas
and ends, deep to the clavicular portion of the pectoralis major, by dividing
four terminal branches—acromial, clavicular, deltoid, and pectoral.

The **acromial branch** runs upwards and laterally, across the tip of the cora
process, to the acromion; it anastomoses with the deltoid branch, with the acro
branches of the suprascapular, and with the posterior circumflex humeral artery.

The **clavicular branch** is a long slender artery which runs upwards and medially
the sterno-clavicular joint, anastomosing with the superior thoracic, with branche
the suprascapular, and with the first perforating branch of the internal mammary ar
It supplies the adjacent muscles and the sterno-clavicular joint.

The **deltoid branch** descends, in the groove between the pectoralis major and del
muscles, where it lies by the side of the cephalic vein, as far as the insertion of
deltoid. It anastomoses with the acromial branch and with the anterior circumflex hum
artery; and it gives branches to the pectoralis major and deltoid muscles and to the s

The **pectoral** is a large branch which descends between the two pectoral muscles
both of which it gives branches, and it anastomoses with the intercostal and lat
thoracic arteries.

(3) The **lateral thoracic artery** arises from the second part of the axill
and descends, along the lateral border of the pectoralis minor, to anastomose w
the intercostal and subscapular arteries and with the pectoral branch of t
acromio-thoracic. It supplies the adjacent muscles, and sends *external mamm
branches* to the lateral part of the mammary gland.

(4) The **subscapular artery** is the largest branch of the axillary. It ar
from the third part of the artery opposite the lower border of the subscapul
along which it descends, giving branches to the muscle and to the medial
of the axilla. After a short course it gives off the circumflex scapular art
and then, accompanied by the nerve to the latissimus dorsi, continues along
lateral border of the scapula to the wall of the thorax, where it anastom
with the lateral thoracic artery, with branches of the intercostal arteries, and w
the deep branch of the transverse cervical. A large muscular branch enters
latissimus dorsi with its nerve at a well-defined neuro-vascular hilum (p. 409).

The **circumflex scapular artery** is frequently larger than the continuation of the pa
trunk. It arises about 1½ inches from the origin of the subscapular artery, and pa
backwards into the triangular space which lies between the subscapularis muscle ab
the teres major below, and the long head of the triceps laterally. Turning round
usually grooving the lateral border of the scapula, under cover of the teres mino
enters the infraspinous fossa, where it breaks up into branches which anastomose
the deep branch of the transverse cervical artery and the suprascapular artery.
the triangular space the artery gives off two branches; one passes into the subscap
fossa and anastomoses there with the same two arteries; the other runs downward
the inferior angle of the scapula, between the teres major and minor muscles. S
branches are given also to the deltoid and long head of triceps.

(5) The **posterior circumflex humeral artery** arises from the third part of
axillary artery and passes backwards, accompanied by the circumflex nerve, thro
the quadrangular space, which is bounded by the teres minor and subscapu
muscles above, the teres major below, the long head of the triceps medially, and
humerus laterally. It turns round the surgical neck of the humerus, under cove
the deltoid muscle, and ends in numerous branches which supply a large portio
the deltoid and anastomose with the anterior circumflex humeral and acro
thoracic arteries. As a rule it is only slightly smaller than the subscapular arte

Branches.—**Muscular branches** are given to the adjacent muscles, and a br
ascends, through the deltoid, to the acromion, where it anastomoses with the acro
branches of the suprascapular and acromio-thoracic arteries. A *descending branch*
downwards along the lateral head of the triceps to anastomose with the ascending br
of the profunda brachii artery; frequently this communication is enlarged so
the posterior circumflex humeral appears to take origin from the profunda brachii.
artery also supplies articular branches to the shoulder joint, and nutrient branche
the proximal end of the humerus.

5) The **anterior circumflex humeral artery** is a small branch; it is given om the third part of the axillary close to, or in common with, the posterior nflex. It passes laterally, deep to the coraco-brachialis and the two heads of iceps, around the front of the surgical of the humerus, and it ends by tomosing with the posterior humeral mflex. It gives muscular branches to adjacent muscles, one of which runs wards along the tendon of insertion ne pectoralis major. At the bicipital ve it gives off a well-marked branch h ascends along the tendon of the long of the biceps to the shoulder joint.

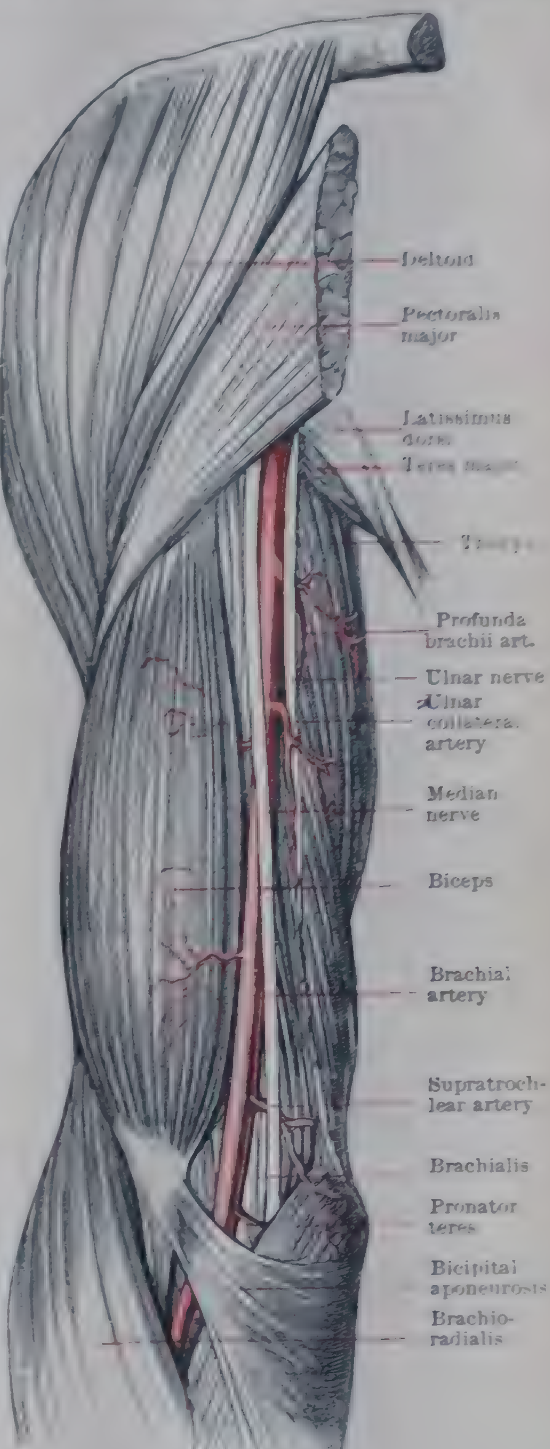

Fig. 1088.—Brachial Artery and its Branches.

BRACHIAL ARTERY

The **brachial artery** is the direct con- ation of the axillary. It begins at the r border of the teres major, and ends, he cubital fossa, opposite the neck of radius, by dividing into the radial and r arteries. It runs downwards at first e medial side of the humerus and then ont of it. Its position and that of the ary artery may be indicated on the ace, when the arm is abducted, by a drawn from the middle of the clavicle he centre of the bend of the elbow.

Relations.—*Posterior.*—It lies, success- , anterior to the long head of the triceps the radial nerve and the profunda vessels vening; the medial head of the triceps; nsertion of the coraco-brachialis; and the hialis. *Anterior.*—It is overlapped *an- rly* by the medial border of the biceps; it rossed, at the middle of the arm, by the ian nerve, and, in addition, it is covered leep and superficial fascia and skin. In cubital fossa a thickened portion of the fascia, called the bicipital aponeurosis, rates it from the median cubital vein and anterior branch of the medial cutaneous e of the forearm, both of which lie in the rficial fascia. *Lateral.*—To the *lateral side* in relation, proximally, with the median e, and, distally, with the biceps. *Medial.*— he *medial side* it is in relation, in the proxi- part of its extent, with the basilic vein, medial cutaneous nerve of the forearm, the ial cutaneous nerve of the arm, and the ulnar nerve, and in the distal part with the ian nerve. Two venæ comitantes, a medial and a lateral, accompany the artery, and munications between them pass across the vessel.

Variations.—The brachial artery is rarely prolonged beyond its usual point of bifurcation; uncommonly, however, it bifurcates at a higher level. Of the two terminal branches of radial, one may divide into radial and common interosseous, the other forming the ulnar; e may divide into radial and ulnar, whilst the other is the common interosseous. nally the brachial artery ends by dividing into three branches—viz., the radial, the ulnar, the common interosseous. The common interosseous was the original trunk (p. 1375 and 1135).

High division " of the brachial artery occurs most commonly in the proximal third of the r arm, and least commonly in the distal third; the resulting trunks are often united near bend of the elbow by a more or less oblique anastomosis.

When there is high division of the brachial artery the radial branch may pierce the deep fascia of the arm near the bend of the elbow and descend in the forearm in the superficial fascia; or it may run deeper and pass behind the tendon of the biceps. The ulnar branch sometimes runs, on the medial intermuscular septum, towards the medial epicondyle, and then laterally towards the middle of the bend of the elbow, behind a band of fascia from which the proximal fibres of the pronator teres arise, or behind the supracondylar process of the humerus if it is present. More commonly the ulnar branch descends towards the medial epicondyle and crosses superficial to the flexor muscles or deep to the palmaris longus; and in a few cases it is subcutaneous. Rarely the ulnar artery accompanies the ulnar nerve behind the medial epicondyle; it has then obviously been formed by enlargement of the ordinary ulnar collateral and posterior ulnar recurrent arteries.

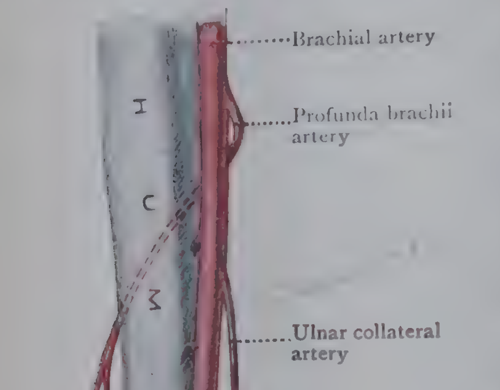

Fig. 1089.—Diagram of Anastomosis around Elbow Joint. (Cf. Pl. LXXXI p. 1296.)

Instead of following its usual course along the brachialis muscle, the brachial artery may accompany the median nerve behind a supracondylar process (p. 255), or ligament, as in many carnivora; it may pass in front of the median nerve instead of behind it. It may give off a "vas aberrans" or a median artery, and any of its ordinary branches may be absent.

The vas aberrans given off from the brachial artery usually ends in the radial artery, sometimes in the radial recurrent, and rarely in the ulnar artery.

Branches of Brachial Artery

(1) The **profunda brachii artery** is a large branch which arises from the postero-medial side of the brachial soon after its origin. It runs downwards and laterally in the groove for the radial nerve, and divides at the back of the humerus into two descending branches—anterior and posterior. Not infrequently the division takes place at a higher level, and the artery appears double. The *anterior descending branch* accompanies the radial nerve through the lateral intermuscular septum and then descends between the brachio-radialis and the brachialis to the front of the lateral epicondyle, where it anastomoses with the radial recurrent artery. The *posterior descending branch* continues downwards behind the lateral intermuscular septum to the back of the lateral epicondyle, where it anastomoses with the interosseous recurrent and supratrochlear arteries.

Behind the humerus one of the descending branches gives off: (*a*) a slender twig which descends with the nerve to the anconeus muscle in the medial head of the triceps to the back of the elbow where it anastomoses with the supratrochlear artery; (*b*) a *nutrient branch* which enters a foramen on the posterior surface of the humerus; and (*c*) an *ascending branch* which anastomoses with the descending branch of the posterior circumflex humeral artery.

(2) **Muscular branches** are given to the adjacent muscles; one for the main supply of the biceps divides, each branch entering, with the corresponding branch of the nerve, a distinct neuro-vascular hilum on the deep surface of a belly.

(3) A small **nutrient branch** arises from the middle of the brachial and enters the nutrient foramen on the antero-medial surface of the humerus.

(4) The **ulnar collateral artery** is smaller than the profunda, with which it sometimes arises by a common trunk; usually, however, it springs from the postero-medial side of the middle of the brachial artery. It runs downwards and backwards with the ulnar nerve, through the medial intermuscular septum, and then, passing more vertically, reaches the back of the medial epicondyle of the humerus, where it ends by anastomosing with the posterior ulnar recurrent and supratrochlear arteries.

(5) The **supratrochlear artery** arises from the medial side of the brachial artery about two inches above its bifurcation. It runs medially between the median nerve and the brachialis. It then pierces the medial intermuscular septum and turns laterally between the medial head of the triceps and the posterior surface of the bone to reach the lateral epicondyle. It supplies the adjacent muscles and it anastomoses in front of the medial epicondyle with the anterior ulnar recurrent, behind the medial epicondyle with the posterior ulnar recurrent and the ulnar collateral, on the back of the humerus with the twig from the profunda which follows the nerve to the anconeus, and behind the lateral epicondyle with the posterior descending branch of the profunda and with the interosseous recurrent artery (Pl. LXXXI, p. 1296).

RADIAL ARTERY

The **radial artery** (Figs. 1090 and 1091) is the smaller of the two terminal branches of the brachial artery, but it is in more direct line with the parent trunk. It begins in the cubital fossa opposite the neck of the radius, and it ends in the palm of the hand by anastomosing with the deep branch of the ulnar artery and thus completing the deep palmar arch.

The trunk is divisible into **three parts**. The *first part* lies in the forearm. It runs downwards and slightly laterally to the apex of the styloid process of the radius. The *second part* curves round the lateral side of the wrist, and across the scaphoid and trapezium, to reach the proximal end of the first interosseous space. The *third part* passes forwards through the first interosseous space to the palm of the hand, where it joins the deep branch of the ulnar artery.

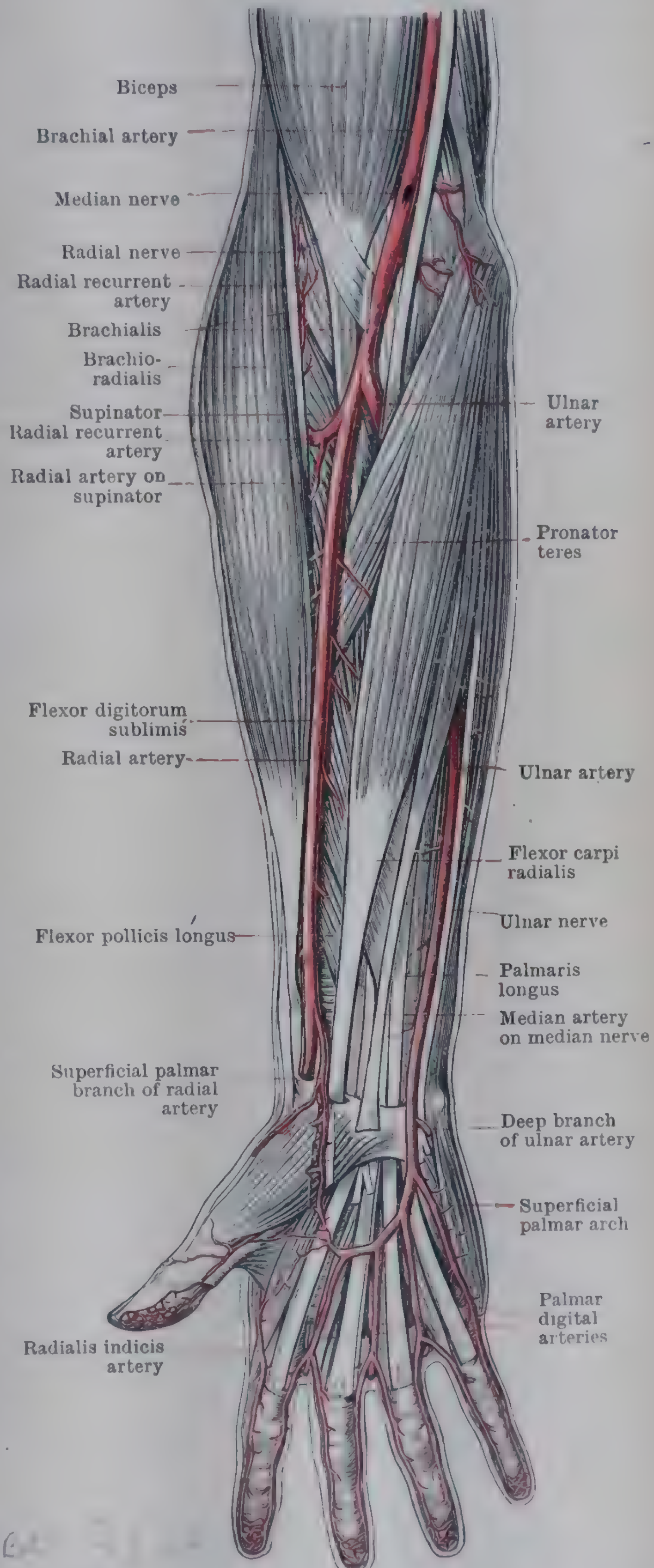

Fig. 1090.—Superficial Dissection of Forearm and Hand, showing Radial and Ulnar Arteries and Superficial Palmar Arch with its Branches.

Relations of First Part.—*Posterior.*—It passes successively across the following structures: the tendon of insertion of the biceps, the supinator, the pronator teres, the radial portion of the flexor digitorum sublimis, the flexor pollicis longus, the pronator quadratus, and the lower end of the radius.

Anterior.—The artery is covered superficially, in the proximal half, by the border of the brachio-radialis; in the remainder of its extent it is covered only by skin and fasciæ.

To the *radial side* are the brachio-radialis and the radial nerve. The nerve lies

near to the middle third of the artery. To the *ulnar side* are the pronator ter proximally, and the flexor carpi radialis, distally. Two venæ comitantes lie along tl sides of the artery.

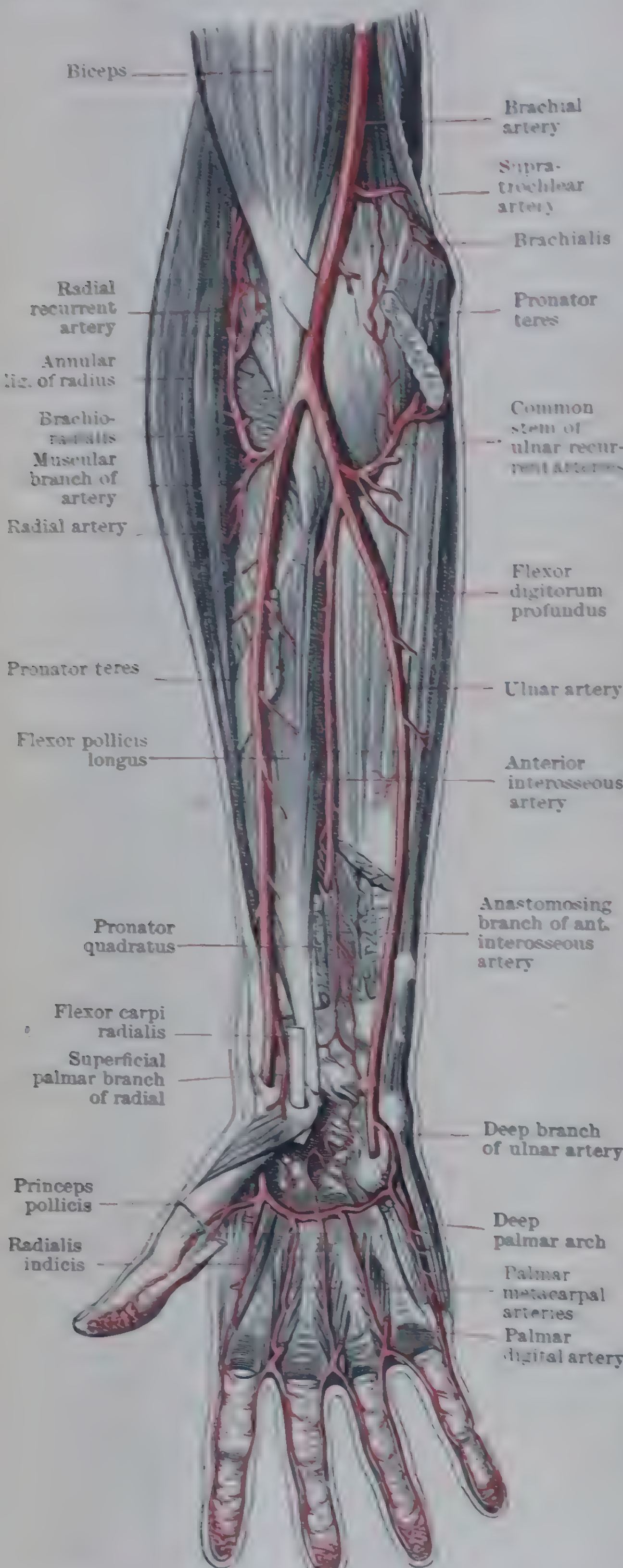

Fig. 1091.—Deep Dissection of Forearm and Hand, showing Radial and Ulnar Arteries and Deep Palmar Arch with its Branches.

Branches of First Part.—Tl **radial recurrent artery** arises in tl cubital fossa, where it springs fro the lateral side of the radial, on tl surface of the supinator. It runs t wards the radial border of the forear passes between the radial nerve and i posterior interosseous branch, and th runs upwards to the lateral epicond of the humerus, where it anastomos with the anterior descending branch the profunda brachii. The radial recu rent supplies numerous branches to t adjacent muscles.

Muscular branches supply t muscles on the radial side of the fo arm.

The **superficial palmar bran** (Fig. 1090) is a slender vessel whi arises a short distance above the wr and runs downwards across the b of the thumb. It usually pierces t superficial muscles of the thenar em ence, and ends either in their substan or by uniting with the ulnar artery complete the *superficial palmar arch.*

An **anterior carpal branch** pas medially, between the synovial shea of the flexor tendons and the rad attachment of the anterior radio-car ligament. It anastomoses with t anterior carpal branch of the ulnar arte to form the *anterior carpal arch*, and receives communications from the a terior interosseous artery and from t deep palmar arch.

Relations of Second Part. As it curves round the radial si and the dorsum of the wrist, the rad artery lies upon the lateral ligame of the wrist, and upon the scaph bone and the trapezium. It is cross by the tendons of the abductor polli longus, the extensor pollicis brevis, a the extensor pollicis longus; more sup ficially it is covered by skin, and fascia, which contains the commenceme of the cephalic vein and some filame of the radial nerve.

Branches of Second Part (F 1092).—The **posterior carpal bran** runs medially on the distal row of t carpus, deep to the extensor tendo and joins the posterior carpal branch the ulnar artery to complete the *poster* *carpal arch.* From the arch three **dorsal metacarpal arteries** run downwards on t second, third, and fourth dorsal interosseous muscles, and divide opposite the heads the metacarpal bones, each into two **dorsal digital arteries** which supply the adjac sides of the fingers and anastomose with the palmar digital arteries.

Two *dorsal digital arteries of the thumb* and a *radial dorsal digital artery of*

r take independent origin from the radial artery; the former run along the dorsal ders of the thumb and anastomose with the palmar digital branches of the princeps cis; the latter, from which the adjacent vessel of the thumb may arise, runs downwards the ulnar head of the first dorsal interosseous muscle to reach the radial border of index finger.

Each dorsal metacarpal artery is connected with the deep palmar arch by a *proximal rating branch* which passes through the proximal part of the corresponding interosseous e, and with a digital branch from the superficial palmar arch by a *distal perforating branch* ch passes through the distal part of the space. The first dorsal metacarpal (which runs on second dorsal interosseous muscle) may arise direct from the radial or in common with the terior carpal branch.

Relations of Third Part.—The third part of the radial artery passes between two heads of the first dorsal interosseous muscle to reach the palm, where it turns dially, deep to the oblique head of the adductor pollicis, and, after passing through proximal fibres of the transverse head, or between the two heads of that muscle, it tes with the deep branch of the ulnar artery, completing the *deep palmar arch*.

Branches of Third Part.—The **princeps pollicis artery** is given off as soon as radial artery enters the palm. It runs downwards, on the palmar aspect of the first tacarpal bone, between the adductor and the opponens pollicis, and under cover of the g flexor tendon. Near the distal end of the bone it divides into two *palmar digital teries*, which run along the sides of the thumb and anastomose with the dorsal digital teries (Pl. LXXXII, p. 1297).

The **radialis indicis artery** is a branch which descends between the ulnar head of the st dorsal interosseous muscle and the adductor pollicis and along the radial side the index finger to its tip. It supplies the adjacent tissues, and not uncommonly it astomoses with the superficial palmar arch.

Variations.—The **radial artery** may be absent, its place being taken by branches of the nar or interosseous arteries. Its origin may be higher than usual, from the axillary, or from e brachial. It may end in muscular branches in the forearm, or as the superficial palmar, or carpal branches; the distal portion of the artery is then usually replaced by branches of the nar or interosseous arteries. Occasionally the radial divides some distance proximal to the ist into two terminal branches, one of which gives off the carpal branches, and becomes e superficial palmar, whilst the other crosses superficial to the extensor tendons and passes to e back of the wrist.

The radial artery may run a superficial course, or, and especially when it arises at a more stal level than usual, it may pass deep to the pronator teres and the radial origin of the flexor gitorum sublimis. Sometimes it passes to the back of the wrist across the brachio-radialis, and may lie superficial to the extensor tendons of the thumb, instead of deep to them.

Its branches may be diminished or increased in number. The radial recurrent may spring om the brachial or ulnar arteries, or may be represented by several branches from the proximal rt of the radial. The radial dorsal digital artery of the index finger may be large, and ay replace the princeps pollicis and the radialis indicis. The posterior carpal branch and rsal metacarpal arteries may be replaced—the former by branches of the interosseous arteries of e forearm, and the latter by the proximal perforating branches of the deep palmar arch.

The princeps pollicis and radialis indicis arteries may be absent, their places being taken ther by branches of the superficial palmar arch or by the radial dorsal digital artery of the dex.

ULNAR ARTERY

The **ulnar artery** (Figs. 1090 and 1091) is the larger terminal branch, but is n less direct line with the brachial artery. It begins in the cubital fossa, pposite the neck of the radius, and ends in the palm of the hand, where it nastomoses with the superficial palmar branch of the radial artery to form the uperficial palmar arch.

From its origin it runs obliquely, downwards and medially, deep to the muscles hat arise from the medial epicondyle, to the junction of the proximal and middle hirds of the forearm, where it comes into relation with the ulnar nerve. It then uns straight, on the radial side of the ulnar nerve, to the wrist, where it passes n to the front of the flexor retinaculum and ends there, at the radial side of the isiform bone, by dividing into its *deep branch* and the *superficial palmar arch* Pl. LXXXII, p. 1297).

Relations—*Posterior.*—In succession it lies in front of the distal part of the brachialis, he flexor digitorum profundus, and the flexor retinaculum. *Anterior.*—It is crossed, in

the oblique part of its course, by the pronator teres, the median nerve (which is separated from the artery by the ulnar head of the pronator teres), the flexor digitorum sublimis the flexor carpi radialis, and the palmaris longus. In the middle third of the forearm it is overlapped by the flexor carpi ulnaris, and in the distal third it is covered by skin and fasciæ only. For a short distance above the wrist the palmar cutaneous branch of the ulnar nerve lies in front of it. On the flexor retinaculum it may be bound down by a fascial slip which passes from the superficial surface of the retinaculum to the pisiform bone and the tendon of the flexor carpi ulnaris. Two communicating venæ comitantes lie one on each side of the artery. On the *radial side* there is also, in its distal two-thirds, the flexor digitorum sublimis. On its *ulnar side* are the flexor carpi ulnaris and the ulnar nerve.

Branches.—The **anterior ulnar recurrent artery** is a small branch which arises in the cubital fossa, frequently in common with the posterior ulnar recurrent. It runs upwards, under cover of the pronator teres, to the front of the medial epicondyle and anastomoses with branches of the supratrochlear artery.

The **posterior ulnar recurrent artery**, larger than the anterior, arises in the cubital fossa from the ulnar side of the ulnar artery; it ascends, on the flexor profundus and under cover of the muscles which arise from the medial epicondyle, to the back of that prominence, where it passes between the humeral and ulnar heads of the flexor carpi ulnaris and anastomoses with the ulnar collateral and supratrochlear arteries. It gives branches to the adjacent muscles and to the elbow joint.

The **common interosseous artery** is a short trunk which springs from the postero-lateral side of the ulnar artery in the distal part of the cubital fossa. It passes backwards towards the proximal border of the interosseous membrane, and divides into anterior and posterior interosseous branches.

The **anterior interosseous artery** runs downwards on the anterior surface of the interosseous membrane, between the adjacent borders of the flexor pollicis longus and the flexor digitorum profundus, to the proximal border of the pronator quadratus, where it pierces the interosseous membrane; it then continues downwards, first on the posterior surface of the membrane, deep to the extensor pollicis longus and extensor indicis, and then on the distal end of the radius, in the groove for the extensor digitorum; and it ends on the back of the carpus by joining the posterior carpal arch. It is accompanied on the front of the interosseous membrane by the anterior interosseous nerve, and on the back of the membrane by an articular filament of the posterior interosseous nerve.

Branches.—It supplies **muscular branches** to the adjacent muscles, and gives *nutrient* branches to the radius and ulna. A slender *communicating* branch passes distally, deep to the pronator quadratus and on the interosseous membrane, to anastomose with the anterior carpal arch. After it has passed to the back of the forearm, it anastomoses with the posterior interosseous artery. The **median artery** is a long, slender branch which arises from the proximal part of the anterior interosseous and runs with the median nerve to the palm, where it anastomoses with recurrent branches of the superficial palmar arch.

The **posterior interosseous artery** is usually smaller than the anterior interosseous. It passes to the back of the forearm between the proximal border of the interosseous membrane and the oblique cord, and then between the supinator and the abductor pollicis longus, after which it descends between the superficial and deep muscles on the back of the forearm giving branches to them. It ends in the distal part of the back of the forearm by dividing into small branches, which anastomose with the anterior interosseous artery and so with the posterior carpal arch. As it crosses the abductor pollicis longus it is accompanied by the posterior interosseous nerve, but in the remainder of its course it is separated from the nerve by the deep muscles.

Branches.—An **interosseous recurrent artery** is given off at the distal border of the supinator. It runs upwards, on the posterior surface of the supinator, under cover of the anconeus, to the back of the lateral epicondyle of the humerus, where it anastomoses with the posterior descending branch of the profunda brachii and with branches of the supratrochlear artery. **Muscular branches** supply the adjacent muscles, and the artery also supplies the skin on the back of the forearm and the wrist.

The **anterior carpal branch** of the ulnar artery is a small branch given off above the flexor retinaculum; it passes towards the radial side, deep to the flexor tendons and their sheaths, on the anterior radio-carpal ligament, and anastomoses with the anterior carpal branch of the radial to form the anterior carpal arch.

The **posterior carpal branch** arises from the ulnar side of the ulnar artery, immediately proximal to the pisiform bone. It passes, deep to the tendons of the flexor and

ensor carpi ulnaris, to the back of the carpus, where it unites with the posterior carpal anch of the radial to form the posterior carpal arch.

The **deep branch of the ulnar artery** descends between the abductor and flexor giti minimi, and, turning wards the radial side, deep the flexor, the opponens, and e long flexor tendons and their eaths, it joins the radial tery to complete the *deep lmar arch.*

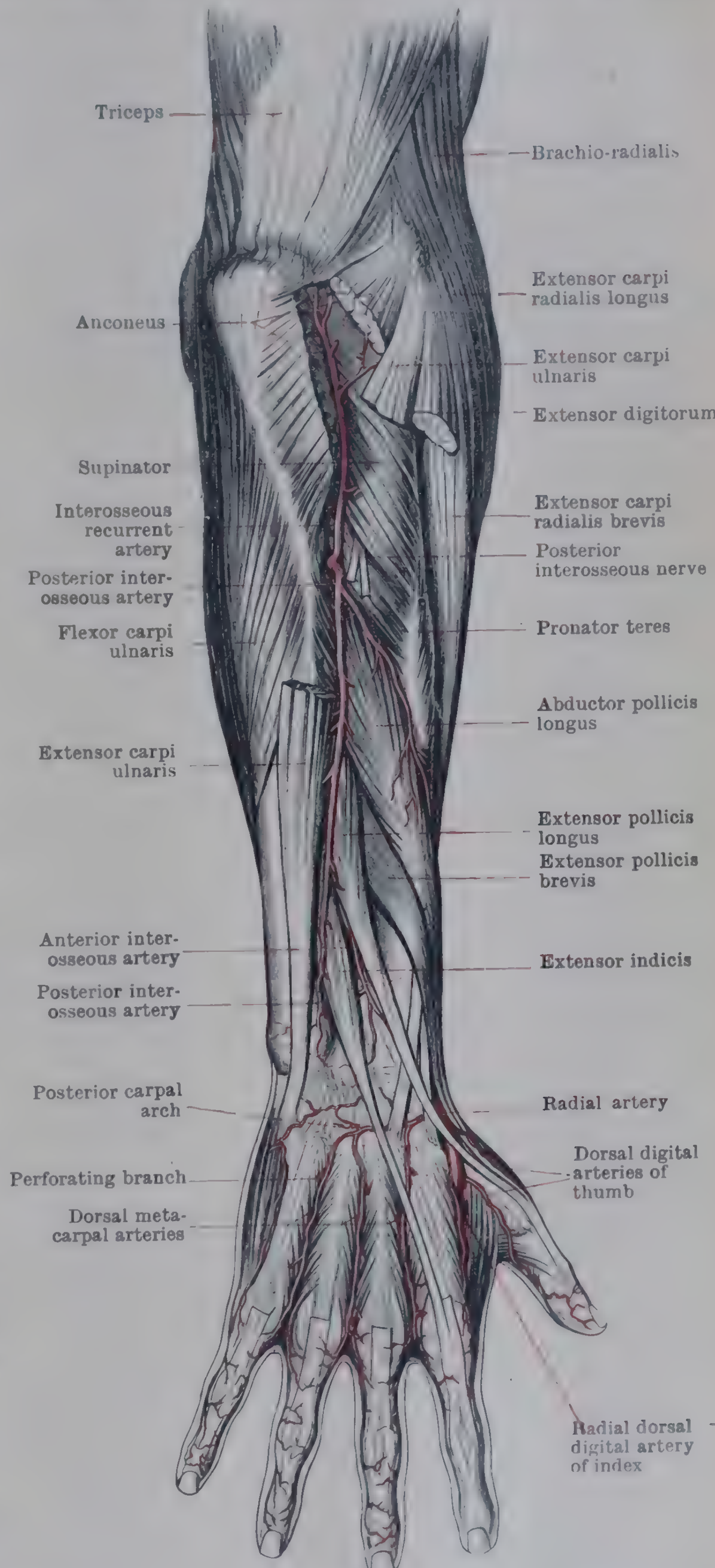

Fig. 1092.—Posterior Interosseous Artery and Second Part of Radial Artery, with their Branches.

Variations.—The **ulnar artery** ay be absent, being replaced by e median artery or the anterior terosseous artery, and it may end the deep palmar arch instead of the superficial. It rarely arises ore distally than usual, and hen it arises higher up it most ommonly passes superficial to the uscles which spring from the edial epicondyle. Moreover, it ien frequently has no interosseous ranch, the latter vessel spring-ng from the radial artery. In xplanation it may be noted that ie anterior interosseous artery is he original continuation of the rachial. Even when it begins at ie usual level the ulnar artery iay pass superficial to the muscles hat arise from the medial epi-ondyle, and its interosseous and ecurrent branches then spring rom the radial artery.

The **interosseous arteries** may rise separately from the ulnar nstead of by a common inter-sseous trunk. The recurrent oranches of the ulnar may spring rom the common interosseous, vhich itself may be a branch of he radial.

The **median artery**—the com-panion artery of the median ierve—usually a branch of the nterior interosseous, may spring from the axillary, brachial, or ulnar rteries; it may be much larger han usual (Pl. LXXXI, p. 1296), ind it may end either by breaking ip into digital arteries or by join-ng one or more digital branches of he superficial palmar arch or the irch itself.

ARTERIAL ARCHES OF WRIST AND HAND

The **anterior carpal arch** (Fig. 1091) lies on the radial attachment of the anterior radio-carpal ligament, deep to the long flexor tendons and their synovial sheaths. It is formed by the union of the anterior carpal branches of the radial and ulnar arteries, and it receives a communicating branch from the anterior interosseous artery and recurrent branches from the deep palmar arch. Branches from it supply the ligaments and synovial membranes of the radio-carpal and intercarpal joints.

The **posterior carpal arch** (Fig. 1092) lies on the back of the distal row of the carpus deep to the extensor tendons and their sheaths. It is formed by the union of the posterior carpal branches of the radial and ulnar arteries, and receives the terminal branches of the anterior and posterior interosseous arteries. It supplies adjacent joints and gives off three **dorsal metacarpal arteries.**

The **superficial palmar arch** (Fig. 1090) is the main terminal branch of the ulnar artery. It extends from the ball of the little finger to the ulnar border of the flexor pollicis brevis, and reaches distally to a line drawn across the palm at the level of the distal border of the fully abducted thumb. It is completed on the radial side by the superficial palmar branch of the radial, or by the radialis indicis or the princeps pollicis artery. It is accompanied by venæ comitantes and it is covered by the skin and superficial fascia and the palmar aponeurosis, and, on the ulnar side of the palm, by the palmaris brevis. It is in contact dorsally with the flexor and opponens digiti minimi, and with the palmar digital branches of the ulnar and median nerves, as well as with the flexor tendons and the lumbrical muscles. It is often irregular in its appearance (Pl. LXXXII, p. 1297).

Branches.—Four **palmar digital arteries** arise from the convex side of the arch. The most ulnar of the four passes along the ulnar border of the little finger, accompanied by a palmar digital branch of the ulnar nerve; the other three pass downwards, each between two flexor tendons and superficial to a palmar digital nerve and a lumbrical muscle, towards the interdigital clefts, where, at the level of the base of the proximal phalanges, it divides into two branches which supply the contiguous sides of the fingers bounding the cleft. As the branches pass along the sides of the fingers they lie behind the corresponding digital nerves and supply branches to the joints, to the flexor tendons and their sheaths, and to the skin and subcutaneous tissues on the palmar surfaces of the fingers; they give off dorsal branches also which anastomose with the dorsal digital arteries and supply the tissues on the dorsal surfaces of the middle and distal phalanges. Some of the dorsally directed branches form a plexus in the matrix of the nail. In the pulp of the finger-tips anastomosing twigs join to form arches from which numerous branches are given off to the skin and subcutaneous fat. For a note on the arterio-venous anastomoses found in the distribution of these arteries, see p. 1246.

Each of the three palmar digital arteries which pass to interdigital clefts is joined, just before it divides, by a palmar metacarpal artery from the deep palmar arch and a distal perforating branch from a dorsal metacarpal artery. The digital artery to the ulnar side of the little finger is joined by a branch which arises either from the medial palmar metacarpal artery or from the deep palmar arch.

The **deep palmar arch** (Fig. 1091) extends from the base of the metacarpal bone of the little finger to the proximal end of the first interosseous space. It is formed by the terminal part of the radial artery and its anastomosis with the deep branch of the ulnar. It is from half to three-quarters of an inch (12 to 18 mm.) proximal to the level of the superficial palmar arch. It lies deeply in the palm, in contact with the proximal ends of the shafts of the metacarpal bones and on the origin of the interossei muscles, and deep to the long flexor tendons and their synovial sheaths.

Branches.—The **palmar metacarpal arteries** are three vessels which pass downwards over the interosseous muscles of the three ulnar interosseous spaces, deep to the flexor tendons. They end by joining the palmar digital arteries immediately before these vessels divide.

Three small **perforating branches** pass backwards through the interosseous spaces, between the heads of the second, third, and fourth dorsal interosseous muscles, and join the dorsal metacarpal arteries.

Small *recurrent branches* pass upwards to join the anterior carpal arch, and other small branches are distributed to the adjacent joints

Variations.—The **superficial palmar arch** is sometimes absent; its branches are then given off from the deep arch. Or it may be larger than usual, and it may be completed on the radial side by the radialis indicis, the princeps pollicis, or the median artery.

The **deep palmar arch** is much more rarely absent than the superficial arch. When absent its branches are supplied by the superficial arch, the proximal perforating branches of the dorsal metacarpal arteries, or the anterior carpal arch.

BRANCHES OF DESCENDING THORACIC AORTA

The branches given off from the descending thoracic aorta are distributed iefly to the walls of the thorax and to the thoracic viscera. They contribute so to the supply of the spinal cord and its membranes, of the vertebral column, d of the upper part of the abdominal wall. The branches, which are numerous d for the most part arranged in pairs, are as follows:—

Visceral
- Bronchial
- Œsophageal
- Pericardial
- Mediastinal

Parietal
- Posterior intercostal
- Subcostal
- Phrenic
- The vas aberrans

Visceral Branches of Descending Thoracic Aorta

The **bronchial arteries** are usually two in number—an upper and a lower— nd both pass to the left lung. The *upper left bronchial artery* arises from the ront of the aorta opposite the fifth thoracic vertebra; the *lower left bronchial rtery* usually takes origin at a slightly lower level. Both vessels are directed ownwards and laterally to the back of the bronchus which they accompany, nd, dividing similarly, they follow its ramifications in the lung. They not only upply the walls of the bronchial tubes and the substance of the lungs, but also ive branches to the broncho-pulmonary lymph-glands, the pulmonary vessels, he pericardium, and the œsophagus. (See also p. 720.)

As a rule there is only one *right bronchial artery*. It arises from the third ight posterior intercostal artery (*i.e.*, the first right intercostal branch of the aorta) fter that artery has crossed behind the œsophagus; and in its course and distribution it corresponds to the bronchial arteries of the left side. It may, however, rise from the upper left bronchial artery or, more rarely, directly from the aorta.

Variations.—The **bronchial arteries** obviously correspond to splanchnic arteries and their continuations to diverticula from the walls of the gut; therefore the usual origin of the right bronchial artery must result from the persistence of an anastomosis between a splanchnic artery and the first part of a somatic intersegmental artery; the origin of the right from the upper left bronchial artery, which sometimes occurs, is due to the fusion of the roots of two splanchnic arteries. The occasional origin of a bronchial vessel from an internal mammary artery can result only from the persistence and enlargement of an anastomosis between a splanchnic artery and the ventral branch of a somatic segmental artery. The origin of a bronchial branch from a subclavian artery may have the same or a different significance on opposite sides of the body. A bronchial artery which arises from the left subclavian artery corresponds with the origin of the right bronchial artery from the third right posterior intercostal artery; it is due to the persistence of an anastomosis between a splanchnic artery and the root of a somatic intersegmental artery. The origin of a bronchial artery from a right subclavian artery may be due to a similar cause; it may, on the other hand, be due to the enlargement of an anastomosis between a splanchnic branch of the descending aorta and a splanchnic branch of the fourth right aortic arch. A bronchial artery occasionally arises from the inferior thyroid; that is due to the persistence and enlargement of an anastomosis between splanchnic arteries.

Nakamura (1924) has analysed the variations in the origin of the bronchial arteries; Berry, Brailsford & Daly (1931) surveyed the problem of anastomoses between pulmonary and bronchial vessels from the historical point of view; Berry (1935), using injection methods, found no anastomoses between pulmonary and bronchial arteries; but Hudson, Moritz & Wearn (1932) have shown that there are numerous anastomoses between the bronchial and other arteries, including the coronary arteries of the heart. See also the reference to the subpleural plexus of Turner on p. 1280.

The **œsophageal branches** are usually four or five small branches that spring from the front of the aorta and pass forwards to the œsophagus, in the walls of which they ramify, anastomosing above with branches of the left bronchial and inferior thyroid arteries, and below with œsophageal branches of the left gastric and the phrenic arteries.

The **pericardial branches** are three or four small irregular vessels which are distributed on the surface of the pericardium.

Small **mediastinal branches** pass to the fatty areolar tissue and the lymph-glands in the posterior mediastinum.

Parietal Branches of Descending Thoracic Aorta

Posterior Intercostal Arteries.—Nine pairs of posterior intercostal art (III-XI) arise from the back of the aorta—usually separately but, not commonly, a pair may take origin by a common trunk. They are distribute the lower nine intercostal spaces, to the vertebral column, to the contents of vertebral canal, and to the muscles and skin of the back. The first three on side give branches to the mammary gland also. The arteries of opposite closely correspond, but, since the upper part of the descending thoracic lies on the left of the vertebral column, most of the right posterior in costal arteries cross the front of the column, behind the œsophagus, the tho duct, and the vena azygos, and are longer than the left arteries. In other res the course of each artery is almost identical. As each artery runs backw and laterally, across the side of the vertebral column, to an intercostal spa passes behind the pleura, and is crossed by the sympathetic trunk. The l arteries are crossed by the splanchnic nerves also, and those on the left side crossed by the superior or inferior hemiazygos vein.

As each artery passes laterally, between the necks of two adjacent ribs, it asc to the upper border of the space to which it belongs, and, passing either behi in front of the corresponding intercostal nerve, reaches the angle of the r rib where it enters the costal groove, in which it is continued along the space. the space, as far as the angle of the rib, it lies between the pleura and the post intercostal membrane. Then it is continued forwards between the innermost i costal and the internal intercostal muscles (see p. 448). In the costal groove artery lies between the corresponding vein above and the intercostal nerve be and it ends by anastomosing with an anterior intercostal branch of the inte mammary or of the musculo-phrenic artery. The lower two posterior interc arteries, on each side, extend beyond their spaces into the abdominal wall, anastomose with branches of the superior epigastric, subcostal and lumbar arte The first right intercostal branch of the aorta (posterior intercostal artery frequently gives off the right bronchial artery.

Branches.—The **posterior branch** arises as the intercostal artery reaches the passes backwards, between the necks of the ribs which bound the space, medial to superior costo-transverse ligament, and then, accompanied by the posterior primary r of a spinal nerve, between the adjacent transverse processes, to the vertebral groove, w it divides into medial and lateral terminal branches. The medial branch passes backw and medially, either over or through the multifidus, giving branches to the muscles bet which it passes and to the vertebral column. The lateral branch runs laterally u cover of the longissimus thoracis to the interval between it and the costalis. *Mus branches* supply the muscles and *cutaneous branches* pass to the skin of the back. *spinal branch* passes through the corresponding intervertebral foramen, and enters vertebral canal, to the contents and walls of which it is distributed. Twigs from the s branches run medially, on the roots of the spinal nerve, to supply the membranes c spinal cord and reinforce the anterior and posterior spinal arteries. Others anast with twigs from adjacent arteries on the backs of the bodies of the vertebræ to a series of vertical arches connected by short transverse anastomoses; from anastomosing arteries branches of supply enter the bodies of the vertebræ through vascular foramina. Similar though less regular anastomoses are formed on the pos wall of the vertebral canal, and they assist in the supply of the laminæ, articular proc and the roots of the spines of the vertebræ (p. 1388, and Fig. 1147).

A **collateral branch** arises near the angle of the rib. It descends and forwards along the lower border of the intercostal space, to anastomose in front wi anterior intercostal branch of the internal mammary or musculo-phrenic artery. collateral branches of the lower two intercostal arteries, on each side, are incons when present they are small, and end in the abdominal wall.

Several **nutrient branches** supply the rib above, and **muscular branches** to the adj muscles are given off by both the main trunk and its collateral branch.

A **lateral cutaneous** branch accompanies the lateral cutaneous branch of the costal nerve. Those of the third, fourth, and fifth spaces give a ***mammary branch*** t mammary gland; these branches anastomose with branches of the lateral thoracic internal mammary arteries.

In addition to the secondary branches above named, the trunk of the third posterior rcostal artery anastomoses with the superior intercostal, and may supply the whole he greater part of the second intercostal space. Longitudinal anastomoses between acent trunks and also between adjacent posterior branches of posterior intercostal eries sometimes exist near the necks of the ribs, or near the transverse processes.

The **subcostal arteries** are in series with the posterior intercostal arteries, l are distributed in the same manner. The trunk runs along the lower border the twelfth rib in company with the subcostal nerve. It passes below the eral arcuate ligament to the abdomen, and there crosses in front of the quadratus nborum, and behind the kidney. It next pierces the aponeurosis of origin of the nsversus abdominis, and runs between the transversus and the internal oblique scles, anastomosing with the lower intercostal arteries, with the lumbar arteries, d with branches of the superior epigastric artery.

Variations.—Variations of the **posterior intercostal arteries** are not very common, but they significant and interesting. Corresponding vessels of opposite sides may arise from a mon stem which has been formed by the fusion of the roots of two somatic intersegmental eries after or simultaneously with the fusion of the primitive dorsal aortæ. The number of ercostal arteries may be reduced, one artery supplying two or more intercostal spaces; in such es the roots of origin of some of the somatic intersegmental arteries in the thoracic region ve disappeared, and the precostal anastomoses between their ventral branches have persisted. Occasionally the number of the intercostal arteries is increased, an additional artery being en to the second intercostal space, which is usually supplied by the superior intercostal ery; that is brought about by the persistence of the root of the tenth somatic intersegmental ery and the disappearance of the precostal anastomosis between the ventral branches of the th and tenth somatic intersegmental arteries. Very rarely the third posterior intercostal ery sends a branch upwards between the necks of the ribs and the transverse processes of the per thoracic region; that branch supplies the upper intercostal spaces, the superior intercostal ery being small or absent, and it ends by becoming the deep cervical artery. It is due to persistence of the postcostal anastomoses in the upper thoracic region, and is a repetition of a ndition regularly present in some carnivores.

Phrenic branches are given off from the lower part of the thoracic aorta. They e small vessels which ramify on the upper and posterior surfaces of the diaphragm, d anastomose with the pericardiaco-phrenic and musculo-phrenic branches of the ternal mammary arteries.

The **vas aberrans** is a variable and inconstant branch of the thoracic aorta; represents the dorsal roots of the fourth and sixth right aortic arches of the nbryo. When present it arises from the front and right side of the upper part of e descending aorta near the upper left bronchial artery, and passes upwards and the right behind the œsophagus; it frequently anastomoses with the right perior intercostal artery, and it may be enlarged and form the first part of e right subclavian artery.

BRANCHES OF ABDOMINAL AORTA

The branches of the abdominal portion of the aorta are distributed almost ntirely to the walls and contents of the abdominal cavity, but some supply nall branches to the vertebral column and to the contents of the vertebral canal, nd others are prolonged into the true pelvis. They are divisible into visceral nd parietal groups, both of which include paired and single (unpaired) vessels.

Visceral	**Paired**	Suprarenal
		Renal
		Testicular or Ovarian
	Single	Cœliac
		Superior mesenteric
		Inferior mesenteric
Parietal	**Paired**	Phrenic
		Lumbar
		Common iliac
	Single	Median sacral

Paired Visceral Branches of Abdominal Aorta

There are three pairs of **suprarenal arteries**—the superior, middle, and inferior. Of these only the middle arise directly from the aorta; the superior spring from he phrenic arteries, and the inferior from the renal arteries.

The **middle suprarenal arteries** are a pair of small branches which arise, behind the pancreas, from the sides of the aorta, close to the origin of the superior mesenteric artery. They run, one on each side, laterally and upwards, upon the crura of the diaphragm just above the renal arteries, to the suprarenal glands, to which they are distributed. They anastomose with the superior and inferior suprarenal arteries.

The **renal arteries** (Fig. 1096) arise, one on each side, from the aorta, about half an inch below the origin of the superior mesenteric artery and opposite the second lumbar vertebra.

Both arteries, on account of the functional nature of the kidneys, are of large size, and the right is frequently slightly lower in position than the left. Each artery runs almost transversely to the hilum of the corresponding kidney. It passes anterior to the crus of the diaphragm and the psoas muscle. The left artery lies posterior to the pancreas; the right vessel passes behind the inferior vena cava, the head of the pancreas, and the second part of the duodenum. The renal vein usually lies below and anterior to the artery, but near the kidney the vein not infrequently occupies a posterior position.

On reaching the hilum of the kidney each artery divides into three branches, two of which pass in front of the pelvis of the ureter and between it and the renal vein, and the third behind the pelvis. In the renal sinus these primary branches break up into numerous secondary branches which enter the kidney substance between the pyramids. Their intimate distribution is described on p. 735.

Branches.—Each renal artery gives off small **ureteric branches to the upper part of the ureter, which anastomose with branches of the testicular or ovarian arteries,** and an **inferior suprarenal artery, which passes upwards to the lower part of the suprarenal gland.**

Small branches, which anastomose with the lumbar arteries, are also given to the aortic **lymph-glands and to the renal fat.**

Variations.—The **renal arteries** frequently deviate from the normal arrangement. They may spring from a common stem, or there may be two or more renal arteries on one or both sides. The *accessory arteries* are more common on the left than on the right side, and an accessory artery arising below the ordinary vessel is more common than one arising above it.

Accessory renal arteries may be derived not only from the aorta, but also from the common iliac or internal iliac arteries; they have been described as arising also from the phrenic, testicular, lumbar, and median sacral arteries, and even from the external iliac artery. As the kidney is developed in the region of the first sacral vertebra, and afterwards ascends to its permanent position, it is not surprising that it occasionally receives arteries from the main stem of more than one of the segments of the body through which it has passed, and it is usually found that the lower the position of the kidney in the abdomen the more likely it is to receive its arteries from the lower part of the aorta or from the common iliac arteries. The accessory renal arteries which spring from the phrenic, the testicular, and lumbar arteries can only be the result of the persistence and enlargement of anastomosing channels between the renal and either another intermediate visceral artery, or a somatic artery.

The **testicular** or **ovarian arteries** are long, slender vessels which spring from the front of the aorta a short distance below the origins of the renal arteries.

Each **testicular artery** runs downwards, on the anterior surface of the psoas major, to the deep inguinal ring, where it comes into relation with the vas deferens. It accompanies the vas deferens through the inguinal canal into the scrotum to supply the testis.

Relations.—*Posterior.*—The right artery passes in front of the inferior vena cava, and as each artery descends, on the anterior surface of the psoas major, it passes in front of the corresponding genito-femoral nerve and ureter, and the lower part of the external iliac artery.

Anterior.—Each artery is in relation anteriorly with the peritoneum; but crossing in front of the right artery and intervening between it and the peritoneum are the third part of the duodenum, the right colic and the ileo-colic vessels, and the lower parts of the superior mesenteric vessels; and the cæcum may overlap it. Crossing anterior to the left artery are the superior and inferior left colic vessels and the terminal part of the descending colon.

In the lower part of the abdominal portion of its course each testicular artery is accompanied by two veins which issue from the pampiniform plexus in the inguinal canal and enter the abdomen through the deep inguinal ring, but at a higher level the two veins fuse into a single stem which is usually lateral to the artery.

As it approaches the inguinal canal each testicular artery passes in front of the lower

PLATE LXXXI

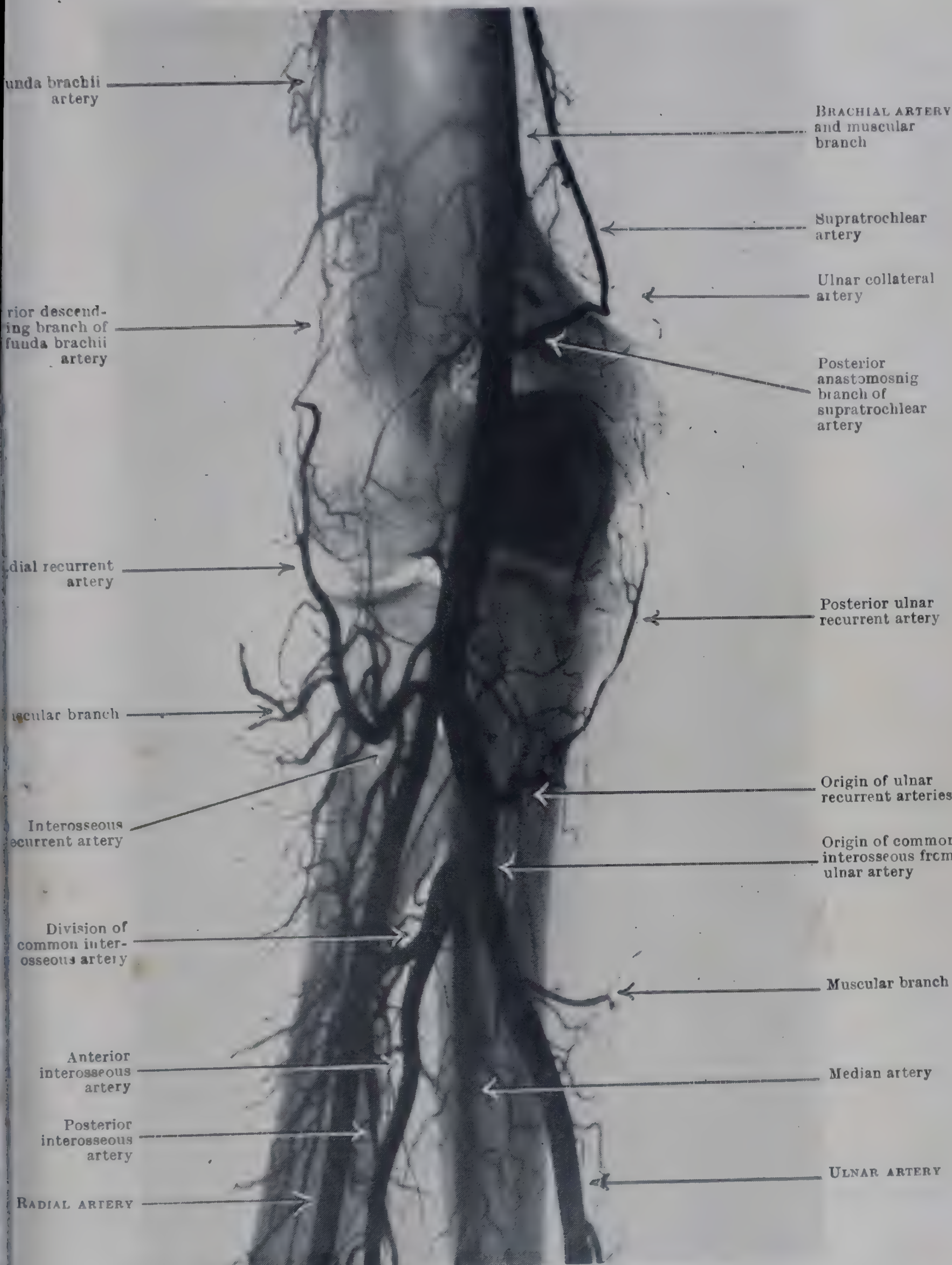

Plate LXXXI.—Radiograph of Elbow Region after radio-opaque injection of the Arteries (from positive print).

Cf. Fig. 1089, p. 1286. The median artery (p. 1291) is larger than usual.

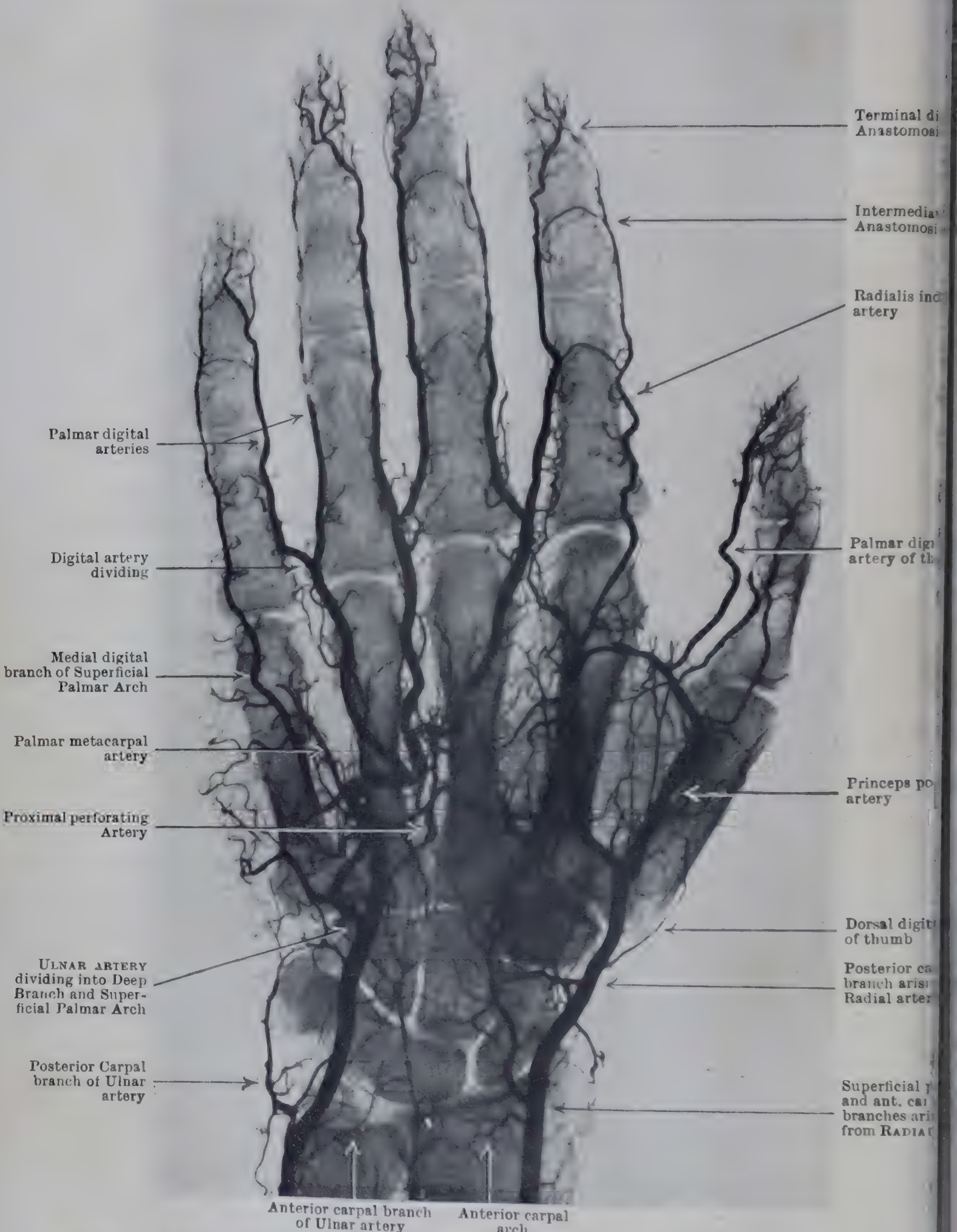

PLATE LXXXII.—RADIOGRAPH OF HAND AFTER RADIO-OPAQUE INJECTION OF THE ARTERIES (from positive print).

Cf. Figs. 1090-1092, pp. 1287-1291. The superficial palmar arch is irregular and appears to be completed by a branch of the princeps pollicis artery (see p. 1292).

end of the external iliac artery; and as it runs downwards and medially, in the canal, it is accompanied by the vas deferens, and is more or less enclosed in the meshes of the pampiniform venous plexus. At the lower end of the canal it passes through the superficial inguinal ring and descends to the scrotum, lying antero-lateral to the vas deferens and in close association with the anterior group of testicular veins. At the upper end of the testis it breaks up into branches, some of which are distributed to the testis and others to the epididymis. It anastomoses with the artery to the vas deferens and the cremasteric artery. (For details, see p. 756.)

Branches.—In the abdominal part of its course each testicular artery gives off **ureteric branches** to the abdominal part of the ureter, and twigs to the perirenal fat, the peritoneum, and the aortic lymph-glands.

The course and the relations of each **ovarian artery**, as far as the external iliac artery, are the same as the relations of the corresponding testicular artery; but it then turns medially to enter the true pelvis by crossing the external iliac vessels an inch below the origin of the artery, and passes between the layers of the infundibulo-pelvic ligament to reach the broad ligament of the uterus. In the broad ligament it runs medially, below the uterine tube, to the level of the ovary. There it turns backwards and passes into the mesovarium, where it breaks up into terminal branches which enter the ovary through the hilum in its anterior border. As it lies in the broad ligament each ovarian artery is accompanied by the pampiniform plexus of ovarian veins. In the lower portion of the abdominal part of its course it is accompanied by two veins which issue from the pampiniform plexus at the brim of the true pelvis and unite at a higher level into a single trunk.

Branches.—In the abdominal part of its course the branches of the ovarian artery are the same as those of the testicular artery.

In the pelvic part of its course it gives branches which supply the uterine tube, the round ligament of the uterus, and anastomose with the uterine artery.

Variations.—The **testicular** or **ovarian arteries** may be double on one or both sides; the arteries of the two sides may spring from a common trunk, or each may arise from the renal, accessory renal, or suprarenal artery. The right artery may pass behind the inferior vena cava instead of in front of it. The testicular and ovarian arteries arise from the upper lumbar portion of the aorta, because the testes and ovaries are developed in and obtain their arterial supply in that region, and the vessels are elongated as the testes and ovaries descend to their permanent positions.

Single Visceral Branches of Abdominal Aorta

The **cœliac artery** (Figs. 1093 and 1096) arises from the front of the abdominal aorta, immediately below the aortic orifice of the diaphragm and between its crura. It is a short but wide vessel which runs almost horizontally forwards, below the caudate lobe of the liver, for a distance of about half an inch (12 mm.). It ends by dividing into three branches—the left gastric, the hepatic, and the splenic.

Relations.—The trunk lies behind the lesser sac of the peritoneum below the caudate lobe of the liver and above the upper border of the pancreas and the splenic vein. It is surrounded by the cœliac plexus of nerves.

Branches.—The **left gastric** is the smallest branch of the cœliac artery. It runs obliquely upwards and to the left, and reaches the lesser curvature of the stomach close to the œsophagus. It then turns sharply forwards, downwards, and to the right, and runs towards the pyloric end of the stomach to anastomose with the right gastric branch of the hepatic artery. In the first part of its course the artery lies on the left crus behind the lesser sac; it then curves over the upper border of the lesser sac (between the layers of the left gastro-pancreatic fold when that fold of peritoneum is present), and is continued between the layers of the lesser omentum.

When the left gastric artery reaches the stomach it gives off **œsophageal branches** which pass upwards on the œsophagus to anastomose with œsophageal branches of the thoracic aorta and with the phrenic artery. On the lesser curvature it often divides into two parallel vessels from which branches are distributed to both surfaces of the stomach. They anastomose with the short gastric branches of the splenic artery, and with branches of the gastro-epiploic arterial arch on the greater curvature of the stomach.

The **splenic artery** (Fig. 1093) is the largest branch of the cœliac artery. Accompanied by the splenic vein, which lies below it, it runs a tortuous course behind the stomach and the lesser sac of peritoneum along the upper border of the pancreas. It lies in front of the left suprarenal gland and the upper part of the left kidney, and passes forwards between the two layers of the lieno-renal ligament, in which it divides into five to eight terminal **splenic branches** which enter the hilum of the spleen and supply the splenic substance. For the peculiarities of the distribution of these branches, see p. 831 and Fig. 718.

Branches.—Numerous small **pancreatic** branches are given off to the pancreas. A larger branch (*pancreatica magna*), occasionally present, enters the upper border of the pancreas, about the junction of its middle and left thirds, and runs from left to right in the substance of the pancreas, a little above and posterior to the pancreatic duct. The pancreatic branches anastomose with one another and with branches of the pancreatico-duodenal arteries.

The **short gastric arteries**, four or five in number, are given off either from the end of the splenic artery or, more commonly, from some of its terminal branches. They

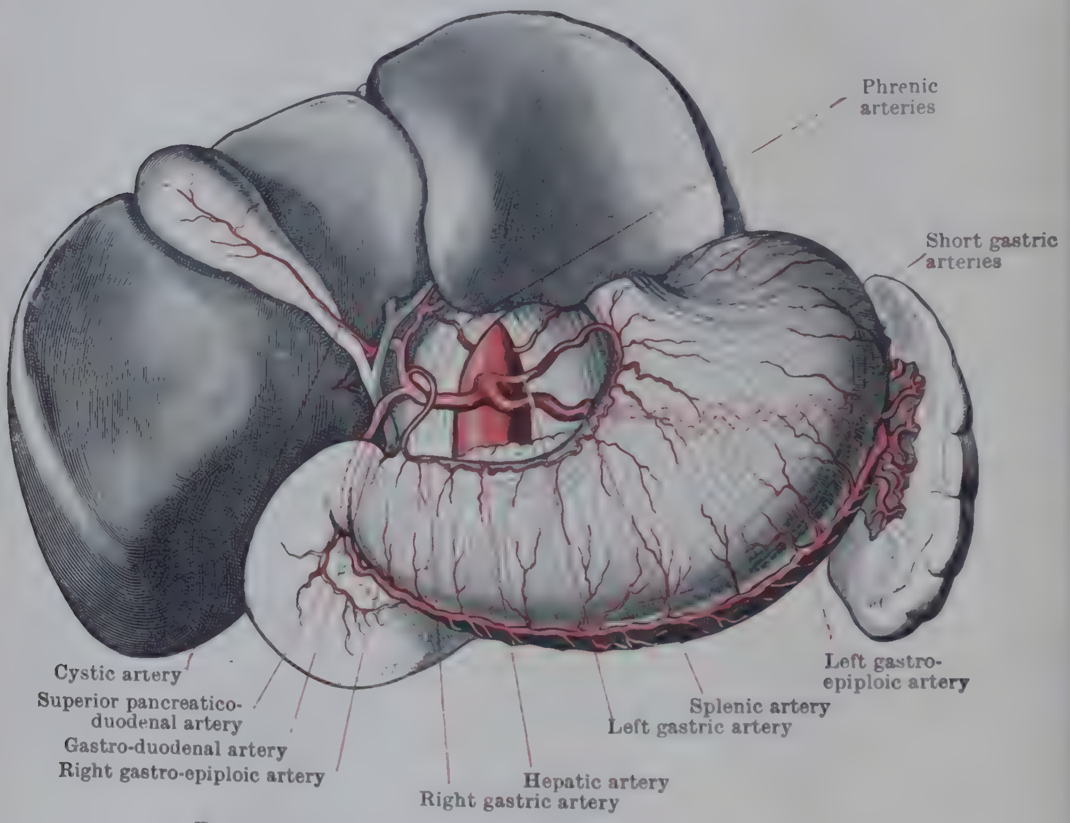

Fig. 1093.—Cœliac Artery and its Branches.

pass between the layers of the gastro-splenic ligament to the left part of the greater curvature of the stomach, and anastomose with the œsophageal, the left gastric, and the left gastro-epiploic arteries.

The **left gastro-epiploic artery** arises from the splenic, or from one of its terminal branches, and passes forwards, between the layers of the gastro-splenic ligament, to the left end of the lower part of the greater curvature of the stomach, along which it is continued, from left to right, between the anterior two layers of the greater omentum. It ends by anastomosing with the right gastro-epiploic artery. It gives off numerous branches to both surfaces of the stomach; they anastomose with the short gastric and with branches of the left and right gastric arteries. Long, slender *omental branches* pass to the omentum.

The **hepatic artery** (Fig. 1093) runs along the upper border of the head of the pancreas to the upper border of the first part of the duodenum, where it enters the lesser omentum and ascends between its layers at its free margin. In the omentum it is in front of the portal vein and to the left of the bile-duct, and near the porta hepatis it divides into right and left terminal branches.

Branches.—The **gastro-duodenal artery** arises as soon as the hepatic reaches the first part of the duodenum, descends behind it and ends opposite its lower border. In its course it lies between the neck of the pancreas and the first part of the duodenum, and anterior to the portal vein. The bile-duct is on its right side. The vessel ends by dividing into the right gastro-epiploic and superior pancreatico-duodenal arteries. The **right gastro-epiploic artery** is the larger; it passes from right to left, along the greater curvature of the stomach, between the anterior layers of the greater omentum, and unites with the left gastro-epiploic branch of the splenic artery. From the arterial arch so formed, branches pass upwards on both surfaces of the stomach to anastomose with branches of the right and left gastric arteries. *Omental branches* pass downwards in the greater omentum. The **superior pancreatico-duodenal artery** runs a short course to the right, between the duodenum and the head of the pancreas, and divides into anterior and posterior terminal branches, which descend, the former in front of and the latter behind the head of the pancreas, to anastomose with similar branches of the inferior pancreatico-duodenal artery. They supply the head of the pancreas, anastomosing in it with the pancreatic branches of the splenic artery; branches are given also to the second part of the duodenum and to the bile-duct.

The **right gastric artery** is a small branch which arises as the hepatic enters the lesser omentum. It runs between the layers of the lesser omentum to the pylorus, and then along the lesser curvature of the stomach. It gives branches to both surfaces of the stomach and ends by anastomosing with the left gastric artery. It also gives a branch to the first part of the duodenum.

Terminal Branches.—The **right branch** passes, either in front of or behind the common hepatic duct and behind the cystic duct, to the right end of the porta hepatis; there, it divides into two or more branches which enter the substance of the liver and accompany the branches of the portal vein and the hepatic duct. As it crosses the junction of the hepatic and cystic ducts, the right branch gives off the cystic artery. The **cystic artery** runs downwards and forwards, along the cystic duct, to the gall-bladder, where it divides into anterior and posterior branches; the anterior passes downwards between the gall-bladder and the visceral surface of the liver, to both of which it gives offsets; the posterior branch is distributed on the posterior surface of the gall-bladder, and lies between it and the peritoneum. The **left branch** is longer and narrower than the right. It runs to the left end of the porta hepatis, gives branches to the caudate and quadrate lobes, crosses the fissure for the ligamentum teres, and breaks up into branches which terminate in the substance of the left lobe of the liver.

Variations.—The **cœliac artery** may be absent, its branches arising separately from the aorta or from some other source. Sometimes it gives off only two branches, usually the left gastric and splenic, and occasionally it gives four branches, the additional branch being either a second left gastric artery or a separate gastro-duodenal artery. The **left gastric artery** is occasionally double; it may spring directly from the aorta, and it may give off the left hepatic or an accessory hepatic artery. The **splenic artery** may arise from the middle colic, from the left hepatic, or from the superior or inferior mesenteric artery. The **hepatic artery** may spring directly from the aorta or from the superior mesenteric artery; the left hepatic artery, or an accessory hepatic artery, arises occasionally from the left gastric artery and runs to the liver in the upper part of the lesser omentum. Other accessory hepatic arteries are not uncommon, and they originate either from the superior mesenteric, renal, or inferior mesenteric artery. (For these variations, consult Flint, 1923 and Petrén, 1929.)

The **superior mesenteric artery** (Figs. 1094, 1095, 1096) springs from the front of the aorta, about half an inch (12 mm.) below the origin of the cœliac artery and opposite the first lumbar vertebra.

It passes obliquely downwards and forwards, crossing anterior to the left renal vein, the uncinate process of the head of the pancreas, and the third part of the duodenum; on the duodenum it enters the root of the mesentery, in which it continues to descend, curving obliquely from above downwards and to the right, to the right iliac fossa, and crossing, in this part of its course, in front of the aorta, the inferior vena cava, the right ureter, and the right psoas major muscle. At its origin it lies behind the pancreas and the splenic vein; where it passes in front of the duodenum it is crossed in front by the transverse colon; and in the lower part of its extent it is behind the coils of small intestine. The superior mesenteric vein runs along its right side. It ends by anastomosing with the ileo-colic artery.

Branches.—The branches of the superior mesenteric artery supply the duodenum and the pancreas in part, the whole of the small intestine below the duodenum, and the large intestine nearly as far as the left colic flexure.

The **inferior pancreatico-duodenal artery** arises either from the trunk of the superior mesenteric, at the upper border of the third part of the duodenum, or from the first

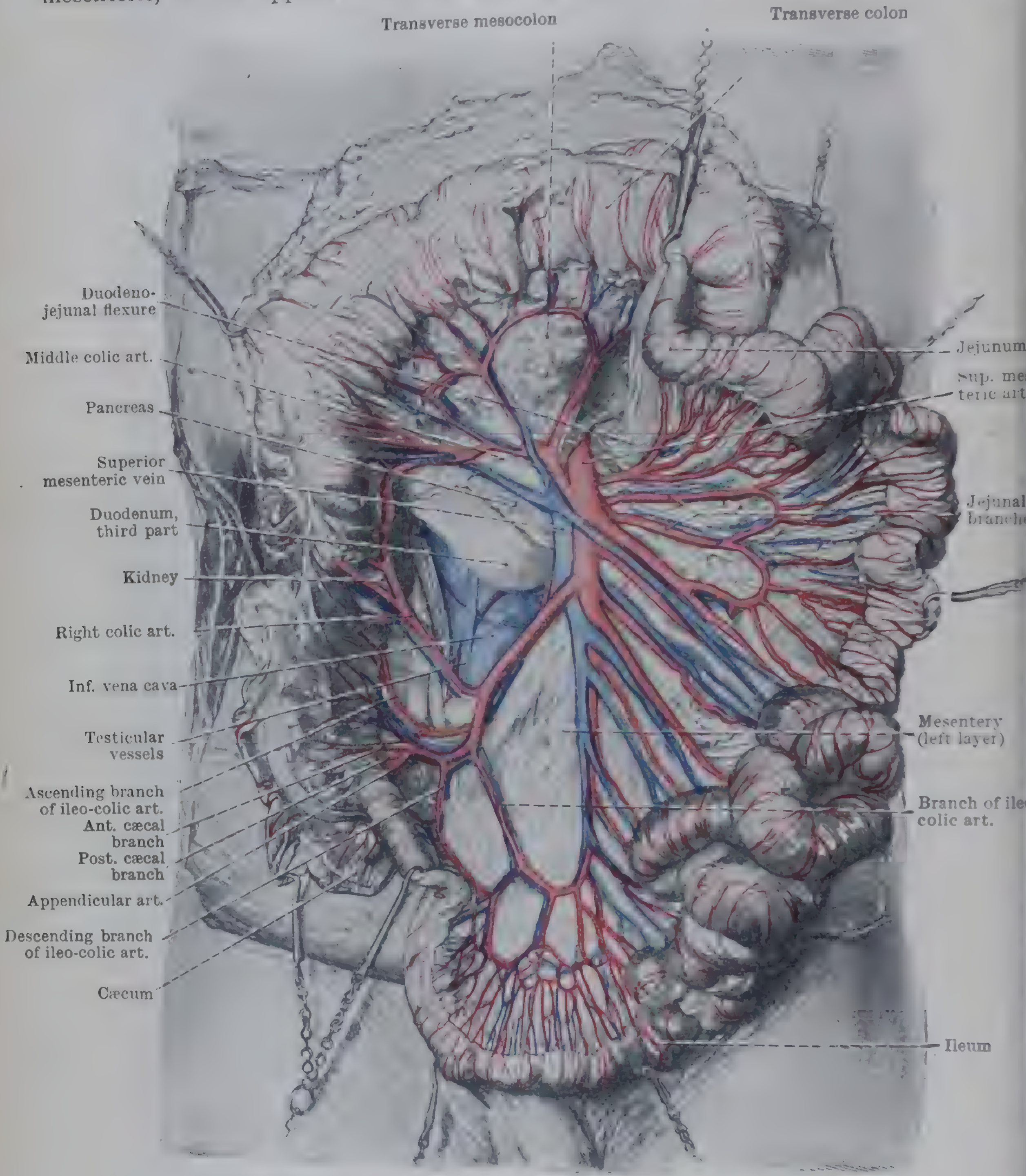

FIG. 1094.—SUPERIOR MESENTERIC ARTERY AND ITS BRANCHES.

Note the difference in the number and arrangement of the loops formed by the jejunal as contrasted with the ileal branches, that the right colic and ileo-colic arteries arise by a common trunk, and that the terminal branches of the ileo-colic are irregular.

jejunal branch. It runs to the right, between the head of the pancreas and the third part of the duodenum, and ends by dividing into two branches, anterior and posterior, which ascend, the former in front of the head of the pancreas, the latter behind it; they supply the head of the pancreas and the duodenum, and they anastomose with the similar branches of the superior pancreatico-duodenal artery.

The branches to the small intestine, varying from ten to sixteen in number, are separable into two groups—**jejunal** and **ileal**. They spring from the convexity of the superior mesenteric artery and pass obliquely forwards and downwards, between the layers of the mesentery, each dividing into two branches which anastomose with

djacent arteries to form a series of arcades from which secondary branches are given ff. The upper jejunal branches form only one or two arches, but the process of division nd union is repeated three or four times in the case of the ileal branches; thus four or ive tiers of arches are formed, in the longer, lower part of the mesentery. The branches rom the terminal arcades pass to the wall of the gut, generally to one or other side, but ccasionally a terminal branch divides and passes to both sides. According to Cokkinis (1930) the terminal branches from any one terminal arcade neither anastomose with one another nor with the branches of adjacent terminal arcades, but Ross (1947; 1950) and Doran (1950) have shown, by means of corrosion preparations, that they do in fact anastomose in the wall of the gut; these terminal branches can therefore no longer be regarded as "end-arteries". Branches from the successive arcades are given off also to the mesenteric lymph-glands.

The **ileo-colic artery** arises by a common trunk with the right colic, or separately lower down from the right side of the superior mesenteric, and passes downwards and to the right, behind the peritoneum either in front of or behind the superior mesenteric vein, towards the lower part of the ascending colon. It ends by dividing into an ascending branch which anastomoses with the lower branch of the right colic, and a descending branch which supplies the lower part of the ascending colon, sends branches to the front and back of the cæcum, gives off the appendicular artery, and ends in a branch to the lower part of the ileum which anastomoses with the end of the superior mesenteric trunk.

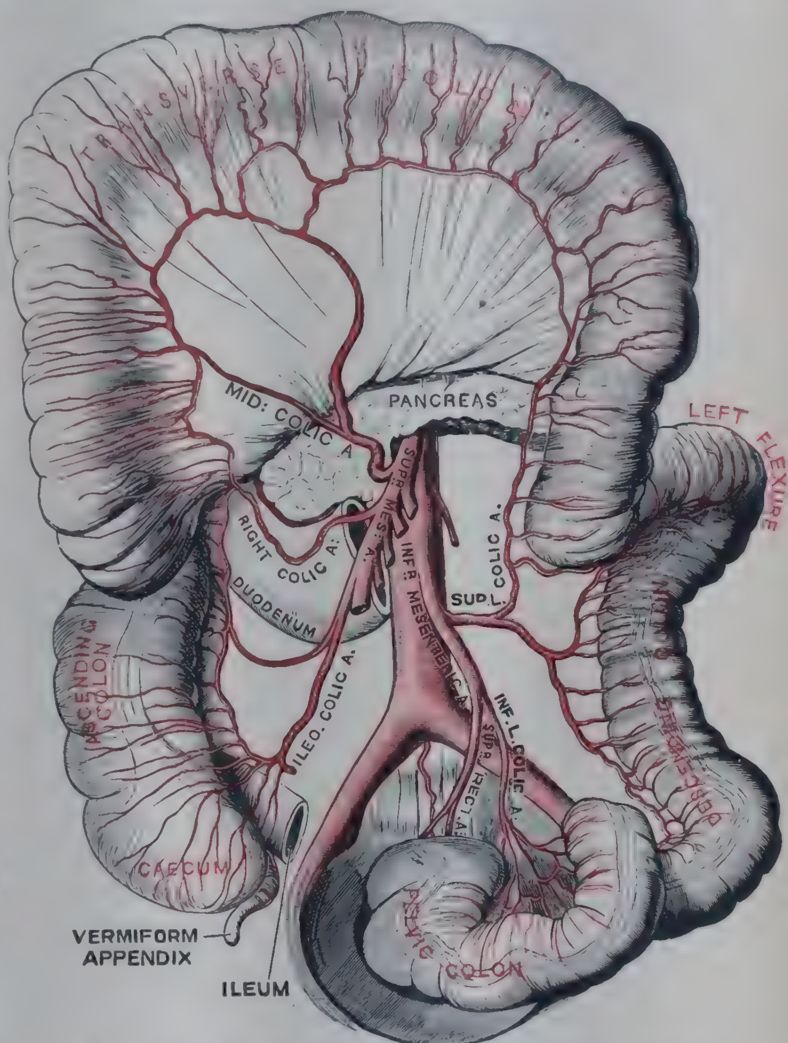

FIG. 1095.—DISTRIBUTION OF SUPERIOR AND INFERIOR MESENTERIC ARTERIES.

There are usually two inferior left colic arteries.

The *anterior cæcal* branch passes across the front of the ileo-colic junction in the fold of peritoneum called the vascular fold of the cæcum; the *posterior cæcal* branch crosses the back of the ileo-colic junction. The **appendicular artery** passes behind the terminal part of the ileum into the mesentery of the vermiform appendix; it runs near the free margin of the mesentery to the tip of the appendix and gives off a series of short branches which supply the apex of the cæcum and the appendix from its root to its tip.

The **right colic artery** springs from the right side of the superior mesenteric, either alone as the superior mesenteric crosses the duodenum (Fig. 1095), or below the duodenum in the form of a common trunk which divides into right colic and ileo-colic branches (Fig. 1094). It runs to the right, behind the peritoneum on the posterior wall of the abdomen, and in front of the right psoas major, the ureter, and the testicular or ovarian vessels, towards the ascending colon, near which it divides into an ascending and a descending branch. The former passes upwards, and anastomoses, in the transverse mesocolon, with the middle colic artery; the latter descends to anastomose with the upper branch of the ileo-colic. From the loops thus formed branches are distributed to the ascending colon and the beginning of the transverse colon.

The **middle colic artery** is a large branch which springs from the front of the superior mesenteric as it escapes from behind the pancreas. It runs downwards and forwards, in the transverse mesocolon, and ends by dividing into two branches which

anastomose with the right and left colic arteries, forming arcades. Secondary and tertiary loops are sometimes formed and the terminal branches are distributed to the transverse colon.

Variations.—The **superior mesenteric artery** may be double, and it may supply the whole of the alimentary canal from the second part of the duodenum to the end of the rectum, the inferior mesenteric artery being absent. In addition to its ordinary branches it may give off a hepatic, a splenic, a pancreatic, a gastric, a gastro-epiploic, or a gastro-duodenal branch.

The **inferior mesenteric artery** (Figs. 1095, 1096) arises from the front of the aorta towards the left side, about $1\frac{1}{2}$ inches (3-4 cm.) above the bifurcation; it passes downwards and slightly to the left, lying behind the peritoneum and in front of the aorta, and then on its left side in front of the left psoas major muscle, to the upper and left border of the left common iliac artery, where it becomes the superior rectal artery. Its vein runs close to its left side in the lower part of its course, but they are separated by an interval in the upper part.

Branches.—The **superior left colic artery** arises from the left side of the inferior mesenteric near its origin, and divides at a variable point into ascending and descending branches. The *ascending branch* runs upwards and to the left towards the left colic flexure, across the lower part of the left kidney, and divides into two branches; one enters the transverse mesocolon to end by joining the left branch of the middle colic artery, and the other passes to the upper part of the descending colon. The *descending branch*, which may arise separately or may be replaced by the lower division of the ascending branch, passes to the left and divides also into two branches; one anastomoses with the lower division of the ascending branch and supplies the descending colon above the iliac crest. The other branch supplies the descending colon below the iliac crest, and anastomoses with branches of the inferior left colic arteries. The superior left colic artery lies immediately behind the peritoneum, and crosses anterior to the ureter and the testicular or ovarian vessels.

The **inferior left colic arteries**, usually two in number, pass downwards and to the left to the lower part of the descending colon and to the pelvic colon. They lie behind the peritoneum, and in front of the psoas major, the ureter, and the upper part of the iliacus. They end by dividing into branches which anastomose with the terminal twigs of the descending branch of the superior left colic above and with branches of the superior rectal below, forming a series of arches from which branches are distributed to the colon.

The **superior rectal artery** is the direct continuation of the inferior mesenteric. It enters the mesentery of the pelvic colon, crosses the front of the left common iliac artery, descends into the true pelvis as far as the third piece of the sacrum, or, in other words, to the junction between the pelvic colon and the rectum, and divides into two branches which pass downwards on the sides of the rectum. Half-way down the rectum each of the two terminal branches of the superior rectal artery divides into two or more branches which pass through the muscular coats into the sub-mucous tissue, where they divide into numerous small branches which pass vertically downwards, anastomosing with one another, with offsets from the middle rectal branches of the internal iliac arteries, the inferior rectal branches of the internal pudendal arteries, and with branches from the median sacral artery.

The superior rectal artery supplies the muscular and the mucous coats of the pelvic colon and upper part of the rectum but the mucous coat only of the lower part of the rectum (see p. 655).

Variations.—The **inferior mesenteric artery** may give hepatic, renal, or middle colic branches; occasionally it is absent, being replaced by branches of the superior mesenteric, and sometimes, as in ruminants and some rodents, its left colic branch does not anastomose with the middle colic artery.

Parietal Branches of Abdominal Aorta

The **phrenic arteries** (Fig. 1096), right and left, are of small size; they arise, either separately or by a common trunk, from the aorta immediately below the diaphragm, to which they are distributed. Diverging from its fellow, each artery runs upwards and laterally on the corresponding crus of the diaphragm—on the right side passing behind the inferior vena cava, on the left side behind the œsophagus—

nd just before reaching the central tendon of the diaphragm each divides into medial nd lateral terminal branches. The *medial branch* runs forwards, to anastomose with ts fellow of the opposite side, forming an arch, convex forwards, along the anterior border of the central tendon of the diaphragm. Offsets from this arch anastomose with the pericardiaco-phrenic and musculo-phrenic arteries. The *lateral branch*

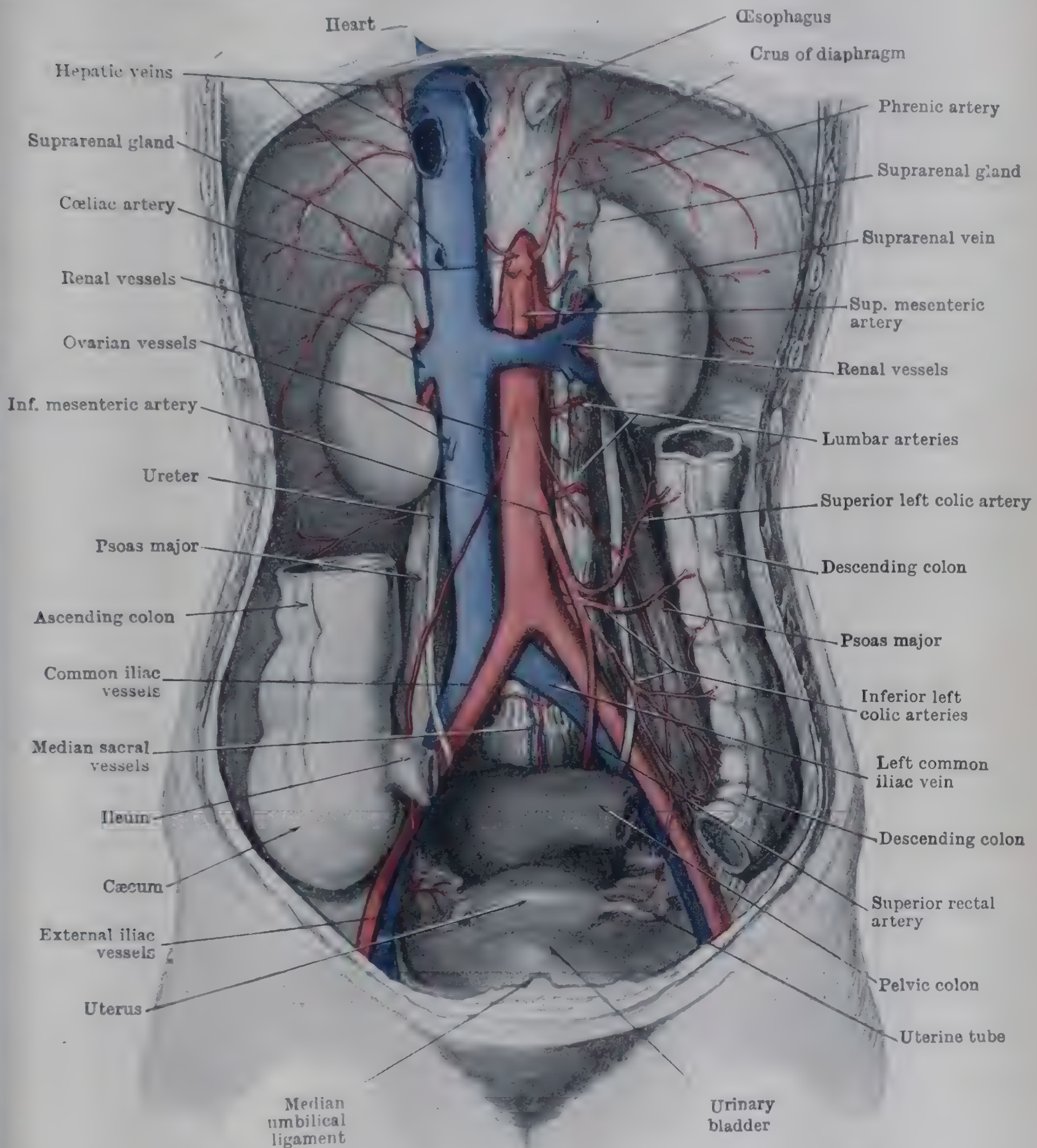

FIG. 1096.—ABDOMINAL AORTA AND ITS BRANCHES.

passes laterally towards the lower ribs, and anastomoses with the musculo-phrenic and lower intercostal arteries.

In addition to supplying the diaphragm, each phrenic artery gives off one or more **superior suprarenal arteries** to the suprarenal gland of its own side. The right artery sends small hepatic branches into the liver through the bare area, and minute branches pass to the inferior vena cava. The left artery gives œsophageal branches which anastomose with œsophageal branches of the aorta and of the left gastric artery.

Variations.—The **phrenic arteries** are very variable; they may arise by a common trunk either from the cœliac artery or from the aorta; they may arise separately either from the aorta or from the cœliac artery; or again, one may spring from the aorta or cœliac artery, and the other from the left gastric, renal, or even from the superior mesenteric artery.

The **lumbar arteries** are in series with the posterior intercostal arteries, and their distribution is very similar. The upper four pairs, like the intercostals, arise either separately or by common trunks, from the back of the aorta; the fifth pair arises from, or in common with, the median sacral artery. From their origins the lumbar arteries pass laterally and backwards, across the front and sides of the bodies of the lumbar vertebræ, to the intervals between the adjacent transverse processes, beyond which they are continued into the lateral part of the abdominal wall.

Each artery, in its backward course, and while still in relation with the vertebral body, is crossed by the sympathetic trunk, and then, after passing medial to, and being protected by, one of the fibrous arches from which the psoas major muscle arises, it runs behind the muscle and the lumbar plexus. The upper two arteries, on each side, pass behind the crus of the diaphragm also. Beyond the interval between the transverse processes of the vertebræ each artery runs laterally behind the quadratus lumborum—the fourth occasionally passing in front of the muscle; each then pierces the aponeurosis of origin of the transversus abdominis, and proceeds forwards in the lateral abdominal wall, between the transversus and internal oblique muscles. On the right side the arteries pass behind the inferior vena cava; but the upper two are separated from the vena cava by the cisterna chyli and the right crus of the diaphragm.

The lumbar arteries anastomose with one another, with the lower posterior intercostal and the subcostal arteries, and with branches of the superior and inferior epigastric and of the deep circumflex iliac and ilio-lumbar arteries. Fine twigs also pass from the lumbar arteries to the extraperitoneal fat; these anastomose with corresponding branches from the phrenic and ilio-lumbar arteries, and with small branches from the hepatic, renal, and colic arteries, to form the *subperitoneal plexus* of Turner (1863).

Branches.—Each lumbar artery gives off, opposite the interval between the vertebral transverse processes, a **posterior branch** of considerable size. It is homologous with and is distributed like the posterior branch of a posterior intercostal artery (p. 1294); a *spinal branch* enters the vertebral canal through the corresponding vertebral foramen. **Muscular branches** are given off both from the main trunk and its posterior branch.

Variations.— Variations of the **lumbar arteries** are very similar to those of the posterior intercostal arteries (p. 1295), and they are due to similar causes. Further, a lumbar artery may have its area of distribution extended into the adjacent segment.

The **median sacral artery** (Fig. 1096) is commonly regarded as a caudal aorta and as the direct continuation of the abdominal aorta. It is, however, of small size, and almost invariably arises from the back of the aorta about half an inch above its bifurcation. It descends in front of the lower two lumbar vertebræ and the sacrum and coccyx, and ends on the pelvic surface of the coccyx by anastomosing with the lateral sacral arteries to form loops from which branches pass to the coccygeal glomus. Opposite the fifth lumbar vertebra it is crossed, anteriorly, by the left common iliac vein, below which it is covered by peritoneum and coils of small intestine as far as the third piece of the sacrum, and in the rest of its extent it is posterior to the rectum. It is accompanied below by venæ comitantes, which, however, unite above to form a single median sacral vein.

In front of the last lumbar vertebra it gives off on each side the **fifth lumbar artery** which is distributed like an ordinary lumbar artery: and as it descends in front of the sacrum it distributes small parietal branches laterally which anastomose with the lateral sacral arteries. The parietal branches usually give off small *spinal* offsets which enter the anterior sacral foramina. Small and irregular visceral branches pass to the rectum and anastomose with the superior and middle rectal arteries.

Variations.—The **median sacral artery** usually springs from the back of the aorta above its bifurcation; it may arise considerably above, or more rarely directly from the bifurcation. Not infrequently it arises from a fourth lumbar artery or from a stem common to the two, and occasionally it arises from a common iliac or internal iliac artery. Sometimes it gives off an accessory renal artery, and occasionally a larger rectal branch arises from it. The vessel is not always present; it may be double, entirely or in part.

COMMON ILIAC ARTERIES

The **common iliac arteries** (Figs. 1096 and 1100) are the terminal branches of the abdominal aorta. They commence opposite the middle of the body of the fourth lumbar vertebra, a little to the left of the median plane. Each artery passes downwards and laterally, across the bodies of the fourth and fifth lumbar vertebræ and the intervening intervertebral disc, and it ends, at the level of the lumbo-sacral disc and anterior to the sacro-iliac joint, by dividing into external and internal iliac branches.

The direction of each common iliac is indicated by a line drawn from the bifurcation of the aorta to a point on the inguinal ligament midway between the pubic symphysis and the anterior superior iliac spine.

The right artery is a little longer than the left, the former being about 2 inches (50 mm.) and the latter $1\frac{3}{4}$ inches (43 mm.) in length.

Relations.—*Anterior.*—Both arteries are covered by peritoneum, and are separated by it from coils of the small intestine. The aortic plexus of sympathetic nerves (Fig. 967, p. 1141) is continued into the hypogastric plexus in front of the upper ends of the arteries and each of them is often crossed, near its termination, by the corresponding ureter.

The left artery is crossed, in addition, by the superior rectal vessels.

Posterior.—Behind the artery, of each side, are the bodies of the fourth and fifth lumbar vertebræ and the intervening intervertebral disc, the sympathetic trunk, and the psoas major muscle. Those relationships, however, are much closer on the left side than on the right. The right common iliac, except at its lower end, where it is in contact with the psoas major, is separated from the structures named by the terminations of the right and left common iliac veins and the commencement of the inferior vena cava. More deeply placed, in the areolar tissue between the psoas major and the lumbar vertebræ, are the obturator nerve, the lumbo-sacral trunk, and the ilio-lumbar artery, which form distant posterior relations to the common iliac artery.

Lateral.—The lateral relations of each artery are coils of small intestine, the ureter, testicular or ovarian vessels, and the genito-femoral nerve.

Medial.—The medial side of each artery is clothed with peritoneum. The left vein is medial to and below its artery, but on a posterior plane. The right vein is at first postero-medial to its artery, but at its upper part it is directly behind the artery and is joined there by the left vein.

Branches.—The external and internal iliac arteries are the only branches.

Variations.—The **common iliac artery** may be longer or shorter than usual, a modification which is determined largely, though not altogether, by the point at which the bifurcation of the aorta takes place. If exceptionally long, it is usually tortuous. In Man the artery is very rarely absent. It occasionally gives off the median sacral or a lateral sacral artery, and ilio-lumbar, testicular, accessory renal or ureteric branches may arise from it.

INTERNAL ILIAC ARTERY

The **internal iliac artery** (Figs. 1097 and 1100) in the fœtus is the direct continuation of the common iliac trunk. It supplies numerous branches to the pelvis, runs upwards on the anterior abdominal wall to the umbilicus as the umbilical artery, and is prolonged through the umbilical cord to the placenta. One of its pelvic branches—the inferior gluteal—is at first the main artery of the lower limb, but subsequently another branch is given off which becomes the chief arterial trunk. That branch is the external iliac artery; it soon equals and ultimately exceeds the internal iliac in size, and the common iliac then appears to bifurcate into those two vessels.

When the placental circulation ceases after the umbilical cord is severed at birth, the part of the internal iliac trunk which extends from the pelvis to the umbilicus atrophies, and is afterwards represented almost entirely by a fibrous cord known as the *lateral umbilical ligament*. The proximal part of the obliterated artery remains pervious to convey blood to its superior vesical branch. The permanent internal iliac artery is a comparatively short vessel. Owing to the arrange-

ment of some of its branches it appears to end in an anterior and a posterior division; the anterior is the original continuation of the vessel, and the posterior is simply a common stem of origin for some of the branches.

With this explanation the artery may be described in the usual manner.

It arises from the common iliac opposite the sacro-iliac joint and at the level of the lumbo-sacral disc, and descends into the true pelvis, to end near the upper border of the greater sciatic notch in two divisions—anterior and posterior—from which the branches of distribution are given off. The artery measures about one and a half inches (35 mm.) in length.

Relations.—*Antero-medial.*—Each internal iliac artery is covered antero-medially by peritoneum, under cover of which the ureter descends along the anterior border of the artery. Some part of the intestine is in contact with the peritoneum covering it, usually the pelvic colon on the left and the terminal part of the ileum on the right. In the female, the ovary and the infundibulum of the uterine tube usually lie close in front of it, but separated from it by the peritoneum and the ureter (Fig. 661, p. 782).

Posterior to it are the internal iliac vein and the commencement of the common iliac vein; behind these are the lumbo-sacral trunk and the sacro-iliac joint.

Lateral.—On its lateral side the external iliac vein separates it from the psoas major muscle, above. At a lower level the obturator nerve, embedded in a mass of fat, intervenes between the artery and the side-wall of the pelvis.

Branches.—The internal iliac artery supplies the greater part of the pelvic wall and contents, and branches are distributed also to the gluteal region and thigh and to the external genital organs.

All the branches may be given off separately from a single undivided parent trunk, but as a rule they arise in two groups that correspond to the two divisions in which the artery, under these circumstances, appears to end. The branches are usually classified as parietal and visceral.

Posterior Division	Anterior Division		
Parietal	**Parietal**	**Visceral**	
Ilio-lumbar Lateral sacral Superior gluteal	Obturator Internal pudendal Inferior gluteal	Umbilical Superior vesical Middle rectal	Inferior vesical (male) Uterine } (female) Vaginal } (female)

Branches of Posterior Division of Internal Iliac Artery

The **ilio-lumbar artery** runs upwards and laterally, out of the true pelvis, to the iliac fossa. It passes anterior to the sacro-iliac joint, between the lumbo-sacral trunk and the obturator nerve, and posterior to the lower part of the common iliac vessels and the psoas major muscle.

In the iliac fossa it divides into an iliac and a lumbar branch. The **iliac branch** ramifies in the iliac fossa and anastomoses with branches of the deep circumflex iliac and obturator arteries; it gives offsets to the iliacus, and supplies a large nutrient branch to the ilium. The **lumbar branch** ascends, behind the psoas major, to the iliac crest. It supplies the psoas and quadratus lumborum, and anastomoses with the lumbar and deep circumflex iliac arteries; it gives off also a *spinal branch*, which enters the intervertebral foramen between the fifth lumbar vertebra and the sacrum, and is distributed like the spinal branches of the lumbar and posterior intercostal arteries.

There are usually two **lateral sacral arteries**—superior and inferior—but they may arise by a common stem.

Both run downwards and medially, on the front of the sacrum. The *inferior* passes anterior to the piriformis and the sacral nerves, and descends, on the lateral side of the sympathetic trunk, to the coccyx, where it ends by anastomosing with the median sacral. The *superior* reaches only as far as the first or the second anterior sacral foramen; then it enters the sacral canal. It anastomoses with the lower lateral sacral and with the median sacral artery. Branches are given off by

the lateral sacral arteries to the piriformis and to the sacral nerves. Spinal offsets pass through the anterior sacral foramina into the sacral canal; they supply the sacral dura mater and the arachnoid, the roots of the sacral nerves and the filum terminale, and anastomose with other spinal arteries. They then pass through the posterior sacral foramina to supply muscles on the back of the sacrum and anastomose with branches of the superior and inferior gluteal arteries.

The **superior gluteal artery** (Figs. 1097 and 1099) is the continuation of the posterior division of the internal iliac artery after it has given off its ilio-lumbar

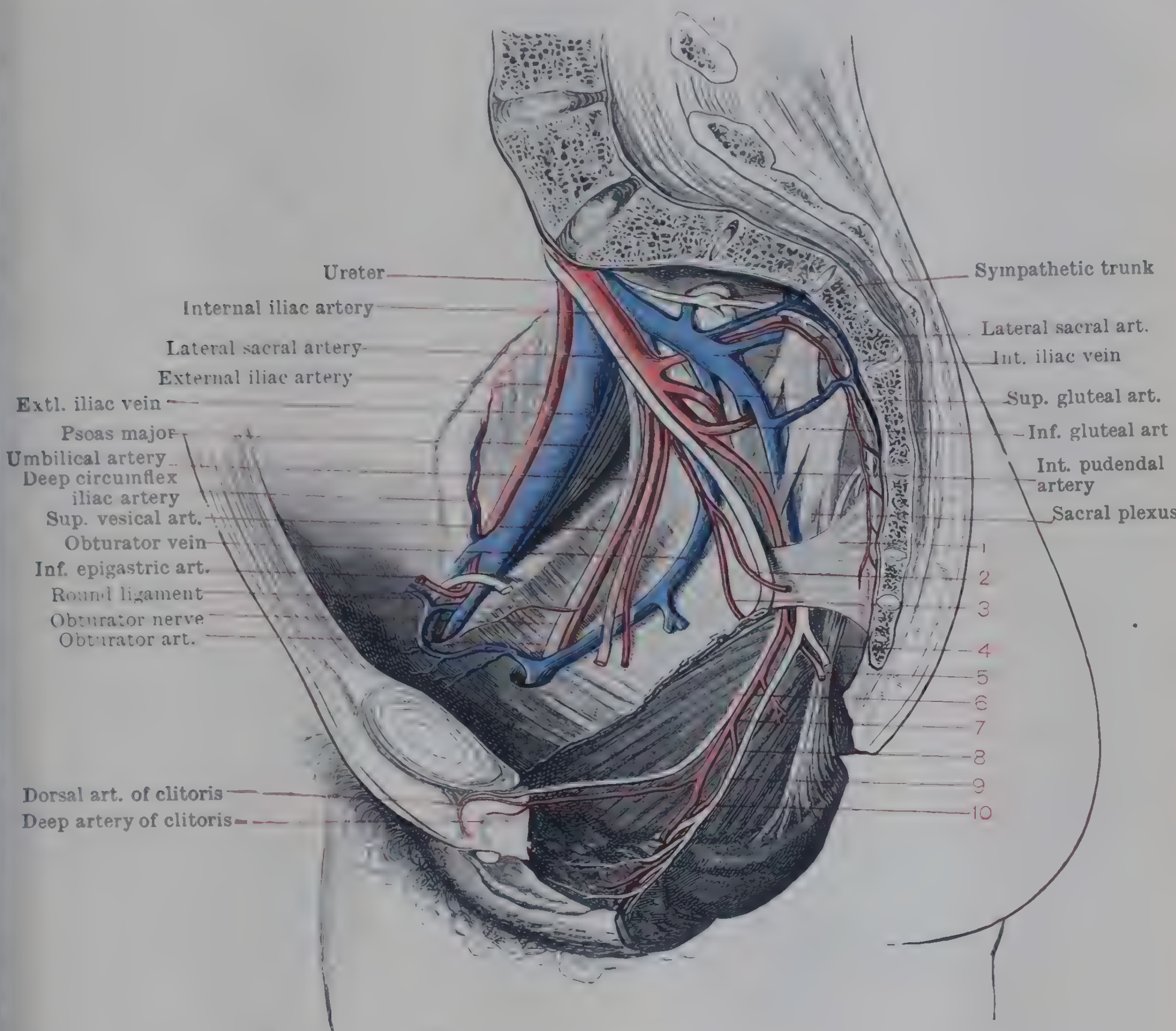

FIG. 1097.—INTERNAL ILIAC ARTERY AND ITS BRANCHES IN THE FEMALE.

1. Sacro-spinous ligament.
2. Uterine artery.
3. Vaginal artery.
4. Inferior hæmorrhoidal nerve.
5. Inferior rectal artery.
6. Dorsal nerve of clitoris.
7. Internal pudendal artery.
8. Perineal nerve.
9. Labial artery.
10. Artery of bulb of the vestibule.

and lateral sacral branches. It is a large vessel which pierces the pelvic fascia, and passes backwards between the lumbo-sacral trunk and the first sacral nerve. It leaves the pelvis through the upper part of the greater sciatic foramen, above the piriformis muscle, and enters the gluteal region, where it divides, under cover of the gluteus maximus and between the adjacent borders of the piriformis and gluteus medius muscles, into superficial and deep branches.

The **superficial branch** divides at once into numerous secondary branches, some of which supply the gluteus maximus, whilst others pass through it, near its origin, to the overlying skin. The branches freely anastomose with branches of the inferior gluteal, internal pudendal, medial circumflex, deep circumflex iliac, and lateral sacral arteries.

The **deep branch** runs forwards between the gluteus medius and minimus, and, after giving a nutrient branch to the ilium, divides into upper and lower branches. The

upper branch runs forwards along the upper border of the gluteus minimus and passes beyond the anterior margins of the gluteus medius and minimus to anastomose, under cover of the tensor fasciæ latæ, with the ascending branch of the lateral circumflex artery. It anastomoses with the deep circumflex iliac artery also, and it supplies muscular branches to the adjacent muscles. The *lower branch*, accompanied by the superior gluteal nerve and its branch to the tensor fasciæ latæ, passes more directly forwards, across the gluteus minimus, towards the greater trochanter. It supplies the gluteal muscles, and anastomoses with the ascending branch of the lateral circumflex artery.

Before leaving the pelvis the superior gluteal artery gives **muscular branches** to the piriformis and the obturator internus, nutrient branches to the hip-bone, and supplies the roots of the sacral plexus.

Parietal Branches of Anterior Division of Internal Iliac Artery

The **obturator artery** (Figs. 1097 and 1100) runs forwards and downwards along the side-wall of the true pelvis, near its brim, to the obturator foramen, through the upper part of which it passes. It ends immediately on entering the thigh by dividing into anterior and posterior terminal branches, which skirt round the margin of the obturator foramen deep to the obturator externus muscle. It is accompanied, in the whole of its pelvic course, by the obturator nerve and vein, the nerve being above the artery and the vein below it.

To its lateral side is the obturator fascia, which intervenes between it and the upper part of the obturator internus muscle, whilst on its medial side it is covered by peritoneum. The ureter intervenes between the posterior part of the artery and the peritoneum. When the bladder is distended it also comes into close relation with the lower and anterior part of the artery. In the female the ovarian vessels and the broad ligament are medial relations of the obturator artery.

Branches.—All the branches except the terminal are given off before the artery leaves the pelvis. *Muscular* branches supply the adjacent muscles; a *nutrient* branch to the ilium passes deep to the ilio-psoas muscle, supplies the bone, and anastomoses with the ilio-lumbar artery; and a *vesical* branch or branches pass medially to the bladder. A **pubic branch**, given off just before the artery leaves the pelvis, ascends on the pelvic surface of the pubis; it anastomoses with its fellow of the opposite side and with the pubic branch of the inferior epigastric, which, in its downward course, may pass on either the lateral or medial side of the femoral ring. In the latter position the branch of the inferior epigastric is important in relation to femoral hernia; the importance is emphasized when, as sometimes happens, the obturator artery arises as an enlarged pubic branch of the inferior epigastric artery instead of from the internal iliac (p. 1312). The *anterior terminal branch* runs forwards and the *posterior* backwards around the margin of the obturator foramen. They lie on the obturator membrane under cover of the obturator externus, and they anastomose together at the lower margin of the foramen Both give off offsets which anastomose with the medial circumflex artery, and supply the adjacent muscles. The posterior branch gives also an **acetabular branch** to the hip joint, which passes upwards, through the acetabular notch, to supply the head of the femur and its ligament.

The **internal pudendal artery** (Figs. 1097 and 1098) arises in common with the inferior gluteal artery. It runs downwards and backwards, to the lower part of the greater sciatic foramen, lying anterior to the piriformis muscle and the sacral plexus, from both of which it is separated by the pelvic fascia. At the lower border of the piriformis it pierces the pelvic fascia, passes between the piriformis and coccygeus muscles, and leaves the pelvis to enter the gluteal region. It is accompanied by venæ comitantes, the pudendal nerve, and the nerve to the obturator internus; and the inferior gluteal vessels lie at first behind and then lateral to it. In the gluteal region it lies on the ischial spine under cover of the gluteus maximus, and between the pudendal nerve and the nerve to the obturator internus, the former being medial to it. It next passes through the lesser sciatic foramen and enters the perineum, in the anterior part of which it ends by dividing into the deep and dorsal arteries of the penis or of the clitoris.

In the first part of its course *in the perineum* the artery lies in the lateral wall of the ischio-rectal fossa, where it is enclosed in a canal in the obturator fascia—

the pudendal canal. This canal, which is situated about 1½ inches above the lower margin of the ischial tuberosity, contains also the pudendal veins and the terminal parts of the pudendal nerve, *i.e.*, the dorsal nerve of the penis or clitoris, which lies above the artery, and the perineal nerve, which lies below it. From the ischio-rectal fossa the internal pudendal artery is continued forwards in the deep perineal pouch close to the ramus of the pubis. About half an inch below the pubic symphysis it pierces the perineal membrane and immediately divides into its terminal branches—the deep artery and the dorsal artery. The division sometimes takes place while the artery is still within the deep perineal pouch.

Branches.—*In the pelvis.*—Small branches to muscles and to the sacral plexus.

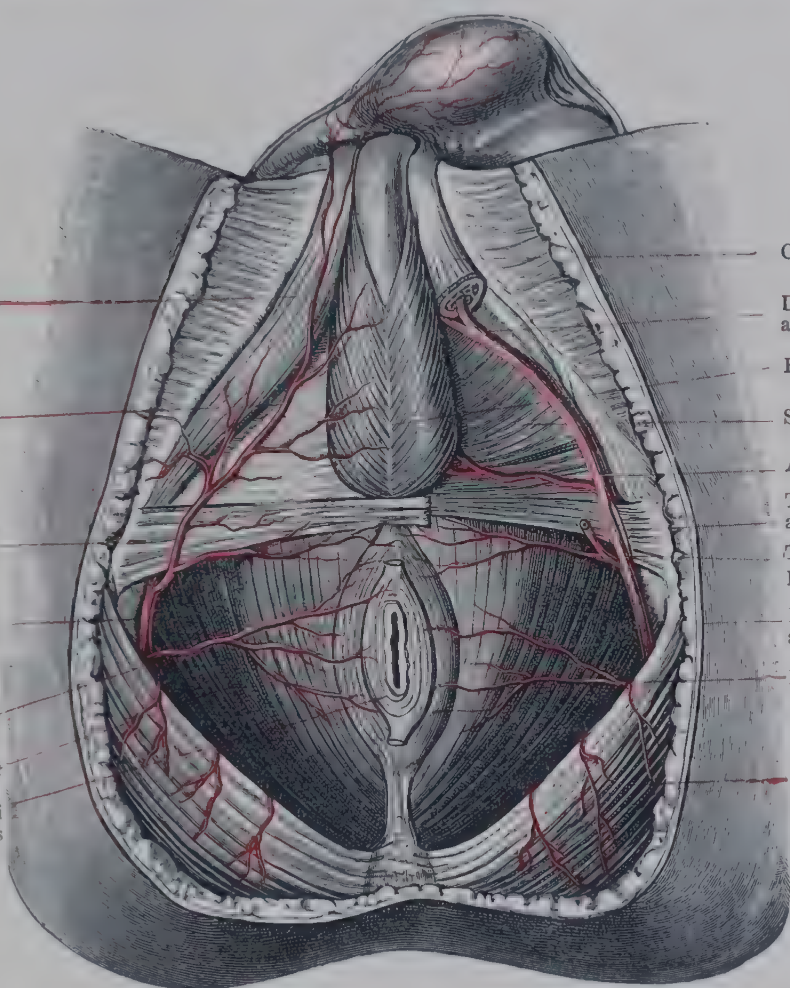

FIG. 1098.—PERINEAL DISTRIBUTION OF INTERNAL PUDENDAL ARTERY IN THE MALE.

In the gluteal region.—*Muscular* branches are distributed to the adjacent muscles and anastomose with branches of the gluteal and medial circumflex arteries.

In the ischio-rectal fossa.—The **inferior rectal artery** pierces the wall of the fascial canal, and runs obliquely forwards and medially. It soon divides into two or three main branches, which may arise separately from the pudendal; they pass across the fossa to the anal canal. The branches of the artery anastomose with the transverse perineal and, in the walls of the anal canal, with their fellows of the opposite side, and with the middle and superior rectal arteries: they supply cutaneous twigs to the region of the anus, and send others round the lower border of the gluteus maximus to supply the lower part of the buttock.

Two **scrotal** or **labial branches** arise in the anterior part of the ischio-rectal fossa, either separately or by common trunk, and pierce the posterior border of the perineal membrane. They are continued forwards, in the urogenital triangle, to the scrotum or the labium majus according to sex, deep to the superficial fascia. They anastomose with their fellows of the opposite side, with the transverse perineal and the external pudendal arteries, and supply the muscles and subcutaneous structures of the urogenital triangle.

The **transverse perineal artery** is a small branch which arises from one of the scrotal or labial branches or from the common trunk; it may arise directly from the internal pudendal. It runs medially along the superficial transversus perinei to the perineal

body, where it anastomoses with its fellow of the opposite side and with the inferior rectal arteries. It supplies adjacent muscles.

In the urogenital triangle.—The **artery of the bulb of the penis**, usually of relatively large size, is given off in the deep perineal pouch. It runs transversely along the posterior border of the sphincter urethræ, and then pierces the perineal membrane a short distance from the side of the urethra to enter the substance of the bulb. It passes onwards in the corpus spongiosum to the glans, where it anastomoses with its fellow and with the dorsal arteries of the penis.

It supplies the sphincter urethræ, the bulbo-urethral gland, the corpus spongiosum penis, and the spongy part of the urethra. *In the female*, the corresponding artery supplies the bulb of the vestibule.

The **deep artery of the penis** (**of the clitoris** in the female) is usually the larger of the two terminal branches. Immediately after its origin it enters the crus, and runs forwards in the corpus cavernosum of the penis (or clitoris), which it supplies.

The **dorsal artery of the penis** (**of the clitoris** in the female) ascends between the crus and the bone, passes forwards between the layers of the suspensory ligament of the penis (or clitoris), and runs along the dorsal surface of the organ, with the dorsal nerve immediately lateral to it, and separated from its fellow of the opposite side by the deep dorsal vein, which lies in the median plane. It supplies the superficial tissues on the dorsal aspect of the penis, sends branches into the corpus cavernosum to anastomose with the deep artery, and its terminal branches enter the glans, where they anastomose with the arteries to the bulb. It anastomoses also with the external pudendal branches of the femoral.

The **inferior gluteal artery** (Figs. 1097 and 1099) arises by a common trunk with the internal pudendal artery. It descends a little postero-lateral to the internal pudendal vessels, pierces the pelvic fascia, runs backwards and laterally between the first and second, or second and third sacral nerves, and leaves the pelvis through the lower part of the greater sciatic foramen to enter the gluteal region just below the piriformis. In the gluteal region it descends along the postero-medial side of the sciatic nerve, deep to the gluteus maximus, and behind the obturator internus, the two gemelli, the quadratus femoris, and upper part of the adductor magnus muscles, to reach the proximal part of the thigh.

Below the lower border of the gluteus maximus the artery is comparatively superficial, and, having given off its largest branches, it descends, as a long slender vessel, with the posterior cutaneous nerve of the thigh.

Branches.—*In the pelvis.*—Small and irregular branches supply the adjacent viscera and muscles and the sacral nerves; they anastomose with branches of the internal pudendal and lateral sacral arteries.

In the buttock.—**Muscular branches** are given off to the muscles of the buttock, and to the proximal parts of the hamstring muscles. They anastomose with the internal pudendal, medial circumflex, and obturator arteries. One or two **coccygeal branches** arise immediately after the artery leaves the pelvis. They run medially, pierce the sacro-tuberous ligament and the gluteus maximus, and end in the soft tissues over the posterior surface of the coccyx and of the lower part of the sacrum. They supply twigs to the gluteus maximus, and anastomose with branches of the gluteal and lateral sacral arteries. An *anastomosing* branch passes laterally, superficial or deep to the sciatic nerve, towards the greater trochanter of the femur. It gives a branch to the back of the hip joint and anastomoses with branches of the gluteal, internal pudendal, medial and lateral circumflex, and the first perforating arteries, taking part in the formation of the so-called "crucial anastomosis" of the thigh. *Cutaneous* branches, accompanying twigs of the posterior cutaneous nerve of the thigh, pass round the lower border of the gluteus maximus muscle to the skin. The **companion artery of the sciatic nerve** is a long slender branch which runs downwards on the surface of the sciatic nerve or in its substance. It supplies the nerve and anastomoses with the perforating arteries.

Visceral Branches of Anterior Division of Internal Iliac Artery

Umbilical Artery.—Atrophy of that portion of the **umbilical artery** which extends from the anterior division of the internal iliac to the umbilicus has already been mentioned. The atrophy is complete between the umbilicus and the origin of the superior vesical artery, but between that origin and the internal

iac it is incomplete, and the lumen of the vessel, though greatly diminished in ze, persists. It is from the incompletely obliterated portion that the superior esical artery arises. The completely obliterated part of the umbilical artery is educed to a fibrous cord which runs along the side of the bladder almost to its pex, and then ascends, on the posterior surface of the anterior abdominal wall, o the umbilicus. In the latter part of its course it is known as the **lateral mbilical ligament**. As it passes along the wall of the true pelvis it is external to he peritoneum, and it is crossed by the vas deferens in the male, and by the round igament of the uterus in the female.

The **superior vesical artery** arises from the pervious part of the umbilical artery, as it lies at the side of the bladder. It passes medially to the upper part of the urinary bladder and divides into numerous branches which anastomose with the other vesical arteries, and it also gives small branches to the median umbilical ligament (urachus), and often to the lower part of the ureter. Not infrequently the *artery of the vas deferens* arises from it.

The **inferior vesical artery** runs medially, upon the upper surface of the levator ani, to the lower part of the bladder. It gives branches also to the seminal vesicle, the vas deferens, the lower part of the ureter and the prostate, and it anastomoses with its fellow of the opposite side, with the other vesical arteries, and with the middle rectal artery.

The **artery of the vas deferens** may arise from either the superior vesical or the inferior vesical artery. It is a long, slender vessel which accompanies the vas deferens to the testis, where it anastomoses with the testicular artery. It anastomoses also with the artery of the cremaster.

The **middle rectal artery** arises either directly from the anterior division of the internal iliac or from the inferior vesical; more rarely it springs from the internal pudendal. It runs medially and is distributed to the rectum; it gives branches also to the prostate, the seminal vesicle, and the vas deferens; and it anastomoses with its fellow of the opposite side, with the inferior vesical, and with the other rectal arteries.

The **vaginal artery** may arise either directly from the anterior division of the internal iliac or from a stem common to it and the uterine artery, and it may be represented by several branches.

It runs downwards and medially, on the floor of the pelvis, to the side of the vagina, and divides into numerous branches which ramify on its anterior and posterior walls. The corresponding branches of opposite sides anastomose and form anterior and posterior longitudinal vessels—the so-called *azygos arteries*. They also anastomose above with the vaginal branches of the uterine arteries, and below with the perineal branches of the internal pudendal. In addition to supplying the vagina, it gives small branches to the bulb of the vestibule, to the base of the bladder, and to the rectum.

The **uterine artery** arises either separately or in common with the vaginal or middle rectal artery. It runs medially and slightly forwards upon the upper surface of the levator ani, to the lower border of the broad ligament, between the two layers of which it passes medially, and arches above the ureter about three-quarters of an inch from the uterus (Figs. 656 (p. 775) and 661). It passes above the lateral fornix of the vagina to the side of the neck of the uterus, and then ascends in a tortuous manner towards the fundus, but at the level of the uterine tube it turns laterally, below the tube and between the layers of the broad ligament, and ends as an *ovarian branch* which anastomoses with the ovarian artery. It supplies the uterus, the ligament of the ovary, and the round ligament of the uterus, and gives off *vaginal* and *tubal branches* to the upper part of the vagina and the medial part of the uterine tube. It anastomoses with its fellow of the opposite side, with the vaginal and ovarian arteries, and, along the round ligament of the uterus, with the inferior epigastric arteries.

Variations.—The **internal iliac artery** varies in length. It is longer and arises at a higher level when the common iliac is short. In rare cases it arises from the aorta without the intervention of a common iliac. Frequently, as in the fœtus, it does not end in anterior and posterior divisions, but forms a single trunk from which the branches are given off.

The visceral branches vary much in number and size, and the **middle rectal** may not b present, its place being taken by branches from the vesical arteries. An accessory renal branch o a ureteric artery sometimes arises from the internal iliac artery.

The **ilio-lumbar branch** often arises from the common iliac instead of the internal iliac the **superior gluteal** and **inferior gluteal** arteries may arise by a common stem. The inferio gluteal artery may, as in the fœtus, constitute the main artery of the lower limb, and run distall to become continuous with the popliteal artery; probably the companion artery of the sciati nerve represents the original continuity of the two vessels (Fig. 1136, p. 1376).

In some instances the **obturator artery** arises from the inferior epigastric artery instead c from the internal iliac. The condition is apparently due to obliteration of the usual origin of th obturator artery and the subsequent enlargement of the anastomosing pubic branches of th obturator and inferior epigastric arteries. The course of the *abnormal obturator artery* is c importance. From its origin it descends into the true pelvis, on the medial side of the externa iliac vein, and usually on the lateral side of the femoral ring; but in three-tenths of examples, an more often in males than in females, it descends on the medial side of the ring. If it passes or the medial side of the ring, the artery may be injured in the operation for the relief of a strangulated femoral hernia.

The obturator artery sometimes gives off an accessory pudendal branch which passes along the side of the prostate, pierces the sphincter urethræ, and ends by dividing into the deep anc dorsal arteries of the penis. When that occurs the internal pudendal artery is small, and i ends as the artery to the bulb. Occasionally the accessory pudendal arises from the interna pudendal artery within the pelvis, or from one of the vesical arteries.

EXTERNAL ILIAC ARTERY

The **external iliac artery** (Figs. 1096, 1100) extends from a point opposite the sacro-iliac joint, at the level of the lumbo-sacral disc, to a point at the inguinal ligament, midway between the anterior superior iliac spine and the pubic symphysis, where it becomes the femoral artery. Its length is three and a hal to four inches (85 to 100 mm.), and in the adult it is usually slightly wider thar the internal iliac artery.

It runs downwards, forwards, and laterally, along the brim of the pelvis resting upon the fascia iliaca, which separates it above from the medial border of the psoas major muscle, and below from its anterior surface; and it is enclosed with its accompanying vein, in a thin fascial sheath.

Relations.—*Anterior.*—It is covered in front by peritoneum, which separates it on the right side from the terminal portion of the ileum, and sometimes from the vermiform appendix, and on the left side, from small intestine, except where the termination of the descending colon crosses it. Several branches of the lower of the two inferior left colic arteries also cross it on the left side. The ureter crosses the artery at its origin and in the female the ovarian vessels cross the artery an inch below its origin. Near its lower end the testicular vessels and the genital branch of the genito-femoral nerve lie on the artery, and they are all crossed by the deep circumflex iliac vein. In the male that part of the artery is crossed also by the vas deferens, and in the female by the round ligament of the uterus. External iliac lymph-glands lie in front and at the sides of the artery, and almost invariably one of these is directly in front of its termination.

Posterior.—The fascia iliaca and psoas major muscle lie behind the artery. Near its upper end the external iliac vein is posterior to the vessel and separates it from the obturator nerve.

Lateral.—On its lateral side is the genito-femoral nerve. *Medial.*—To the medial side is the peritoneum, and at its lower part the external iliac vein.

Branches.—In addition to small branches to the psoas major muscle and to the lymph-glands, two named branches of considerable size spring from the external iliac artery—the inferior epigastric and the deep circumflex iliac.

The **inferior epigastric artery** (Figs. 1097 and 1100) arises, immediately above the inguinal ligament, from the front of the external iliac. It lies in the extraperitoneal fat; it curves forwards from its origin, turns round the lower border of the peritoneal sac, and runs upwards and medially, along the medial side of the deep inguinal ring and onwards towards the rectus abdominis muscle raising a fold of the peritoneum; it then pierces the transversalis fascia, passes over the arcuate line and enters the sheath of the rectus. For a short distance it ascends posterior to the rectus, but it soon penetrates into the substance of the muscle, and breaks up into branches which anastomose with terminal offsets of the

PLATE LXXXIII

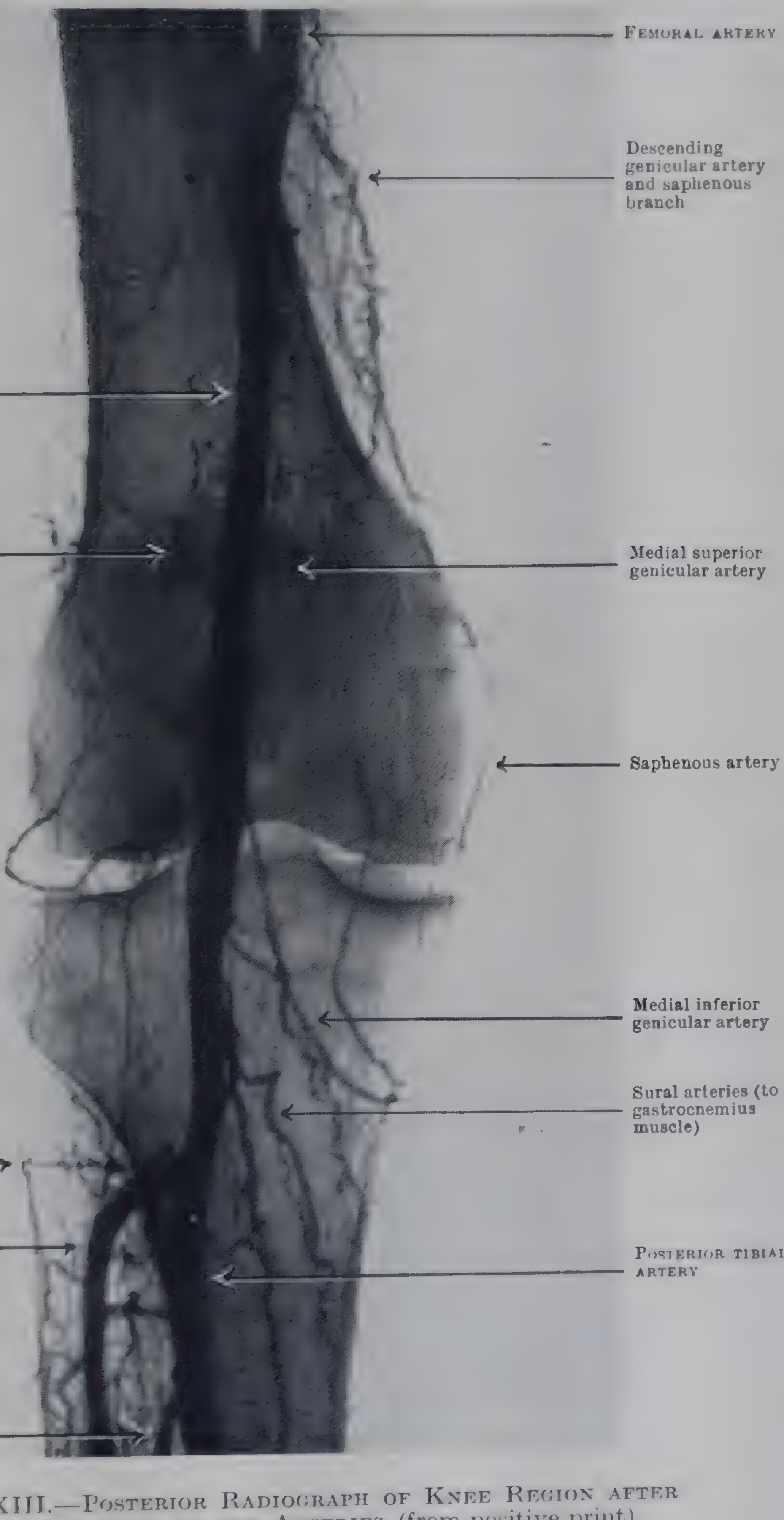

PLATE LXXXIII.—POSTERIOR RADIOGRAPH OF KNEE REGION AFTER RADIO-OPAQUE INJECTION OF THE ARTERIES (from positive print).

Cf. Plate LXXXIV and Figs. 1103, p. 1319, 1104 and 1106, p. 1326.

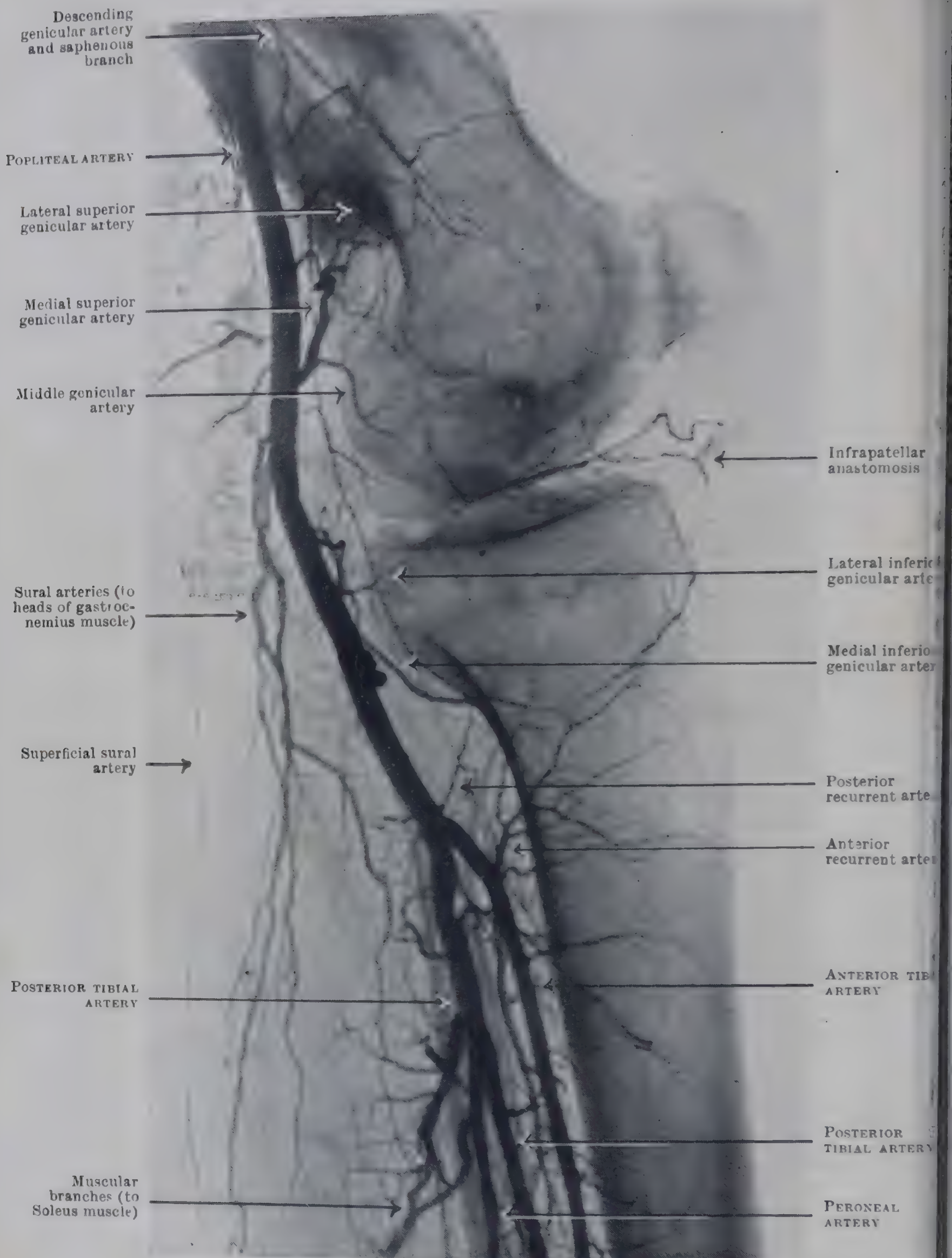

Plate LXXXIV.—Lateral Radiograph of Knee and Calf after radio-opaque injection of the Arteries (from positive print).

Cf. Plate LXXXIII and Figs. 1103, p. 1319, 1104 and 1106, p. 1326.

perior epigastric branch of the internal mammary artery and with the lower osterior intercostal arteries. At the deep inguinal ring, the vas deferens in the male,

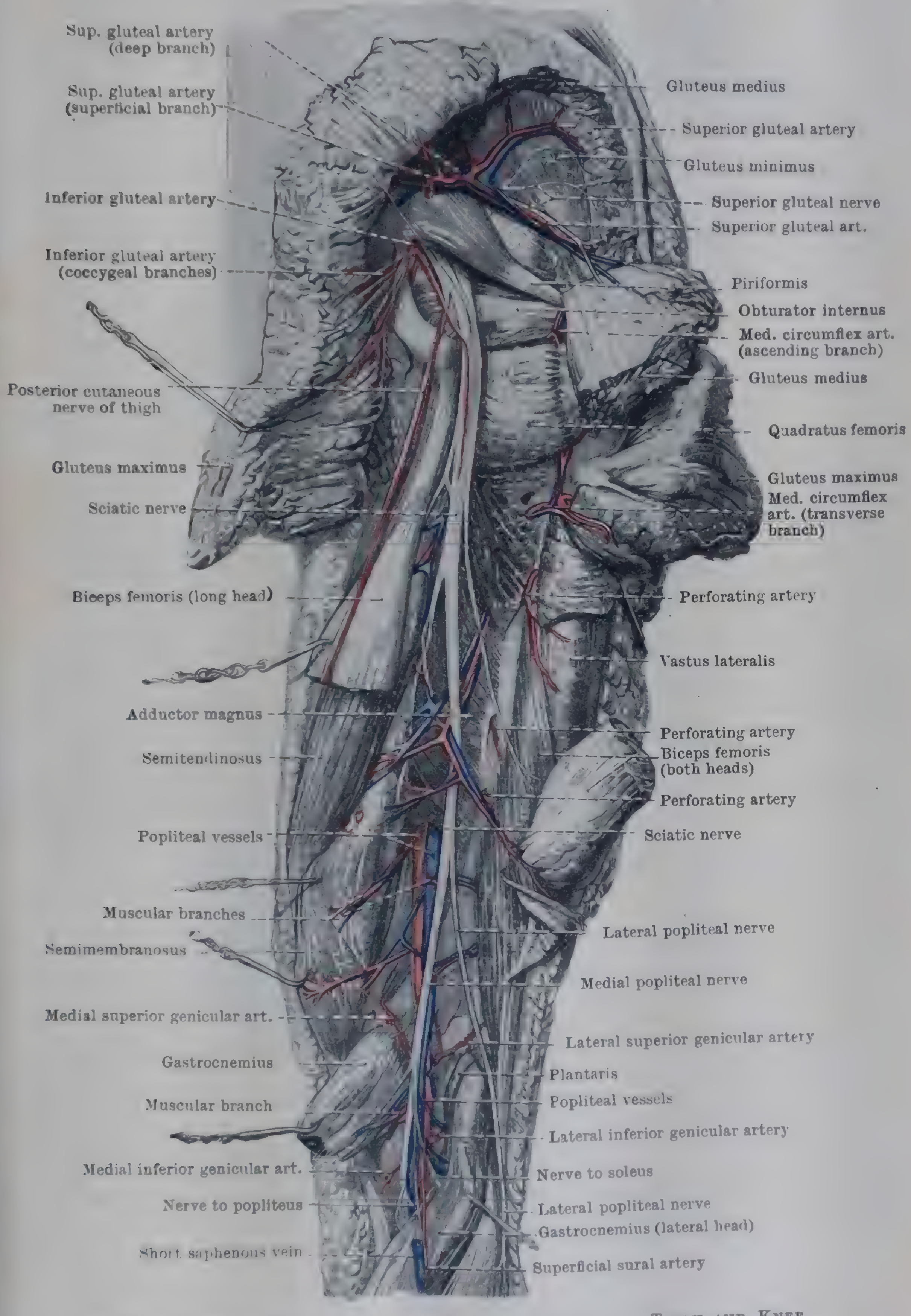

Fig. 1099.—Arteries of Buttock and Posterior Aspect of Thigh and Knee.

Note.—In the specimen there was no anastomotic branch of the inferior gluteal artery, and the transverse terminal branch of the medial circumflex artery pierced the upper part of the adductor magnus.

or the round ligament of the uterus in the female, hooks round the artery and passes medially behind it towards the pelvis.

Branches.—**Muscular branches** supply the muscles of the abdominal wall, ar anastomose with branches of the deep circumflex iliac, the lumbar, and the lower posteri intercostal arteries. **Cutaneous branches** pierce the rectus abdominis and the anterior pa of its sheath, and end in the subcutaneous tissues of the anterior abdominal wa where they anastomose with corresponding branches of the opposite side and wit branches of the superficial epigastric artery. The **artery of the cremaster** in the ma (**artery of the round ligament of the uterus** in the female) is small. It descends throug the inguinal canal and anastomoses with the external pudendal arteries and the scrot or labial branches of the pudendal artery, and in the male with the testicular artery als

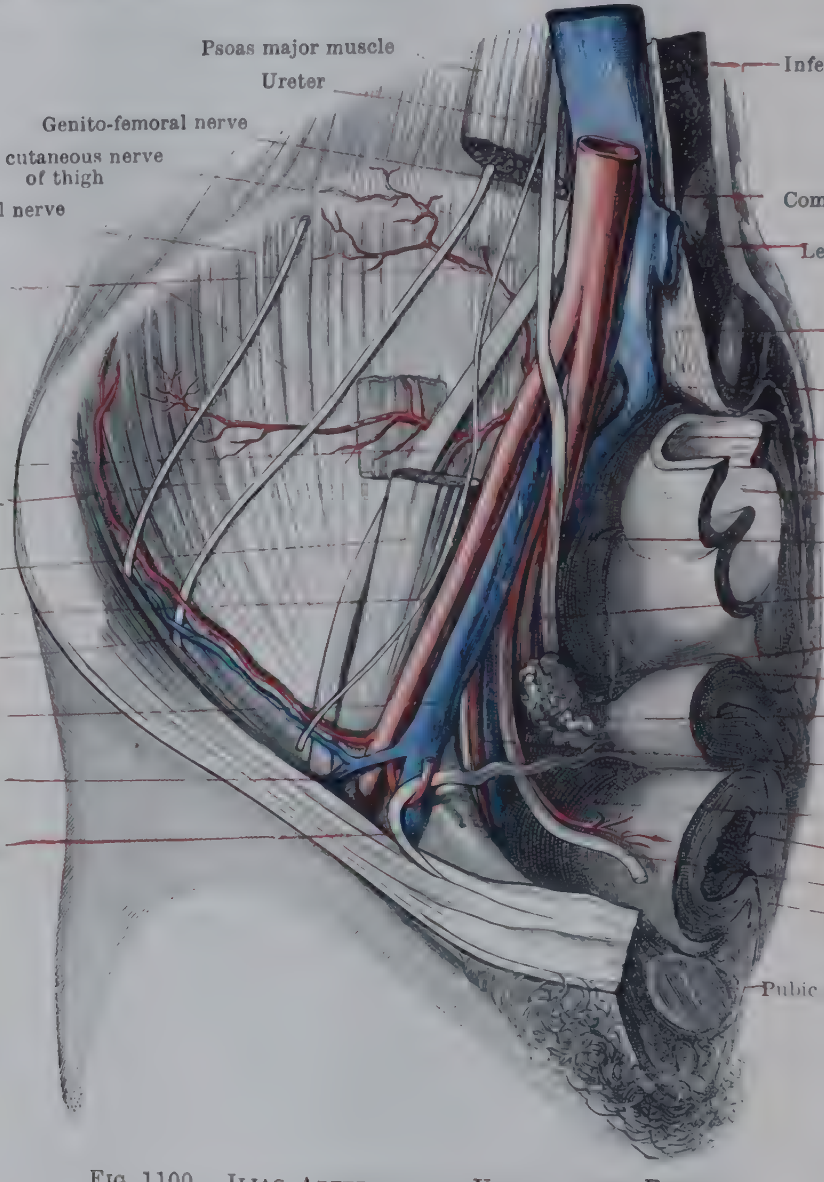

Fig. 1100.—Iliac Arteries and Veins in the Female.

In the male it accompanies the spermatic cord, supplying its coverings, including t cremaster. In the female it runs with the round ligament. The **pubic branch** descen either on the lateral or the medial side of the femoral ring, to anastomose with the pul branch of the obturator artery; it anastomoses also with its fellow of the opposite sid Sometimes, when the obturator branch of the internal iliac artery is absent, the pul branch of the inferior epigastric artery enlarges and becomes the obturator artery, whi descends to the obturator foramen either on the lateral or the medial side of the femor ring (see p. 1312).

The deep circumflex iliac artery (Figs. 1100 and 1101) springs from t lateral side of the external iliac artery, usually a little below the inferior epigastr and immediately above the inguinal ligament. It runs laterally and upwards the anterior superior iliac spine. In that part of its course it lies just above t inguinal ligament, and is enclosed in a fibrous canal formed by the union of t transversalis and iliac fasciæ. A little beyond the anterior superior spine it pierc the transversus abdominis, and is continued between the transversus and t

ternal oblique, to end by anastomosing with branches of the ilio-lumbar tery.

Branches.—**Muscular branches** are given to the adjacent muscles. One of them frequently of considerable size and is known as the **ascending branch**; it pierces the ansversus muscle a short distance in front of the anterior superior spine, and ascends ertically, between the transversus and the internal oblique, anastomosing with the imbar and the epigastric arteries. **Cutaneous branches** pierce the muscles. They id in the skin over the iliac crest, and anastomose with the superior gluteal, the superficial circumflex iliac, and the ilio-lumbar arteries.

Variations.—The **external iliac artery** may be much smaller than usual, especially if ie inferior gluteal artery persists as the main vessel of the lower limb. It may give off two eep circumflex iliac branches, a dorsal artery of the penis, a medial circumflex artery of the iigh, or a vas aberrans (p. 1320), and its deep circumflex iliac and inferior epigastric branches iay arise at higher or lower levels than usual.

ARTERIES OF LOWER LIMB

The main artery of the lower limb is continued from the common iliac rtery. It descends as a single trunk as far as the lower border of the opliteus, and ends there by dividing into the anterior and posterior tibial arteries.)istinctive names are, however, applied to different parts of the artery, corresponding to the several regions through which it passes. Thus in the abdomen it is alled the **external iliac artery**, in the proximal two-thirds of the thigh it receives he name of the **femoral artery**, whilst its distal part, which is situated in the opliteal fossa, is termed the **popliteal artery**.

FEMORAL ARTERY

The **femoral artery** (Figs. 1101 and 1102) is the continuation of the external liac into the thigh. It begins behind the inguinal ligament, passes through the proximal two-thirds of the thigh, and ends at the opening in the adductor magnus.

Course.—Its general direction is indicated by a line drawn from the inguinal ligament, midway between the anterior superior iliac spine and the pubic symphysis, to the adductor tubercle, the thigh being flexed, abducted, and rotated laterally.

In its proximal half the femoral artery lies in the femoral triangle and is comparatively superficial; at the apex of the triangle it passes deep to the sartorius, enters the subsartorial canal (Hunter's canal), and is then more deeply placed.

At their entry into the femoral triangle both the artery and its vein are enclosed, for a distance of $1\frac{1}{4}$ inches (30 mm.), in a funnel-shaped fascial sheath formed of the fascia transversalis in front and the fascia iliaca behind. That sheath is called the **femoral sheath**; it is divided by antero-posterior septa into three compartments. The lateral compartment is occupied by the femoral artery and the femoral branch of the genito-femoral nerve; the intermediate compartment contains the femoral vein; and the medial compartment is the femoral canal.

Relations.—**In Femoral Triangle**—*Anterior.*—The femoral artery is covered superficially by skin and fasciæ, by superficial inguinal lymph-glands and small superficial vessels. The anterior part of the femoral sheath and the cribriform fascia are in front of the proximal part of the artery, and the fascia lata is in front of the distal part. Near the apex of the triangle the artery is crossed by the medial cutaneous nerve, and not infrequently by a tributary of the long saphenous vein. *Posterior.*—It is in relation behind, proximo-distally, with the posterior part of the femoral sheath and the psoas major, the pectineus, and the adductor longus. The nerve to the pectineus passes between the artery and the psoas major; the femoral vein and the profunda artery intervene between it and the pectineus, and the femoral vein separates it from the adductor longus also.

The femoral vein, which lies behind the artery in the lower part of the femoral triangle, passes to its *medial side* above, where it is separated from the artery by the lateral septum of the femoral sheath. On the *lateral side* of the artery are the femoral branch of the genito-femoral nerve, the femoral sheath, and the femoral nerve proximally;

more distally the saphenous nerve and the nerve to the vastus medialis are continued o the lateral side.

In Subsartorial Canal—*Posterior.*—The adductors longus and magnus are behin

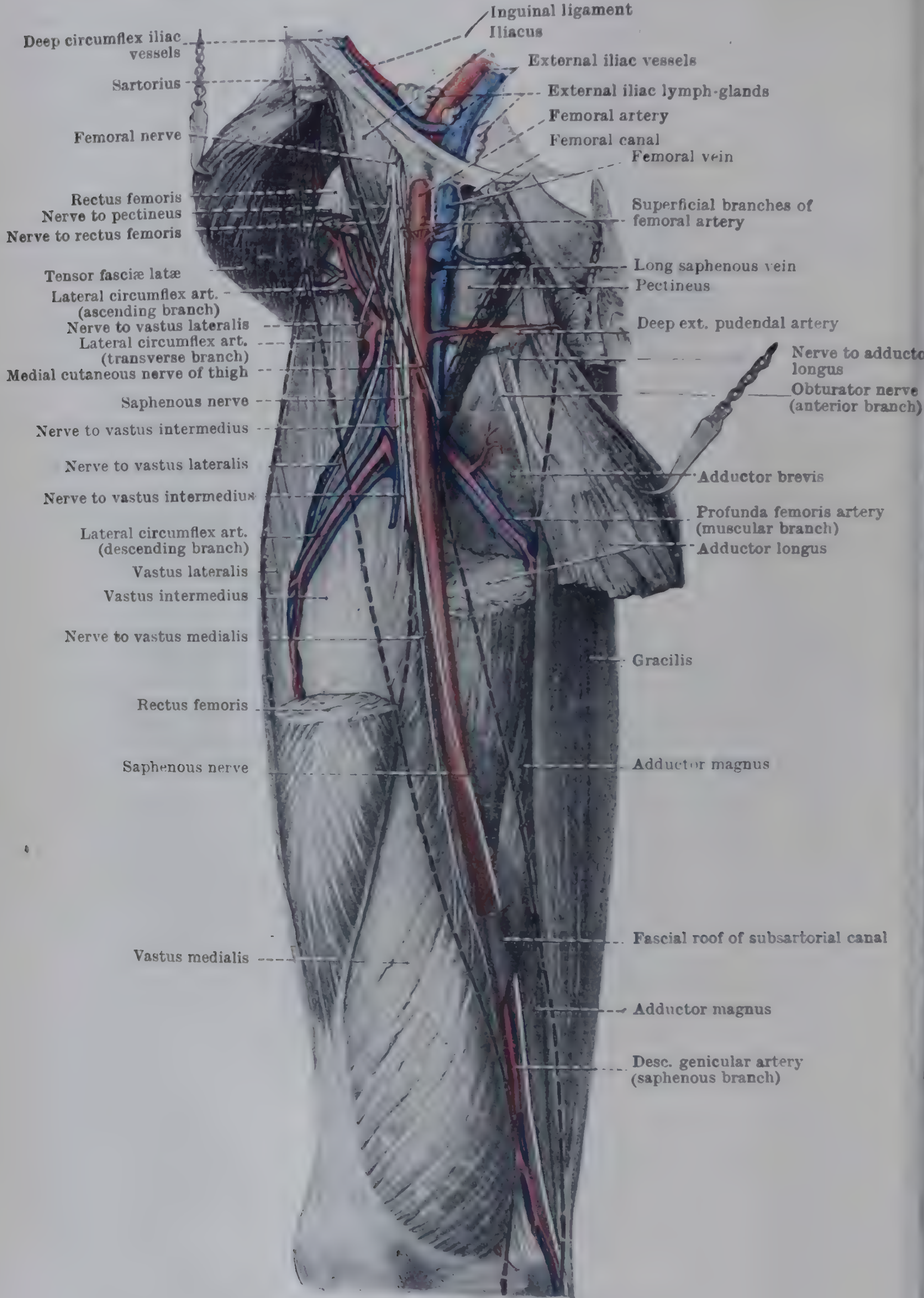

FIG. 1101.—FEMORAL ARTERY AND ITS BRANCHES.
The outlines of the sartorius, the upper part of the rectus femoris, and the adductor longus are indicated by broken black lines.

the artery, but are separated from it by the femoral vein, which is posterior to th artery proximally, and postero-lateral distally. The vastus medialis is *antero-latera* The fascial roof of the canal, the subsartorial plexus of nerves and the sartorius a

tero-medial. The saphenous nerve enters the canal with the artery, and runs first on its lateral side, then anterior, and lastly on its medial side.

Branches.—The femoral artery gives off the following branches :—

(1) Superficial branches.
- (*a*) Superficial circumflex iliac.
- (*b*) Superficial epigastric.
- (*c*) Superficial external pudendal.

(2) Muscular.
(3) Deep external pudendal.
(4) Profunda femoris.
(5) Descending genicular.

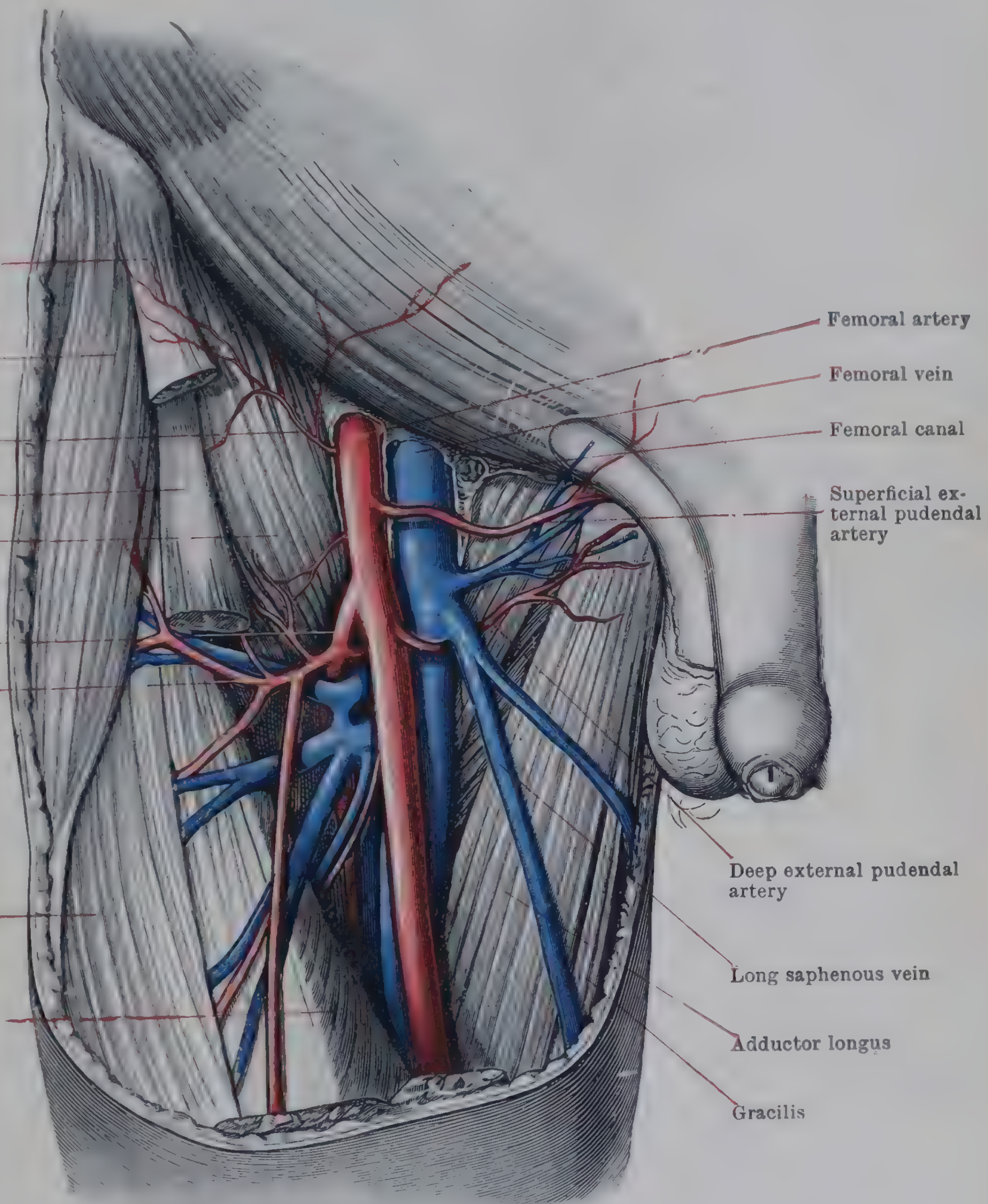

Fig. 1102.—Femoral Vessels in the Femoral Triangle.

The **superficial circumflex iliac artery** springs from the front of the femoral artery just below the inguinal ligament. It pierces the femoral sheath and the fascia lata, lateral to the saphenous opening of the fascia lata, and runs in the superficial fascia as far as the anterior superior iliac spine. It supplies the lateral set of inguinal lymph-glands and the skin of the groin; and it sends branches, through the fascia lata, to anastomose with branches of the deep circumflex iliac artery and to supply the upper parts of the sartorius and tensor fasciæ latæ muscles.

The **superficial epigastric artery** arises near the preceding. It pierces the femoral sheath and the cribriform fascia, and passes upwards and medially towards the umbilicus between the superficial and deep layers of the superficial fascia of the abdominal wall. It supplies the inguinal lymph-glands and the skin; it

anastomoses with its fellow of the opposite side, with the inferior epigastric, and with the superficial circumflex iliac and superficial external pudendal arteries.

The **superficial external pudendal artery** also springs from the front of the femoral artery, and, after piercing the femoral sheath and the cribriform fascia, runs upwards and medially towards the pubic tubercle, where it crosses superficial to the spermatic cord or the round ligament of the uterus and divides into terminal *scrotal* or *labial branches* according to the sex. It supplies the skin of the lower part of the abdominal wall, the root of the dorsum of the penis in the male, and the region of the mons pubis in the female; and it anastomoses with its fellow of the opposite side, with the deep external pudendal, with the dorsal artery of the penis or clitoris, and with the superficial epigastric artery.

The **muscular branches** are distributed to the adjacent muscles.

The **deep external pudendal artery** arises from the medial side of the femoral. It runs medially, anterior to the pectineus, and either anterior or posterior to the adductor longus, to the medial side of the thigh; it then pierces the deep fascia, and ends in the scrotum or the labium majus, where it anastomoses with the scrotal or labial branches of the superficial external and the internal pudendal arteries, and with the artery of the cremaster or of the round ligament.

The **profunda femoris artery** (Fig. 1102) is the largest branch of the femoral artery. It arises from the lateral side of the femoral artery about an inch and a half distal to the inguinal ligament. It curves backwards and medially, passes posterior to the main artery, and runs downwards, close to the medial aspect of the femur, to the distal third of the thigh, where it perforates the adductor magnus and passes to the back of the thigh. Its termination is known as the *fourth perforating artery*. As the profunda artery descends, it lies anterior to the iliacus, the pectineus, the adductor brevis, and the adductor magnus. It is separated from the femoral artery by its own vein, by the femoral vein, and by the adductor longus muscle.

Branches.—**Muscular branches** are given off from the profunda, both in the femoral triangle and between the adductor muscles; many of them end in the adductors, others pass through the adductor magnus, and end in the hamstring muscles, where they anastomose with the transverse branch of the medial circumflex and with the proximal muscular branches of the popliteal artery.

The **lateral circumflex artery** (Figs. 1101 and 1102) springs from the lateral side of the profunda, or occasionally from the femoral artery proximal to the origin of the profunda. It runs laterally, anterior to the iliacus and among the branches of the femoral nerve, to the lateral border of the femoral triangle; then, passing posterior to the sartorius and the rectus femoris, it ends by dividing into three terminal branches—the ascending, the transverse, and the descending. Before its termination it supplies branches to the muscles mentioned and to the proximal part of the vastus intermedius.

The **ascending branch** runs upwards and laterally, posterior to the rectus femoris and the tensor fasciæ latæ, along the trochanteric line, to the adjacent anterior borders of the gluteus medius and gluteus minimus, between which it passes to anastomose with the deep branches of the superior gluteal artery. It supplies twigs to the neighbouring muscles, anastomoses with the gluteal, the deep circumflex iliac, and the transverse branch of the lateral circumflex arteries, and, as it ascends along the trochanteric line, it gives off a branch which passes between the two limbs of the ilio-femoral ligament into the hip joint. The **transverse branch** is small; it runs laterally, between the vastus intermedius and the rectus femoris, passes into the substance of the vastus lateralis, winds round the femur, and anastomoses with the ascending and descending branches, with the perforating branches of the profunda, and with the inferior gluteal and medial circumflex arteries. The **descending branch** runs downwards, posterior to the rectus and along the anterior border of the vastus lateralis, accompanied by the nerve to the latter muscle. It anastomoses with the transverse branch, with twigs of the inferior perforating arteries, with the descending genicular branch of the femoral, and with the lateral superior genicular branch of the popliteal artery.

The **medial circumflex artery** springs from the medial and posterior part of the profunda, at the same level as the lateral circumflex, and runs backwards through the floor of the femoral triangle, passing between the psoas major and the pectineus; then it crosses the upper border of the adductor brevis, and continuing backwards, below the neck of the femur, it passes between the adjacent borders of the obturator externus and

the adductor brevis to the upper border of the adductor magnus, where it divides into two terminal branches—a transverse and an ascending branch.

Branches.—An **acetabular branch** is given off as the artery passes below the neck of the femur. It ascends to the acetabular notch where it anastomoses with twigs from the posterior

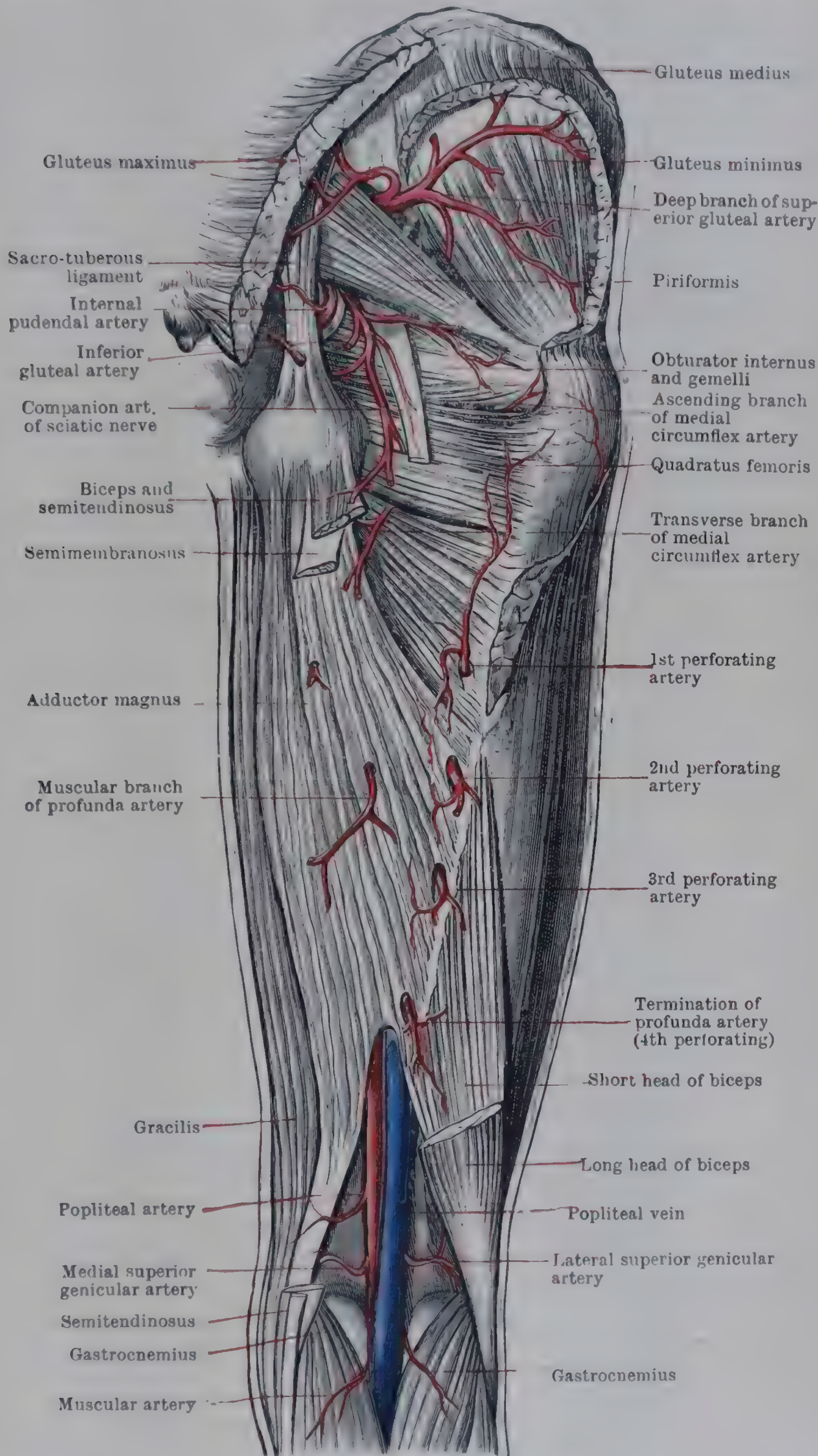

FIG. 1103.—ARTERIES OF GLUTEAL REGION AND BACK OF THIGH AND KNEE.

branch of the obturator artery, and it sends branches into the acetabular fossa and along the ligament of the head of the femur to supply the bone. **Muscular branches** are given off to the neighbouring muscles. The largest of those branches usually arises immediately before the termination of the artery; it runs downwards, on the anterior surface of the adductor magnus, and anastomoses with the muscular branches of the profunda artery. The **ascending branch** passes

upwards and laterally, between the obturator externus and the quadratus femoris to the trochanteric fossa of the femur, where it anastomoses with branches of the superior and inferior gluteal arteries. The **transverse branch** runs backwards to the hamstring muscles—usually between the lower border of the quadratus femoris and the upper border of the adductor magnus, but it may pierce the upper part of the adductor magnus. It anastomoses, in front of the distal part of the gluteus maximus, with the inferior gluteal and first perforating arteries and with the transverse branch of the lateral circumflex, and, in the substance of the hamstrings, with the muscular branches of the profunda.

The **perforating arteries** (Fig. 1103), including the terminal branch of the profunda, are usually described as four in number; but they are often irregular. They curve backwards and laterally, around the back of the femur, lying close to the bone and anterior to the well-marked tendinous arches which interrupt the continuity of muscular attachments; their terminal branches enter the vastus lateralis and anastomose in its substance with one another, with the descending branch of the lateral circumflex, with the descending genicular artery, and with the lateral superior genicular branch of the popliteal.

The **first perforating artery** pierces the insertions of the adductors brevis and magnus. Its branches anastomose, anterior to the gluteus maximus, with the inferior gluteal, and with the transverse branches of the medial and lateral circumflex arteries, forming what is known as the *crucial anastomosis of the thigh.*

The **second perforating artery** pierces the adductors brevis and magnus, and then passes between the gluteus maximus and the short head of the biceps femoris into the vastus lateralis. It anastomoses with its proximal and distal fellows, and with the medial circumflex and the proximal muscular branches of the popliteal artery.

The **third** and **fourth perforating arteries** pass through the adductor magnus and the short head of the biceps femoris into the vastus lateralis. Their anastomoses are similar to those of the second perforating.

A nutrient branch to the femur is given off from either the second or third perforating artery, usually the former; an additional nutrient branch may be supplied also by the first or fourth perforating arteries.

The **descending genicular artery** arises in the distal part of the subsartorial canal, near the termination of the femoral artery, and divides almost immediately into a superficial (saphenous) and a deep (musculo-articular) branch; indeed, very frequently the two branches arise separately from the femoral trunk.

The **saphenous branch** passes through the distal end of the subsartorial canal with the saphenous nerve, and appears superficially, on the medial side of the knee, between the gracilis and the sartorius. It gives twigs to the skin of the proximal and medial part of the leg, and it anastomoses with the medial inferior genicular artery. The **musculo-articular branch** runs towards the knee, in the substance of the vastus medialis, along the anterior aspect of the tendon of the adductor magnus. It anastomoses with the medial superior genicular artery; and it sends branches laterally, one on the surface of the femur and another along the proximal border of the patella, to anastomose with the descending branch of the lateral circumflex, the fourth perforating artery, the lateral superior genicular, and the anterior tibial recurrent (Pl. LXXXIV, p.1313).

Variations.—The **femoral artery** is small and ends in the profunda and circumflex branches, when the inferior gluteal artery forms the principal vessel of the lower limb. The **profunda** branch, which arises usually from the lateral side of the femoral trunk, about 1½ in. (35 mm.) distal to the inguinal ligament, may begin at a more proximal or a more distal level, and from the back or the medial side of the femoral trunk. In rare cases when the profunda arises at a more proximal level than usual it may cross anterior to the femoral vein, above the entrance of the long saphenous vein, after which it passes downwards and laterally behind the femoral vessels (Johnston, 1912). Absence of the profunda has been noted, and in those cases the branches usually given off by it spring directly from the femoral artery.

The femoral artery may be double for a portion of its extent, or it may be joined by a vas aberrans given off from the external iliac artery. In addition to its ordinary branches, it may furnish one or both of the circumflex arteries of the thigh, and sometimes it gives off, near the origin of the profunda, a *long saphenous artery*, such as exists normally in many mammals. This vessel runs downwards through the femoral triangle and the subsartorial canal, and accompanies the saphenous nerve to the medial side of the foot.

The deep circumflex iliac, the obturator, and the inferior epigastric arteries are occasionally given off from the femoral.

POPLITEAL ARTERY

The **popliteal artery** is the direct continuation of the femoral. It begins at the medial and proximal side of the popliteal fossa, under cover of the semimem-

branosus, and ends at the distal border of the popliteus muscle, and on a level with the distal part of the tubercle of the tibia, by dividing into the anterior and the posterior tibial arteries. The artery passes with a slight lateral obliquity from its origin to the interspace between the condyles of the femur, and then descends vertically between them (Pl. LXXXIII, p. 1312).

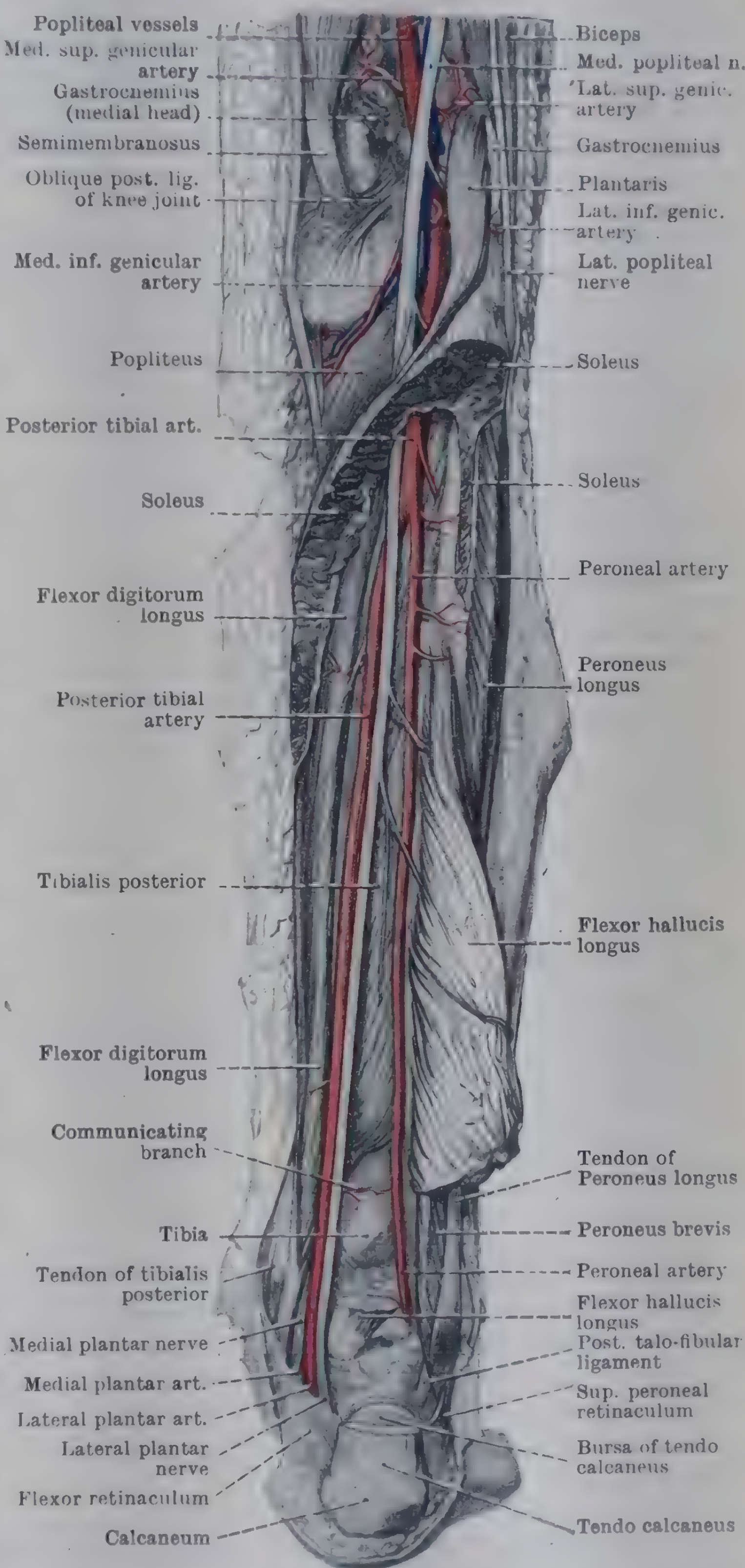

Fig. 1104.—Popliteal and Posterior Tibial Arteries and their Branches.

Relations. — *Anterior.* — It is closely related, from above downwards, to the popliteal surface of the femur, the posterior part of the capsule of the knee joint, and the fascia covering the popliteus.

Posterior. — The artery is overlapped behind, in the proximal part of its extent, by the lateral border of the semimembranosus; it is crossed, about its middle, by the popliteal vein and the medial popliteal nerve, the vein intervening between the artery and the nerve; whilst, in the distal part of its extent, it is overlapped by the adjacent borders of the two heads of the gastrocnemius, and is crossed by the nerves to the soleus and popliteus and by the plantaris muscle.

Lateral.—On its lateral side it is in relation, proximally, with the medial popliteal nerve and the popliteal vein, then with the lateral condyle of the femur and the plantaris, and, distally, with the lateral head of the gastrocnemius.

Medial.—On the medial side it is in relation, proximally, with the semimembranosus, then with the medial condyle of the femur, and distally with the medial popliteal nerve, the popliteal vein, and the medial head of the gastrocnemius. Popliteal lymph-glands are arranged irregularly around the artery.

Branches.—Muscular branches are given off in two sets, proximal and distal.

The *proximal muscular branches* are distributed to the distal parts of the hamstring muscles, in which they anastomose with branches of the profunda artery.

The distal muscular or *sural arteries* enter the proximal parts of the muscles of the calf, and they have little or no anastomoses with other arteries. Each head of the gastrocnemius receives a single large branch which enters at a definite neuro-vascular hilum: these branches are virtually end-arteries (Pl. LXXXIV, p. 1313) and damage to one of them may result in necrosis of the entire head it supplies.

There are five **genicular arteries**—namely, lateral superior and inferior, medial superior and inferior, and a middle.

The **lateral superior genicular artery** passes laterally, proximal to the lateral condyle, in front of the biceps tendon, into the vastus lateralis, where it anastomoses with the descending genicular artery, the descending branch of the lateral circumflex, and the fourth perforating artery; it also sends branches distally to anastomose with the lateral inferior genicular and with the anterior recurrent branch of the anterior tibial.

The **medial superior genicular artery** passes medially, proximal to the medial condyle, anterior to the tendon of the adductor magnus, into the vastus medialis. It anastomoses with branches of the descending genicular artery and of the lateral superior genicular artery.

The **lateral inferior genicular artery** runs laterally, across the popliteus muscle and anterior to the plantaris and the lateral head of the gastrocnemius; then, turning forwards, it is joined by an articular branch of the lateral popliteal nerve, and passes deep to the lateral ligament of the knee. It ends by anastomosing with its fellow of the opposite side, with the lateral superior genicular and the anterior recurrent branch of the anterior tibial artery.

The **medial inferior genicular artery** passes medially, distal to the medial condyle of the tibia, along the proximal border of the popliteus and in front of the medial head of the gastrocnemius, to the medial side of the knee, where it turns forwards, between the bone and the medial ligament of the knee, and ends anteriorly by anastomosing with its fellow of the opposite side, with the anterior recurrent branch of the anterior tibial artery, and with the medial superior genicular artery.

The **middle genicular artery** passes directly forwards from the front of the popliteal artery, pierces the central part of the posterior surface of the capsule of the knee joint, and enters the intercondylar notch. It supplies branches to the cruciate ligaments and to the synovial membrane, and is accompanied by an articular branch of the medial popliteal nerve, and sometimes by the articular branch of the obturator nerve.

Cutaneous branches are distributed to the skin over the popliteal fossa. One of these—the *superficial sural artery*—runs along the middle of the back of the calf with the short saphenous vein (Pl. LXXXIV, p. 1313).

Variations.—The **popliteal artery** may exceptionally form the direct continuation of the inferior gluteal artery. It sometimes divides at a more proximal or more distal level than usual, and the division may be into either two or three branches; if three terminal branches are present, they are the anterior and posterior tibial and the peroneal arteries, and if only two, either the anterior and posterior tibial, or the anterior tibial and the peroneal arteries.

Occasionally the artery is double for a short portion of its course, and it has been found to cross, first posterior to the medial head of the gastrocnemius to the medial side of the knee, and then anterior to the medial head of the gastrocnemius to regain the popliteal fossa. The number of its branches may be reduced, or they may be increased by the addition of a vas aberrans which connects it with the posterior tibial artery. Its superficial sural branch may enlarge to form a well-marked *short saphenous artery*.

Posterior Tibial Artery

The **posterior tibial artery**, the larger of the two terminal branches of the popliteal, begins at the distal border of the popliteus and ends midway between the tip of the medial malleolus and the most prominent part of the heel, at the distal border of the flexor retinaculum. It ends by dividing into the medial and the lateral plantar arteries, which pass onwards to the sole of the foot (Fig. 1105, Pl. LXXXVI, p. 1383).

The posterior tibial artery runs downwards and medially, in the posterior part of the leg, between the superficial and deep layers of muscles and covered, posteriorly, by the intermuscular fascia which intervenes between them.

Relations.—*Anterior.*—It is in contact, proximo-distally, with the tibialis posterior, the flexor digitorum longus, the posterior surface of the tibia, and the posterior ligament of the ankle joint.

Posterior.—The artery is crossed by the posterior tibial nerve about an inch distal to its origin. Elsewhere it is in contact with the intermuscular fascia which binds down the deep layer of muscles. More superficially the proximal half of the artery is covered by the fleshy parts of the soleus and gastrocnemius muscles; the distal half of the artery is much nearer the surface, and is covered only by skin and fasciæ. At its termination it lies deep to the flexor retinaculum.

Lateral and Medial.—The posterior tibial nerve lies at first on the medial side of the vessel, then crosses posterior to it, and is continued downwards on its lateral side. In the most distal part of its course the artery is separated from the medial malleolus by the tendons of the tibialis posterior and the flexor digitorum longus, whilst the tendon of the flexor hallucis longus lies lateral to it. It is accompanied by two venæ comitantes.

Branches.—The posterior tibial gives off numerous branches, the largest of which—the peroneal—is one of the chief arteries of the leg. The branches include :—

Large **muscular branches** to the adjacent muscles, including the soleus which is supplied also by a branch from the popliteal artery

Cutaneous branches are distributed to the skin of the medial and posterior part of the leg.

A **circumflex fibular branch** passes laterally round the neck of the fibula through the fibres of the soleus, and anastomoses with the lateral inferior genicular artery. Occasionally it springs from the lower end of the popliteal artery, or from the anterior tibial.

The **nutrient artery to the tibia**, the largest of the nutrient group of arteries to long bones, springs from the proximal part of the posterior tibial, pierces the tibialis posterior and enters the nutrient foramen on the posterior surface of the bone. Before it enters the tibia the nutrient artery gives small muscular branches.

The **communicating branch** unites the posterior tibial to the peroneal artery about an inch above the inferior tibio-fibular joint. It passes between the shaft of the tibia and the flexor hallucis longus.

Calcanean branches arise from the artery just before it divides. They pierce the flexor retinaculum, supply the medial side of the heel, and anastomose with the peroneal and the malleolar arteries.

A **malleolar branch** is distributed to the medial surface of the medial malleolus, anastomosing with malleolar branches of the anterior tibial and peroneal arteries.

The **peroneal artery** (Fig. 1104) is the largest branch of the posterior tibial (Pl. LXXXIV, p. 1313). Arising about 1 inch (25 mm.) below the distal border of the popliteus, it curves laterally across the proximal part of the tibialis posterior to the medial crest of the fibula, along which it passes to the distal part of the interosseous space. About 1 inch proximal to the ankle joint it gives off a perforating branch and then passes, behind the inferior tibio-fibular joint and lateral malleolus, to the lateral side of the heel and the foot. It supplies the ankle, the inferior tibio-fibular and talo-calcanean joints, and anastomoses with a calcanean branch of the lateral plantar artery, and with the tarsal and arcuate branches of the dorsalis pedis.

As the peroneal artery passes laterally from its origin it lies behind the tibialis posterior, and is covered posteriorly by the deep intermuscular fascia and by the soleus. As it descends along the medial crest of the fibula it lies in a fibrous canal between the tibialis posterior in front and the flexor hallucis longus behind. It is accompanied by two venæ comitantes which anastomose around it.

Branches.—**Muscular branches** are distributed to the adjacent muscles. Some pass through the interosseous membrane and help to supply the anterior muscles of the leg.

The **nutrient artery to the fibula** enters the nutrient foramen of that bone.

The **communicating branch** passes across the back of the tibia, about an inch above the inferior tibio-fibular joint, to anastomose with the posterior tibial artery.

The **perforating branch** passes forwards at the junction of the distal border of the interosseous membrane and the interosseous tibio-fibular ligament, and runs, in front of the ankle joint, to the dorsum of the foot, where it anastomoses with the lateral malleolar branch of the anterior tibial artery and with the tarsal branch of the dorsalis pedis ; it also supplies branches to the inferior tibio-fibular joint, to the ankle joint, and to the peroneus tertius.

A **malleolar branch** and **calcanean branches** take part in the anastomosis on the lateral side of the ankle and heel.

Variations.—The **posterior tibial artery** may be small or altogether absent, its place being taken by branches of the peroneal artery ; again, it may be longer or shorter than usual, in conformity with the more proximal or more distal division of the popliteal trunk. The peroneal artery is large, if either the anterior or the posterior tibial artery is small. The perforating branch of the peroneal is almost invariably large when the anterior tibial artery is small ; in some cases it replaces the whole of the dorsalis pedis continuation of the latter vessel ; in others, however, only the tarsal and arcuate branches are so replaced. The peroneal sometimes arises from a stem common to it and the anterior tibial artery.

Plantar Arteries

The **medial and lateral plantar arteries** are the terminal branches of the posterior tibial artery. They arise, under cover of the flexor retinaculum, midway between

the tip of the medial malleolus and the most prominent part of the medial side of the heel (Figs. 1104, 1105, Pl. LXXXVI, p. 1383.)

The **medial plantar artery** is the smaller of the two. It passes forwards, on the medial side of the medial plantar nerve, along the medial side of the foot in the interval between the abductor hallucis and the flexor digitorum brevis, to the head of the first metatarsal bone, where it ends by uniting with the digital branch of the first plantar metatarsal artery which is distributed to the medial side of the big toe. In its course forwards it gives off a branch which ramifies on the superficial surface of the abductor hallucis, branches to the adjacent muscles and articulations, and branches to the skin; it also gives three *digital branches* which anastomose, at the roots of the medial three interdigital clefts, with the medial plantar metatarsal arteries. Some of the cutaneous branches of the medial plantar artery anastomose, round the medial border of the foot, with cutaneous branches of the dorsalis pedis artery.

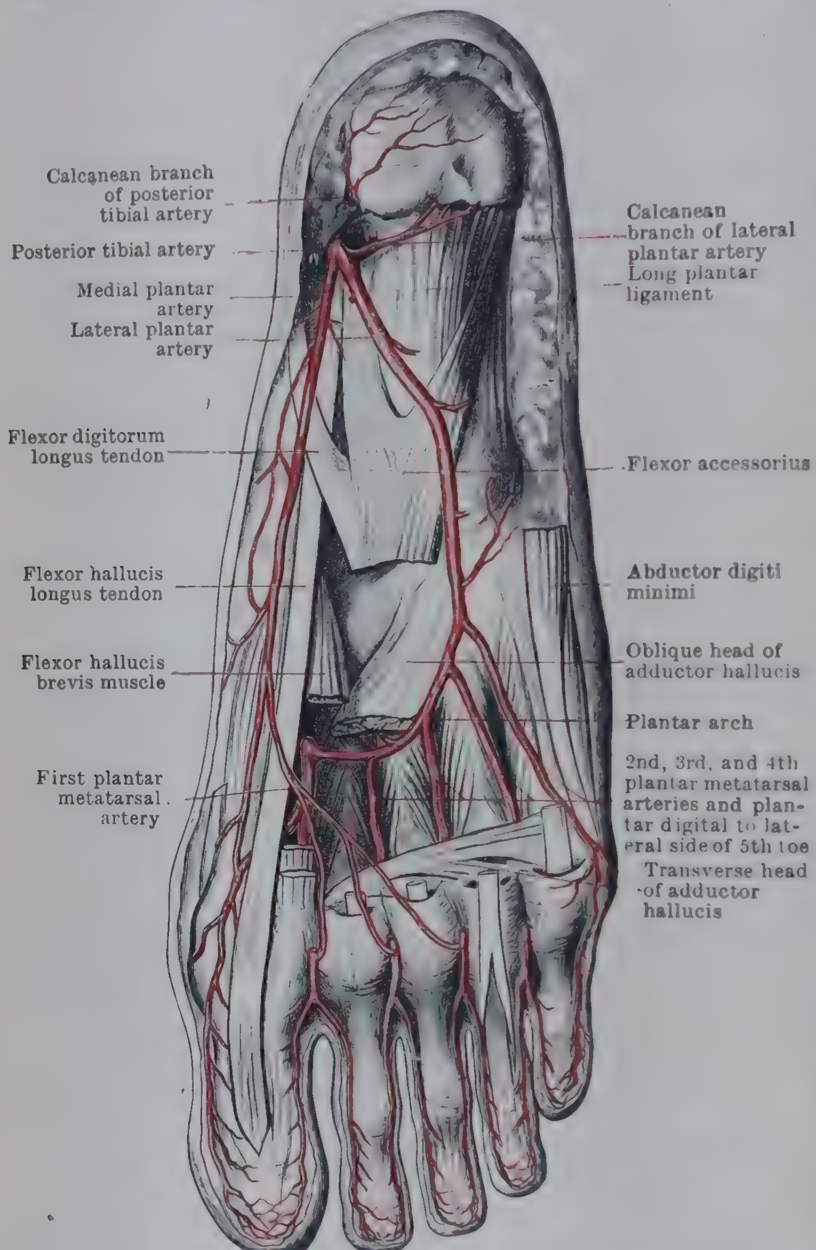

Fig. 1105.—Plantar Arteries and their Branches.

The **lateral plantar artery** is the larger of the two terminal branches of the posterior tibial artery. It runs obliquely forwards across the sole on the lateral side of the lateral plantar nerve, first between the flexor digitorum brevis superficially and the flexor accessorius deeply, and then, in the interval between the flexor digitorum brevis and the abductor digiti minimi, to the medial side of the base of the fifth metatarsal bone. There it turns abruptly medially and, gaining a deeper plane, passes across the metatarsal bones, near their bases, and the origins of the interossei, and above the oblique head of the adductor hallucis, to the lateral side of the first metatarsal bone, where it ends by anastomosing with the dorsalis pedis artery. The last part of the artery is convex forwards and forms the *plantar arch*, which is completed by its junction with the dorsalis pedis.

Branches.—Between its origin and the base of the fifth metatarsal the lateral plantar artery gives off: A **calcanean branch**, which is distributed to the skin and the subcutaneous tissue of the heel; **muscular branches** to the adjacent muscles; and **cutaneous branches** to the skin of the lateral side of the foot.

Between the base of the fifth metatarsal bone and the first interosseous space it forms the **plantar arch**, and gives off: Four **plantar metatarsal arteries**; three **perforating**

branches to the dorsal metatarsal arteries; and twigs to the tarsal joints and the muscles in the vicinity.

The **first plantar metatarsal artery** is a branch of the dorsalis pedis, arising from that artery as it joins the lateral plantar to complete the plantar arch (see p. 1328). The **second, third**, and **fourth plantar metatarsal branches** run forwards on the plantar surfaces of the interossei, the medial two lying dorsal to the oblique head of the adductor hallucis, and all three passing dorsal to the transverse head. At the bases of the interdigital clefts the second, third, and fourth plantar metatarsal arteries divide into **plantar digital arteries** which run along the plantar aspects of adjacent toes, and supply skin, joints, and the flexor tendons and sheaths. Opposite the distal phalanx of each toe the digital arteries of opposite sides of the toe anastomose together. The plantar digital artery *to the lateral border of the little toe* has an independent origin from the lateral plantar artery where it becomes the plantar arch. It crosses the plantar surface of the flexor digiti minimi brevis to reach the lateral border of the toe along which it runs.

The **perforating branches** are three in number; they pass through the lateral three intermetatarsal spaces, between the heads of the dorsal interosseous muscles, and join the corresponding dorsal metatarsal arteries. *Anterior perforating branches*, which also join the dorsal metatarsal arteries, are given off from two or three of the plantar metatarsal arteries just before they divide.

Variations.—The **medial plantar artery** is sometimes very small. It may be absent and its place is then taken by branches of the dorsalis pedis or lateral plantar arteries. The **lateral plantar artery also may** be small; or it may be absent, the plantar arch being then formed entirely by the dorsalis pedis.

Anterior Tibial Artery

The **anterior tibial artery**, the smaller of the two terminal divisions of the popliteal, begins opposite the distal border of the popliteus muscle, and ends in front of the ankle, where it is continued as the dorsal artery of the foot.

Course and Relations.—From its origin, at the back of the leg, the artery passes forwards, between the two slips of the proximal part of the tibialis posterior and through an aperture in the upper end of the interosseous membrane. It then runs downwards, resting, in the proximal two-thirds of its course, against the anterior surface of the interosseous membrane and, subsequently, on the distal part of the tibia and the anterior ligament of the ankle joint. In the proximal third of the anterior compartment of the leg it lies between the extensor digitorum longus laterally and the tibialis anterior medially; in the middle third it is between the extensor hallucis longus and the tibialis anterior; in the distal third the extensor hallucis longus crosses in front of the artery and reaches its medial side, and the most distal part of the vessel lies between the tendon of the extensor hallucis longus on the medial side and the most medial tendon of the extensor digitorum longus on the lateral side. Two venæ comitantes, with numerous intercommunications, lie along the sides of the artery.

The anterior tibial nerve is at first well to the lateral side of the artery, but it approaches the vessel and lies in front of its middle third; more distally the nerve is usually found on the lateral side again, and at the ankle it intervenes between the artery and the most medial tendon of the extensor digitorum longus.

The proximal part of the anterior tibial artery is deeply placed and the adjacent muscles overlap it. In the distal two-thirds of its extent it is easily accessible from the surface; and beyond being covered by the nerve and crossed by the tendon, as already described, is covered, in addition, only by skin, fascia, and the superior extensor retinaculum.

Branches.—Close to its origin the artery gives off a posterior recurrent and sometimes a circumflex fibular branch; after it reaches the front of the leg it gives off anterior recurrent, muscular, cutaneous, and medial and lateral anterior malleolar branches.

The **circumflex fibular branch** is a small vessel that may arise from the posterior tibial or the popliteal artery (see p. 1323).

The **posterior recurrent branch**, also small, and not always present, runs upwards, anterior to the popliteus muscle, to the back of the knee joint. It anastomoses with the

inferior genicular branches of the popliteal, and gives branches to the popliteus muscle and the superior tibio-fibular joint.

The **anterior recurrent branch** arises from the anterior tibial artery in front of the interosseous membrane. It runs upwards and medially, between the proximal part of the tibialis anterior and the lateral condyle of the tibia, accompanied by the recurrent articular branch of the lateral popliteal nerve, and, after supplying the tibialis anterior and the superior tibio-fibular joint, it pierces the deep fascia of the leg; it is connected with the anastomosis round the knee joint, formed by the genicular branches of the popliteal artery, the descending branch of the lateral circumflex artery, and the descending genicular artery.

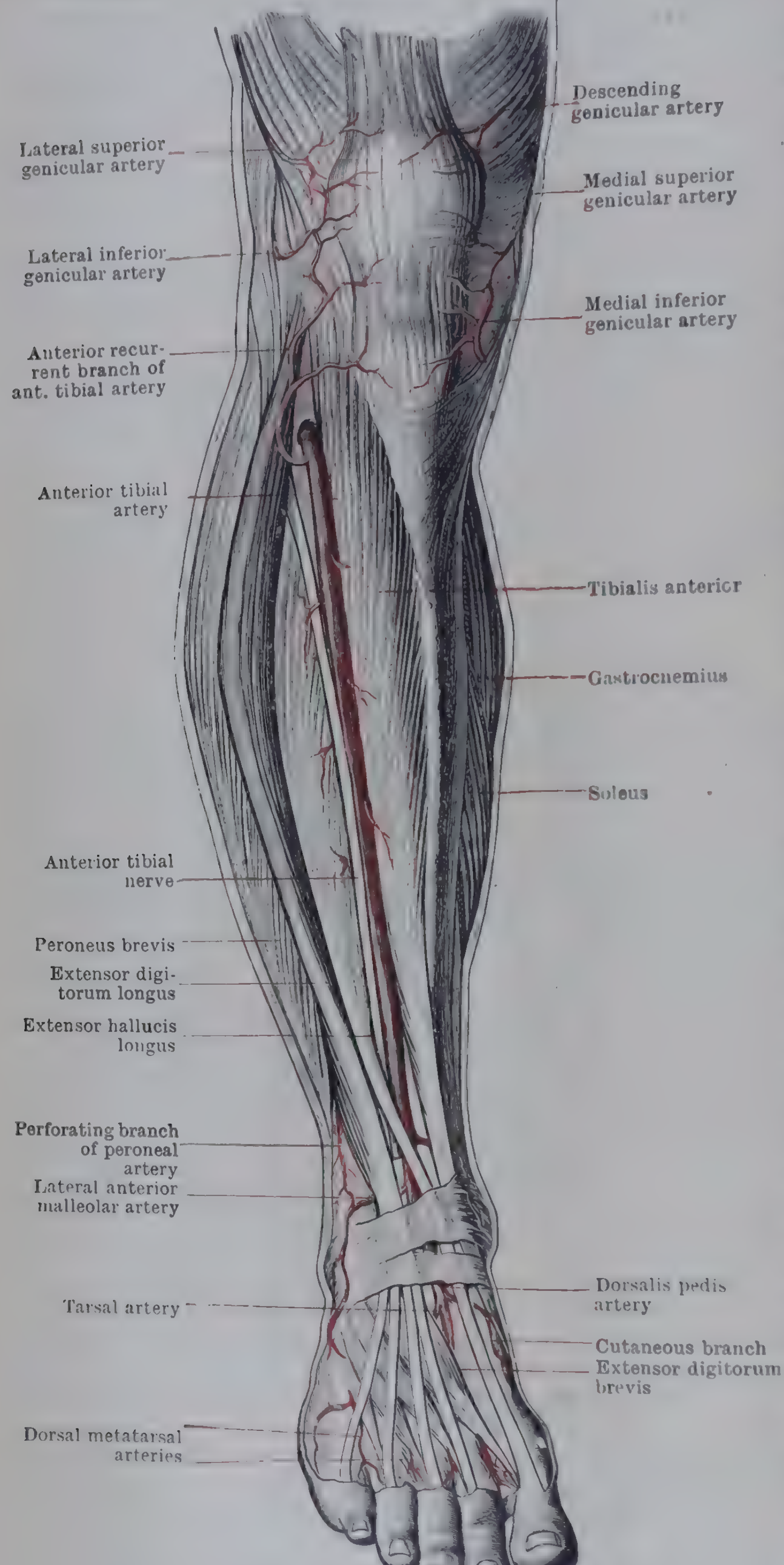

Fig. 1106.—Anterior Tibial Artery and its Branches.

The **muscular branches** are distributed to the adjacent muscles of the front and back of the leg.

The **cutaneous branches** supply the skin of the front of the leg.

The **medial anterior malleolar artery** arises from the lower part of the anterior tibial artery, and is smaller than its companion on the lateral side. It runs medially, posterior to the tibialis anterior tendon, ramifies over the medial malleolus, anastomosing with branches of the posterior tibial artery, and is distributed to the skin and to the ankle joint.

The **lateral anterior malleolar artery**, more constant and larger than the medial, passes laterally, posterior to the extensor digitorum longus and peroneus tertius, towards the lateral malleolus. It anastomoses with the perforating branch of the peroneal artery and with the tarsal artery, and supplies the ankle joint and the adjacent joints.

Dorsalis Pedis Artery.—The dorsal artery of the foot is the direct continuation of the anterior tibial; it begins on the front of the ankle joint and runs to the posterior end of the first interosseous space, where it gives off the first dorsal metatarsal artery and then passes into the sole of the foot between the two heads

of the first dorsal interosseous muscle to unite with the lateral plantar artery in the formation of the plantar arch (Pls. LXXXV, LXXXVI, p. 1382).

It is covered superficially by skin and fasciæ, including the inferior extensor retinaculum, and it is crossed, just before it reaches the first interosseous space, by the tendon of the extensor hallucis brevis. It rests upon the anterior ligament of the ankle, the head of the talus, the talo-navicular ligament, the navicular bone, the dorsal cuneo-navicular ligament and the intercuneiform ligament between the medial and intermediate cuneiform bones. On its lateral side is the medial terminal branch of the anterior tibial nerve, which intervenes between it and the extensor digitorum brevis and the most medial tendon of the extensor digitorum longus. On its medial side it is in relation with the tendon of the extensor hallucis longus. Two venæ comitantes, one on each side, accompany the artery.

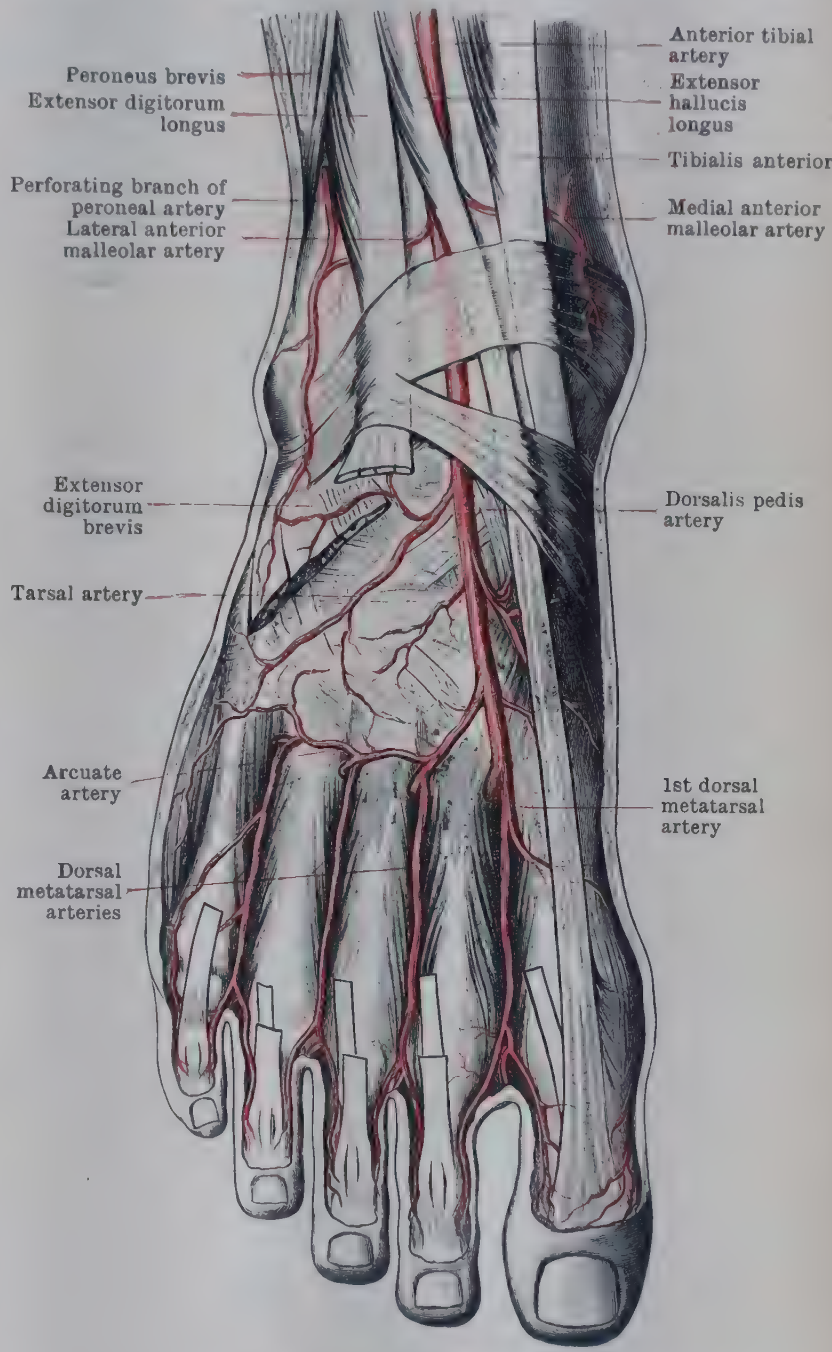

FIG. 1107.—DORSALIS PEDIS ARTERY AND ITS BRANCHES.

Branches.—Cutaneous branches are distributed to the skin on the dorsum and medial side of the foot; they anastomose with branches of the medial plantar artery.

The **tarsal artery** arises opposite the head of the talus; it runs laterally, deep to the extensor digitorum brevis, supplying that muscle and the tarsal joints, and it anastomoses with the perforating branch of the peroneal, the arcuate, and lateral plantar arteries, and with the lateral anterior malleolar artery. Other smaller tarsal branches are given off on both lateral and medial sides of the artery.

The **arcuate artery** arises opposite the medial cuneiform bone. It runs laterally, on the bases of the metatarsal bones, deep to the long and short extensor tendons, supplies the extensor digitorum brevis, and anastomoses with branches of the tarsal and lateral plantar arteries. It gives off three **dorsal metatarsal arteries**, second, third, and fourth, which run forwards on the interosseous muscles in the lateral three interosseous spaces to the clefts of the toes, where each divides into two *dorsal digital arteries* for the adjacent sides of the toes bounding the cleft to which it goes. The lateral side of the little toe receives a branch from the most lateral dorsal metatarsal artery. Each dorsal metatarsal artery gives off a *posterior perforating branch*, which passes through the posterior part of the intermetatarsal space, between the heads of the dorsal interosseous muscle, to anastomose with the plantar arch, and an *anterior perforating branch*, which passes through the anterior part of the space to anastomose with the corresponding plantar metatarsal artery.

The **first dorsal metatarsal artery** is continued forwards from the dorsalis pedis and runs on the dorsal surface of the first dorsal interosseous muscle. It ends by dividing into dorsal digital branches for the adjacent sides of the first and second toes. Before it divides it usually gives off a *dorsal digital branch* which passes, deep to the tendon of the extensor hallucis, to the medial side of the big toe.

As the dorsalis pedis unites with the lateral plantar artery to complete the plantar arch it gives off the **first plantar metatarsal artery,** which passes forwards, along the first intermetatarsal space, to the base of the first interdigital cleft, where it divides into *plantar digital arteries* for the adjacent sides of the first and second toes; before it divides it gives off a *plantar digital artery* to the medial side of the big toe.

Variations.—The **anterior tibial artery** may be absent, its place being taken by branches of the posterior tibial and peroneal arteries. It is longer than normal when the popliteal artery divides at a higher level than usual, and in those cases it may pass either posterior or anterior to the popliteus muscle. Occasionally the anterior tibial artery and its dorsalis pedis continuation are larger than normal, and the terminal part of the dorsalis pedis takes the place, more or less completely, of the lateral plantar artery.

VEINS

Veins commence in the networks of capillaries. They converge towards the heart, and unite with one another to form larger and still larger vessels, until, finally, seven large trunks are formed which open into the atria of the heart. Three of the trunks—the **superior vena cava**, the **inferior vena cava**, and the **coronary sinus**—belong to the *systemic circulation*; they contain venous blood, and open into the right atrium. The remaining four—the **pulmonary veins**—belong to the *pulmonary circulation*; they return oxygenated blood from the lungs, and open into the left atrium. They are described on p. 1243.

In addition to the systemic and pulmonary veins, there is also a third group of veins, constituting the **portal system**, in which blood from the abdominal part of the alimentary canal, and from the spleen and pancreas, is conveyed to the liver. The portal system is peculiar in that it both begins and ends in capillaries; and its communications with systemic veins are of clinical importance (p. 1367). From the sinusoidal capillaries in the liver the *hepatic veins* arise, and as those open into the inferior vena cava the blood of the portal system is finally poured into the general systemic circulation. The hepatic veins receive also the blood supplied to the liver by the hepatic arteries.

For a general survey of the anatomy and physiology of the venous system with full bibliography, consult the monograph by Franklin (1937).

SYSTEMIC VEINS

The **systemic veins** return blood to the right atrium of the heart through the superior vena cava, the inferior vena cava, and the coronary sinus. The two venæ cavæ receive blood from the head and neck, the body-wall, the limbs, and from the abdominal and pelvic viscera. The coronary sinus receives blood from the veins of the walls of the heart alone.

The veins in general are much more numerous than the arteries and of greater capacity; also they anastomose more freely and in many parts of the body they form *venous plexuses* composed of networks of thin-walled, intercommunicating vessels, *e.g.*, the pterygoid plexus (p. 1340), the pampiniform plexuses of the testis and ovary (p. 1356) and the venous plexuses of the pelvic organs (p. 1358). The presence of *valves* in the veins is of importance in the maintenance of the circulation; their structure has been described on p. 1223.

General Arrangement.—The veins of the head and neck, the body-wall and limbs, form two groups: (1) the superficial veins; (2) the deep veins.

The **superficial veins** lie in the superficial fascia; they begin in the capillaries of the skin and subcutaneous tissues, and are very numerous. They freely anastomose with one another, and they also communicate with the deep veins, in which they end after piercing the deep fascia. They may or may not accompany superficial arteries.

The **deep veins** accompany arteries, and are known as *venæ comitantes.* The large arteries have only one accompanying vein, but with the medium-sized and small arteries there are usually two venæ comitantes, which anastomose freely with each other by short transverse channels of communication.

Visceral veins usually accompany the arteries which supply viscera in the head, neck, thorax, and abdomen. As a rule there is only one vein with each visceral artery, and, with the exception of those which enter into the formation of the portal system, they end in the deep systemic veins.

The **venous sinuses** which are found inside the cranium (p. 1344) differ from ordinary veins in that they are formed by channels, between the two layers of the dura mater, lined by endothelium only and have no muscular coat.

CORONARY SINUS AND VEINS OF HEART

The **coronary sinus** (Fig. 1057) is a short, but relatively wide, venous trunk which receives the majority of the veins of the heart. It lies in the lower part of the atrio-ventricular groove, between the left atrium and the left ventricle, and it is covered superficially by some of the muscular fibres of the atrium.

It terminates in the lower and posterior part of the right atrium, between the orifice of the inferior vena cava on the right, and the right atrio-ventricular orifice in front; an imperfect valve, consisting of one cusp, called the **valve of the coronary sinus**, is situated at the right margin of the opening of the sinus into the atrium (Fig. 1060).

The apertures of the tributaries of the coronary sinus are not provided with valves, except those of the great and small cardiac veins, and their valves are often incompetent.

Tributaries.—The **great cardiac vein** (Fig. 1058) begins at the apex of the heart. It ascends in the anterior interventricular groove to the atrio-ventricular groove; it then turns to the left, passes round the left surface of the heart into the lower part of the atrio-ventricular sulcus, and ends in the left extremity of the coronary sinus. It receives tributaries from the walls of both ventricles and from the wall of the left atrium. It receives also the *left marginal vein* which ascends from the apex of the heart along its left border.

The **small cardiac vein** is very variable; as a rule it begins at the lower border of the heart near the apex and passes to the right to the atrio-ventricular groove, in which it turns to the left, and ends in the right extremity of the coronary sinus. It receives tributaries from the walls of the right atrium and the right ventricle.

The **middle cardiac vein** begins at the apex of the heart, and passes backwards in the inferior interventricular groove to end in the coronary sinus near its right extremity. It receives tributaries from the walls of both ventricles; some of those from the left ventricle, of which one may be large, end independently in the coronary sinus.

The **oblique vein of the left atrium** (Fig. 1057) is a small venous channel which descends obliquely on the posterior wall of the left atrium, and ends in the coronary sinus. It is of special interest inasmuch as it represents the left superior vena cava of some other mammals, and is developed from the left duct of Cuvier. It is continuous above with the *ligament of the left vena cava* (see Pericardium, p. 1242).

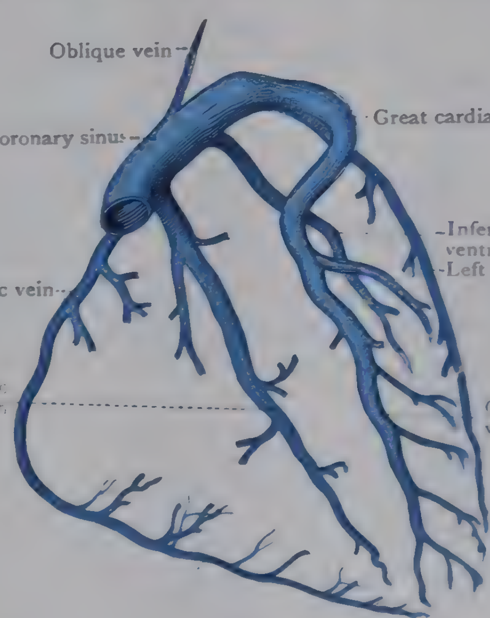

FIG. 1108.—DIAGRAM OF VEINS ON SURFACE OF HEART.

Veins of Heart which do not end in Coronary Sinus.—The **anterior cardiac veins** are two or three small vessels which ascend on the anterior wall of the right ventricle to the atrio-ventricular groove, across which they pass to end directly in

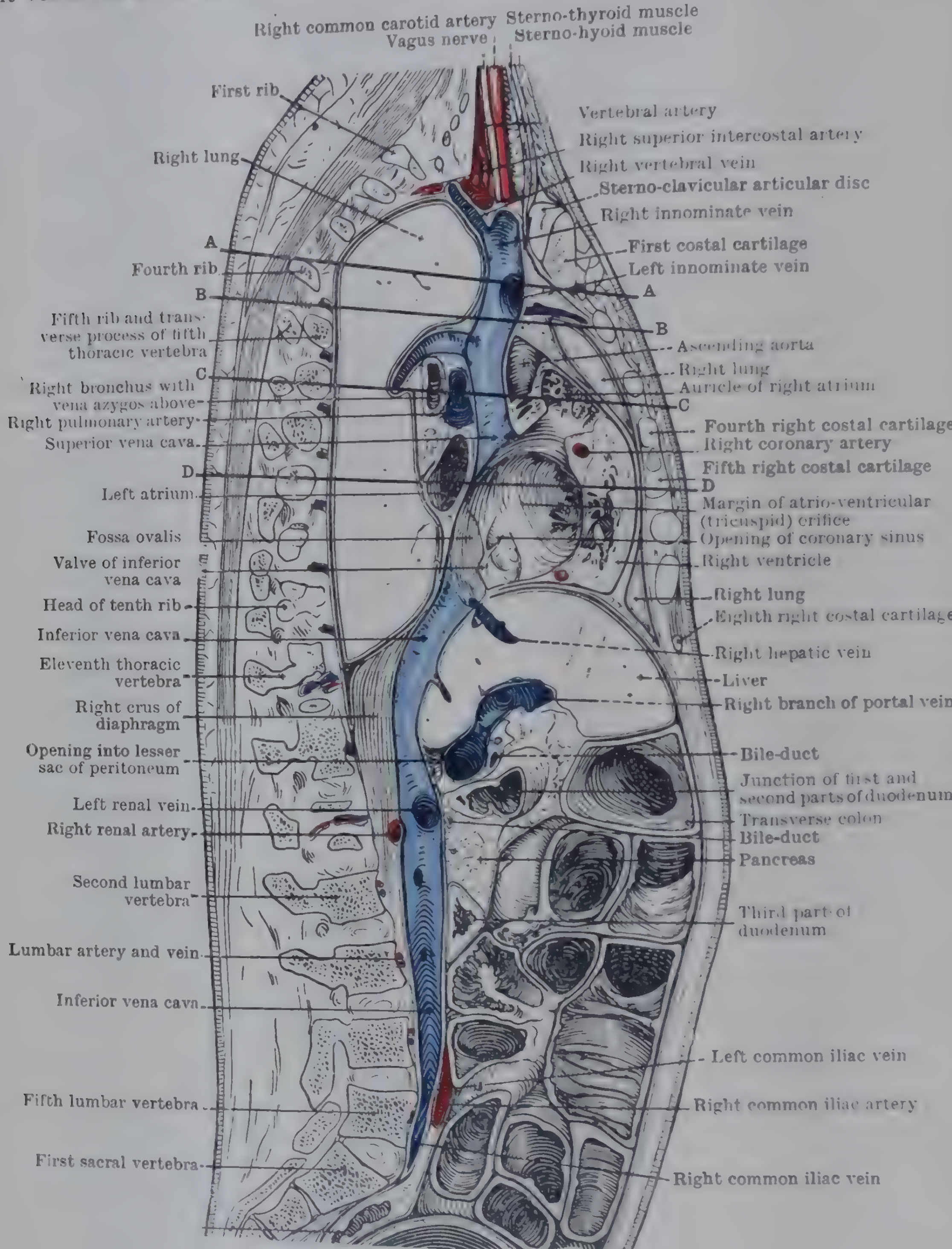

FIG. 1109.—SAGITTAL SECTION OF BODY OF YOUNG MAN THROUGH SUPERIOR AND INFERIOR VENÆ CAVÆ.

A-A. Plane of section of Fig. 1085.
B-B. Plane of section of Fig. 1110.
C-C. Plane of section of Fig. 1070.
D-D. Plane of section of Fig. 1063.

the right atrium. The **venæ cordis minimæ** are a number of small veins which begin in the substance of the walls of the heart and end directly in its cavities, principally in the atria.

SUPERIOR VENA CAVA

The **superior vena cava** (Figs. 1071 and 1109) returns the blood from the head and neck, the upper limbs, the thoracic wall, and a portion of the upper part of the wall of the abdomen. It is formed, at the lower border of the first right costal

cartilage, by the union of the two innominate veins, and it descends to the level of the third right costal cartilage, where it opens into the upper and posterior part of the right atrium. It is about 3 inches (75 mm.) long; in the lower half of its extent it is enclosed within the fibrous layer of the pericardium, and it is covered in front and on each side by the serous layer.

Relations.—It is overlapped *anteriorly* by the margins of the right lung and pleura and by the ascending aorta. The lung and pleura intervene between it and the second and third costal cartilages, the internal intercostal muscles in the first and second intercostal spaces, and the internal mammary vessels. It is in relation *posteriorly* with the right margin of the trachea, the vena azygos, which opens into it at right angles, the right bronchus, the right pulmonary artery, and the upper right pulmonary vein. On its *left side* are the ascending aorta and the origin of the innominate artery, whilst on the *right side* it is in close relation with the right pleura—the phrenic nerve and the pericardiaco-phrenic vessels intervening.

Tributaries.—In addition to the two innominate veins, by the union of which it is formed, the superior vena cava receives only one large tributary—the vena azygos; but several small pericardial and mediastinal veins open into it.

Abnormalities.—The **superior vena cava** may develop on the left side instead of on the right. That peculiarity is due to the persistence of the left common cardinal vein (duct of Cuvier) (p. 1381) instead of the right, and it is associated with absence of the coronary sinus, which is replaced by the lower part of the left superior vena cava. In one exceptional case the opening of the coronary sinus into the heart was obliterated, and the cardiac veins terminated in a trunk which passed upwards to the left innominate vein. That trunk was obviously formed by enlargement of the left duct of Cuvier and the lower part of the left anterior cardinal vein. Not very uncommonly, as the result of the persistence of both ducts of Cuvier, there are two superior venæ cavæ, the transverse anastomosis which usually forms the left innominate vein being small or absent. In such cases the left innominate vein descends in the left part of the superior mediastinum, crosses the aortic arch, is joined by the left superior intercostal vein, and becomes the left superior vena cava, which descends anterior to the root of the left lung and ends in the lower and back part of the right atrium. It receives the great cardiac vein and replaces the coronary sinus. This arrangement is normal in many mammals. Occasionally in Man the left superior vena cava terminates in the left atrium, and the coronary sinus, which represents a part of the sinus venosus, has been seen to have a similar ending; both these abnormal endings are the result of malposition of the atrial septum.

Vena Azygos and its Tributaries

The **vena azygos** is variable in its origin. It usually springs from the back of the inferior vena cava at the level of the renal veins (see *right lumbar azygos vein*, p. 1332), and enters the thorax through the aortic opening of the diaphragm, but may begin, between the diaphragm and the body of the twelfth thoracic vertebra, as the continuation of the right subcostal vein, or from the junction of that vein and the right ascending lumbar vein. It ascends through the posterior mediastinum to the upper part of the fifth thoracic vertebra. There it enters the superior mediastinum, arches forwards above the root of the right lung, and ends, opposite the second costal cartilage, by entering the back of the superior vena cava just before the vena cava pierces the pericardium. It frequently possesses imperfect valves.

Relations.—In Posterior Mediastinum.—*Posteriorly*, it rests upon the lower eight thoracic vertebræ, the intervertebral discs, and the anterior longitudinal ligament; and it crosses the posterior intercostal arteries of the right side. *Medial* to it are the thoracic duct and the descending aorta. *Lateral* to it there are the diaphragm, the greater splanchnic nerve, and the right pleura and lung. *Anteriorly*, it is related, in succession, to the diaphragm, the overlapping right pleura and lung, and the œsophagus. **In Superior Mediastinum.**—The root of the lung is *below*. The trachea and the right vagus are *medial*. The right pleura and lung are *lateral*. The vein grooves the lung deeply above its hilum, and therefore the pleura and lung are also *above*.

Tributaries.—(1) Right bronchial veins. (2) Œsophageal, pericardial and phrenic veins. (3) Mediastinal veins. (4) Right ascending lumbar vein. (5) Right subcostal vein. (6) Right posterior intercostal veins of the lower eight spaces. (7) Right superior intercostal vein formed

by the union of the posterior intercostal veins of the second and third spaces. (8) Inferior vena hemiazygos and superior vena hemiazygos, which convey much of the blood of the left side of the thoracic and abdominal walls to the vena azygos.

The **superior vena hemiazygos** begins, at the vertebral end of the fourth intercostal space of the left side, as the continuation of the fourth posterior intercostal vein. It runs downwards and forwards on the body of the fourth thoracic vertebra to reach the aorta, and descends close along the left side of the descending aorta as far as the eighth thoracic vertebra. There, it bends abruptly to the right and crosses behind the aorta and the thoracic duct to end in the vena azygos. Till it bends to the right it is under cover of the pleura, and crosses superficial to the upper left posterior intercostal arteries. Its **tributaries** are: (1) the left bronchial veins; (2) some mediastinal veins; and (3) the

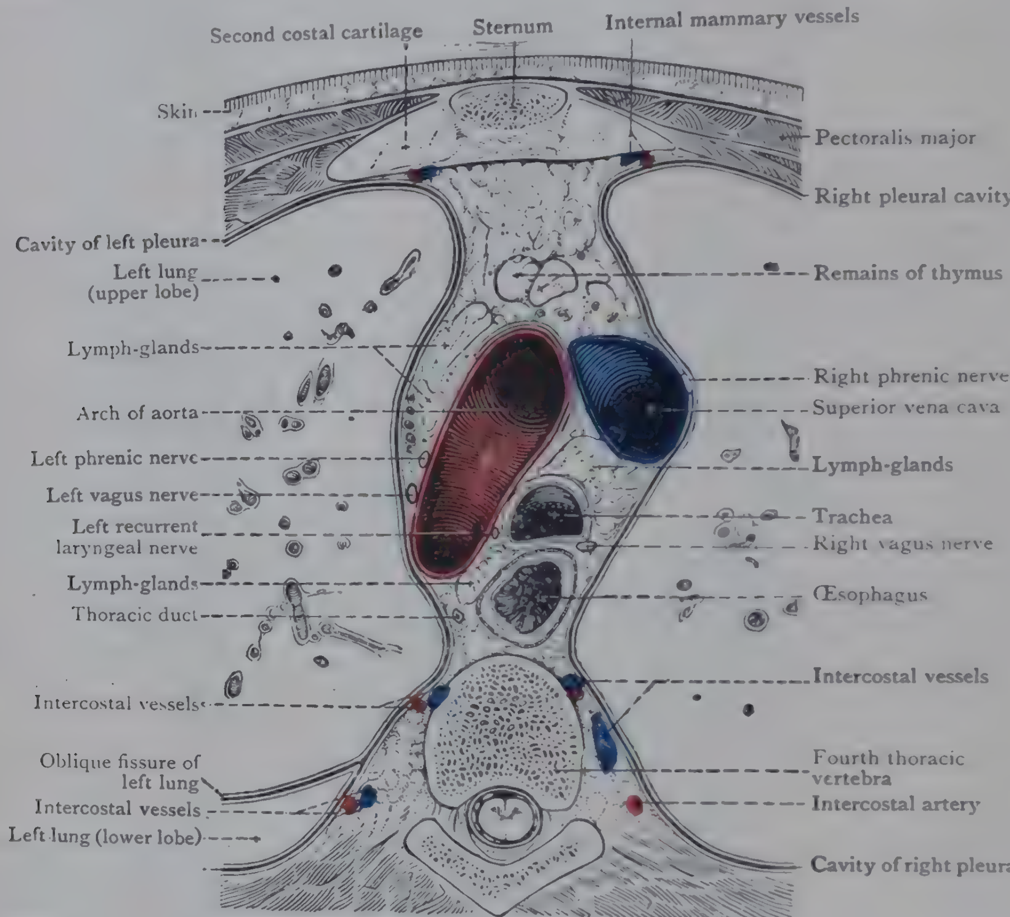

FIG. 1110.—TRANSVERSE SECTION OF THORAX OF YOUNG MAN THROUGH ARCH OF AORTA. The section is in the Plane B-B, FIG. 1109.

left posterior intercostal veins of the fourth, fifth, sixth, and seventh spaces, and, sometimes, the eighth. Its upper part is often connected with the left superior intercostal vein.

The **inferior vena hemiazygos** usually springs from the back of the left renal vein (see *left lumbar azygos vein*) and enters the thorax by piercing the left crus of the diaphragm; but it may begin, between the diaphragm and the left side of the body of the twelfth thoracic vertebra, as the continuation of the left subcostal vein or from the junction of that vein and the left ascending lumbar vein. It runs upwards on the vertebral bodies to the ninth vertebra, where it turns abruptly to the right, and crosses behind the aorta and the thoracic duct to end in the vena azygos. In its upward course it is under cover of first the diaphragm and then the left pleura, and it crosses superficial to the lower left posterior intercostal arteries; the greater splanchnic nerve descends close along its lateral side; and the descending aorta is on its medial side and overlaps it anteriorly. Its **tributaries** are: (1) some mediastinal veins; (2) the left ascending lumbar vein; (3) the left subcostal vein; (4) the left posterior intercostal veins of the eleventh, tenth, and ninth spaces, and, sometimes, the eighth.

The azygos and inferior hemiazygos veins are the continuations of the "lumbar azygos veins" (see p. 1383). These veins, when present, may receive the upper two (or more) of the lumbar veins, but in the adult they are often reduced to mere fibrous threads or

may not be found. The *right lumbar azygos vein* is the usual origin of the vena azygos and springs from the back of the inferior vena cava at the level of the renal veins. It passes upwards between the crura of the diaphragm (or pierces the right crus), and enters the thorax through the aortic opening (or to the right of that opening). The *left lumbar azygos vein* is the usual origin of the inferior vena hemiazygos; it arises from the back of the left renal vein, and pierces the left crus.

The **bronchial veins** do not quite correspond to the bronchial arteries, and they are not found on the walls of the smallest bronchi. On each side the tributaries run in front of or behind the bronchial tubes to reach the root of the lung, where they unite, as a rule, into two small trunks; those of the right side open into the vena azygos, and those of the left into the superior vena hemiazygos, or into the left superior intercostal vein. On both sides they receive tracheal and mediastinal veins. Some small bronchial veins, including most of those from the smaller tubes, open into the pulmonary veins.

The **œsophageal**, **pericardial**, and **phrenic veins** are small, irregular vessels that drain blood from the œsophagus, the back of the pericardium, and the posterior part of the diaphragm; and they end in the vena azygos.

The **mediastinal veins** are small, irregular vessels that drain blood from the fat and the lymph-glands of the posterior mediastinum. They end in the azygos vein, in the two hemiazygos veins, and in the bronchial veins.

The **ascending lumbar vein** (p. 1357) is a longitudinal, anastomosing channel that connects the lateral sacral, ilio-lumbar and lumbar veins. The upper two lumbar veins may end in it or may be merely connected by it. It ends in the vena azygos on the right side and the inferior vena hemiazygos on the left side.

The **intercostal veins** are in two sets—an anterior and a posterior. The **anterior intercostal veins** are described on p. 1334.

The **posterior intercostal veins** are eleven on each side. Each vein accompanies a posterior intercostal artery in an intercostal space, and where they lie in the costal groove the vein is above the artery. It is provided with valves, both near its termination and along its course, which prevent the blood from flowing towards the anterior wall of the chest. It receives small unnamed tributaries from the adjacent muscles and bones, and at the vertebral end of the intercostal space it receives a *posterior tributary*, which passes forwards between transverse processes from the back. That tributary is formed by the union of small veins from the muscles of the back, from the plexuses on the fronts and backs of the vertebræ, and from the plexuses inside the vertebral canal. It also receives a *lateral cutaneous tributary* corresponding to the branch of the artery.

The **first posterior intercostal vein** ascends across the front of the neck of the first rib usually on the lateral side of the superior intercostal artery, and arches forwards over the summit of the pleura to end in either the innominate or the vertebral vein. The second and third (and sometimes the fourth) unite to form the **superior intercostal vein.** The **right** superior intercostal vein inclines downwards and forwards to join the vena azygos where that vein begins to arch forwards. The **left** vein runs downwards and forwards to the aorta, and then forwards and upwards on the left side of the aortic arch, superficial to the left vagus and deep to the left phrenic nerve, and joins the lower border of the left innominate vein. The remaining posterior intercostal veins curve forwards over the bodies of the vertebræ; those of the right side end in the vena azygos; those of the left side end in the superior and inferior hemiazygos veins.

Variations.—The **vena azygos** may be formed on the left side; it then arches over the root of the left lung, and ends in the coronary sinus. This is the normal arrangement in some mammals, and it is due to the persistence of the cephalic end of the left posterior cardinal vein, the thoracic part of the left supracardinal vein, and the left duct of Cuvier.

Occasionally the azygos vein is the only vessel by which blood is returned to the heart from the lower limbs and the lower parts of the body walls. In such cases that portion of the inferior vena cava which usually extends from the right renal vein to the liver is absent and the azygos vein is the direct continuation of the inferior vena cava (see p. 1354).

The vena azygos is occasionally enclosed in a fold of pleura and sunk deeply into the right lung, cutting off an accessory lobe—the *lobe of the vena azygos* (p. 715 and Fig. 2, Pl. LXVIII, p. 721).

The **superior and inferior hemiazygos veins** may be absent. In such cases each left intercostal vein opens separately into the vena azygos. On the other hand, the hemiazygos veins may form a continuous trunk which may open by a transverse anastomosis into the azygos vein, or it may join the left innominate vein. When the hemiazygos veins form a single trunk, which receives the left posterior intercostal veins and opens into the left innominate vein, the condition is due to the persistence of the whole of the thoracic part of the azygos venous line, the upper part of the left posterior cardinal vein, and the lower part of the left anterior cardinal vein.

Innominate Veins

The **innominate veins** (Figs. 1069 and 1071) are two in number, right and left. They return blood from the head and neck, the upper limbs, the upper part of the posterior wall of the thorax, the anterior wall of the thorax, and the upper part of the anterior wall of the abdomen. Each innominate vein commences behind the medial end of the clavicle, and is formed by the union of the internal jugular and subclavian veins; the two innominate veins terminate by uniting together, at the lower border of the first costal cartilage of the right side, to form the superior vena cava. To reach that point the left vein has to pass from left to right behind the manubrium sterni, and it is therefore about three times as long as the right vein. The innominate veins do not possess valves.

The **right innominate vein** is a little more than 1 inch (25 mm.) in length. It descends almost vertically to the lower border of the first costal cartilage.

Relations.—In Root of Neck.—The innominate artery is *medial.* The clavicle and the sterno-hyoid and sterno-thyroid muscles are *anterior.* The cervical pleura is *posterior and lateral*; and the internal mammary artery and the phrenic nerve are between it and the pleura. **In Thorax.**—The innominate artery is *medial.* The trachea and the vagus nerve are *postero-medial.* The lung and pleura are *lateral*, but overlap it in front and behind; the phrenic nerve and pericardiaco-phrenic vessels, descending along its right side, are between it and the pleura.

Tributaries.—In addition to the veins by the union of which it is formed, the right innominate vein receives the right vertebral and internal mammary veins, the first right posterior intercostal vein, and sometimes the right inferior thyroid vein or a common trunk of the two veins. The *right lymphatic duct* (or separate lymph-trunks) also opens into it.

The **left innominate vein** passes from left to right, with a slight obliquity downwards, behind the upper half of the manubrium sterni, to the lower border of the first right costal cartilage. It is about 3 inches (60 to 75 mm.) long.

Relations.—In Root of Neck.—*Posteriorly*, it rests first upon the cervical pleura and the internal mammary artery, and next upon the fat surrounding the phrenic and vagus nerves, the cervical cardiac branches of the vagus and sympathetic, and the ascending part of the subclavian artery. *Anteriorly*, the sterno-thyroid and sterno-hyoid muscles separate it from the clavicle and the sterno-clavicular joint. **In Thorax.**—The left common carotid artery and the innominate artery are *posterior* to it, and separate it from the trachea. *Anterior* to it there are the manubrium, the origins of the sterno-hyoid and sterno-thyroid, the remains of the thymus, and, at its termination, the overlapping margin of the right pleura and lung. Its *lower* border is in relation with the arch of the aorta, and on its *upper* border it receives the inferior thyroid vein of one or both sides, or a common trunk.

Tributaries.—It receives the *thoracic duct*, which opens into it at the angle of junction of the internal jugular and subclavian veins and is its most important tributary. It also receives the vertebral, internal mammary, inferior thyroid, and superior intercostal veins of its own side, the first left posterior intercostal vein, and some pericardial, thymic, and mediastinal veins. Sometimes the right inferior thyroid vein joins it, but not uncommonly that vessel ends in the right innominate vein or in the commencement of the superior vena cava.

Internal Mammary Veins.—Each internal mammary artery is accompanied by venæ comitantes; they begin by the union of the venæ comitantes of the superior epigastric and musculo-phrenic arteries, between the sixth costal cartilage and the sterno-costalis; and about the level of the third costal cartilage they fuse into a single vessel which runs on the medial side of the artery and ends in the innominate vein of the same side.

The tributaries of the internal mammary veins are—(*a*) The **venæ comitantes** of the **superior epigastric** and **musculo-phrenic arteries**, which in their turn receive the veins that accompany the branches of those arteries. (*b*) Six **anterior perforating veins**, which accompany the corresponding arteries, one in each of the upper six intercostal spaces. (*c*) Twelve **anterior intercostal veins** from the upper six intercostal spaces, two veins lying in each space with the corresponding branches of the internal mammary artery. (*d*) Small and irregular **pleural, muscular, mediastinal, pericardial**, and **thymic veins**. (*e*) The **pericardiaco-phrenic veins.**

The internal mammary veins are provided with numerous valves which prevent the blood from flowing downwards.

Superior Epigastric Veins.—The venæ comitantes of the superior epigastric artery receive tributaries from the substance of the rectus abdominis, the sheath of the muscle, and the *subcutaneous veins* of the upper part of the abdominal wall; they pass, with the artery, between the sternal and costal origins of the diaphragm, and end in the internal mammary veins.

Musculo-Phrenic Veins.—The venæ comitantes of the musculo-phrenic artery begin in the abdomen, pass through the diaphragm with the musculo-phrenic artery, and end in the internal mammary veins. They receive as tributaries the **anterior intercostal veins** of the seventh, eighth, and ninth intercostal spaces, and venules from the substance of the diaphragm and walls of the abdomen.

The **vertebral veins** correspond only to the extra-cranial parts of the vertebral arteries. Each begins between the skull and the atlas by the union of offsets from the internal vertebral venous plexuses, as they issue from the vertebral canal. It passes across the posterior arch of the atlas, with the vertebral artery, to the foramen in the transverse process of the atlas. In the foramina in the cervical transverse processes, a plexus of venous channels surrounds the artery. At the lower part of the neck efferents from the plexus unite to form a single trunk which issues from the foramen in the transverse process of the sixth cervical vertebra, and descends, between the longus cervicis and scalenus anterior muscles, to end in the back of the upper part of the innominate vein: near its termination there is a unicuspid or bicuspid valve.

Relations.—In the first part of its course the vein lies in the suboccipital triangle. The second, plexiform portion surrounds the artery as it passes through the foramina in the transverse processes of the cervical vertebræ, anterior to the trunks of the cervical spinal nerves. The third part, in the root of the neck, is in front of the first part of the vertebral artery, and behind the internal jugular vein.

Tributaries.—In addition to the offsets from the internal vertebral plexuses by the union of which it is formed, each vertebral vein receives the following tributaries. Small veins join it from the muscles, ligaments, and bones of the deeper parts of the neck, and the lower and posterior part of the head. Tributaries from the internal vertebral plexuses pass out of the vertebral canal by the intervertebral foramina. The **anterior vertebral vein** is formed by the union of tributaries which issue from a venous plexus on the front of the bodies of the cervical vertebræ and the roots of their transverse processes; it lies alongside the ascending cervical artery, and ends in the vertebral vein immediately below the foramen in the sixth cervical transverse process. The **deep cervical vein** begins in the suboccipital triangle from a venous plexus with which the vertebral and occipital veins communicate. It descends behind the cervical transverse processes, in company with the deep cervical artery, turns forwards at the root of the neck, between the transverse processes of the sixth and seventh cervical vertebræ or between the latter and the neck of the first rib, and opens into the vertebral vein. It receives blood from the muscles, ligaments, and bones of the back of the neck. The **first posterior intercostal vein** sometimes opens into the vertebral vein.

Occasionally the venous plexus around the vertebral artery ends below in two terminal trunks—anterior and posterior—instead of one. In those cases the second terminal vessel lies behind the lower part of the vertebral artery, passes through the foramen in the transverse process of the seventh cervical vertebra (which otherwise transmits a small tributary), and turns forwards on the lateral side of the artery to join the anterior trunk, thus forming a common terminal vein which ends in the usual manner.

The **inferior thyroid veins** are formed by the union of tributaries which issue from the isthmus and the lobes of the thyroid gland. The two veins descend, along the front of the trachea, into the superior mediastinum, where the right inferior thyroid vein ends either in the right innominate vein or in the junction of the two innominate veins, and the left in the left innominate vein; or the two veins unite to form a single trunk, which ends usually in the left innominate vein but occasionally in the right, or in the angle between them. As they descend in the neck the inferior thyroid veins are connected by anastomosing channels, and sometimes the anastomoses are so numerous that a venous plexus is formed in front of the lower cervical portion of the trachea.

VEINS OF HEAD AND NECK

Internal Jugular Vein (Figs. 1069, 1071, 1076, 1087, and 1114).—Each internal jugular vein begins in the posterior compartment of the jugular foramen as the direct continuation of the sigmoid sinus, and it ends behind the medial part of the clavicle by uniting with the subclavian vein to form the innominate vein.

Its commencement is dilated and forms the *upper bulb* of the jugular vein. In the upper part of the neck it lies postero-lateral to the internal carotid artery and the last four cranial nerves. As it descends it accompanies first the internal and then the common carotid artery. It inclines forwards as it descends, and gradually passes from its original position, behind and to the lateral side of the internal carotid artery, until it lies more completely to the lateral side of the internal and common carotid arteries, and it overlaps the latter in front. That is more especially the case on the left side, for both internal jugular veins trend slightly towards the right as they descend; consequently, at the root of the neck, the right vein is separated from the common carotid artery by a small interval filled with areolar tissue in which the vagus nerve lies, whilst the left vein is more directly in front of the common carotid artery.

A dilatation, called the *lower bulb*, is present at the lower end of the vein; it is bounded, either above or below, by a valve of two or three semilunar cusps. Sometimes this bulb is bounded by valves both above and below.

Relations.—The vein lies anterior to the transverse processes of the cervical vertebræ, the rectus capitis lateralis, longus capitis, and scalenus anterior muscles, the ascending cervical artery, and the phrenic nerve; the suprascapular and the transverse cervical arteries intervene between it and the scalenus anterior. At the root of the neck the vein lies in front of the first part of the subclavian artery and the origins of the vertebral artery and the thyro-cervical trunk, and on the left side it is anterior to the terminal part of the thoracic duct.

On the antero-medial side of the internal jugular vein, immediately below the skull, are the internal carotid artery and the last four cranial nerves; in the rest of its extent it is in relation, medially, first with the internal and then with the common carotid artery, whilst to its medial side and behind, between it and the large arteries, lies the vagus nerve.

Each internal jugular vein is covered superficially, in the whole of its length, by the sterno-mastoid muscle; near its upper end it is crossed by the styloid process, the stylopharyngeus and stylo-hyoid muscles, and the posterior belly of the digastric, whilst in its lower half, the omo-hyoid, the sterno-hyoid, and the sterno-thyroid muscles are superficial to it, under cover of the sterno-mastoid. Just below the transverse process of the atlas, and under cover of the sterno-mastoid, the vein is crossed, on its lateral side, by the accessory nerve and by the occipital artery; about the middle of its course it is crossed by the descendens cervicalis nerve, and near its lower end by the anterior jugular vein; the latter vessel, however, is separated from it by the sterno-hyoid and sterno-thyroid muscles. Superficial to the vein are numerous deep cervical lymph-glands.

Variations.—The **internal jugular vein** may be either smaller or larger than usual. In either case, compensatory changes in size occur in the transverse and sigmoid sinuses and internal jugular vein of the opposite side, or in the external and anterior jugular veins of the same side.

Tributaries.—The **inferior petrosal sinus** joins it near its commencement, and the **vein of the cochlear canaliculus** is also a direct tributary if it does not join that sinus. Two or three **pharyngeal veins** drain the *pharyngeal venous plexus* on the wall of the pharynx. The common terminal trunk of the **lingual veins** returns part of the blood from the tongue, and may be joined by the **vena comitans n. hypoglossi** which accompanies the hypoglossal nerve and usually ends in the common facial vein. The **superior thyroid vein** accompanies the corresponding artery and its sterno-mastoid branch and receives the **superior laryngeal vein**. The **middle thyroid vein** passes backwards from the lobe of the thyroid gland and crosses the common carotid artery. The **occipital vein** occasionally terminates in the internal jugular vein, but most frequently it ends in the *suboccipital* plexus, which is drained by the vertebral and deep cervical veins (see p. 1335).

The **common facial vein** is formed by the union of the **anterior** and **posterior facial veins**. It crosses the external and internal carotid arteries, and ends in the internal

jugular vein. Just before it disappears beneath the sterno-mastoid, the common facial vein frequently gives off a large branch which descends along the anterior border of the sterno-mastoid to the suprasternal fossa, where it joins the anterior jugular vein.

The **anterior facial vein** (Fig. 1111) begins at the medial angle of the eye by the union of the supra-orbital and supratrochlear veins. It passes downwards and backwards in the face to the lower and anterior part of the masseter muscle, which it crosses, lying in the same plane as the facial artery, but following a much straighter course. After crossing the lower border of the mandible it passes across the submandibular triangle, superficial to the submandibular gland, and separate from the facial

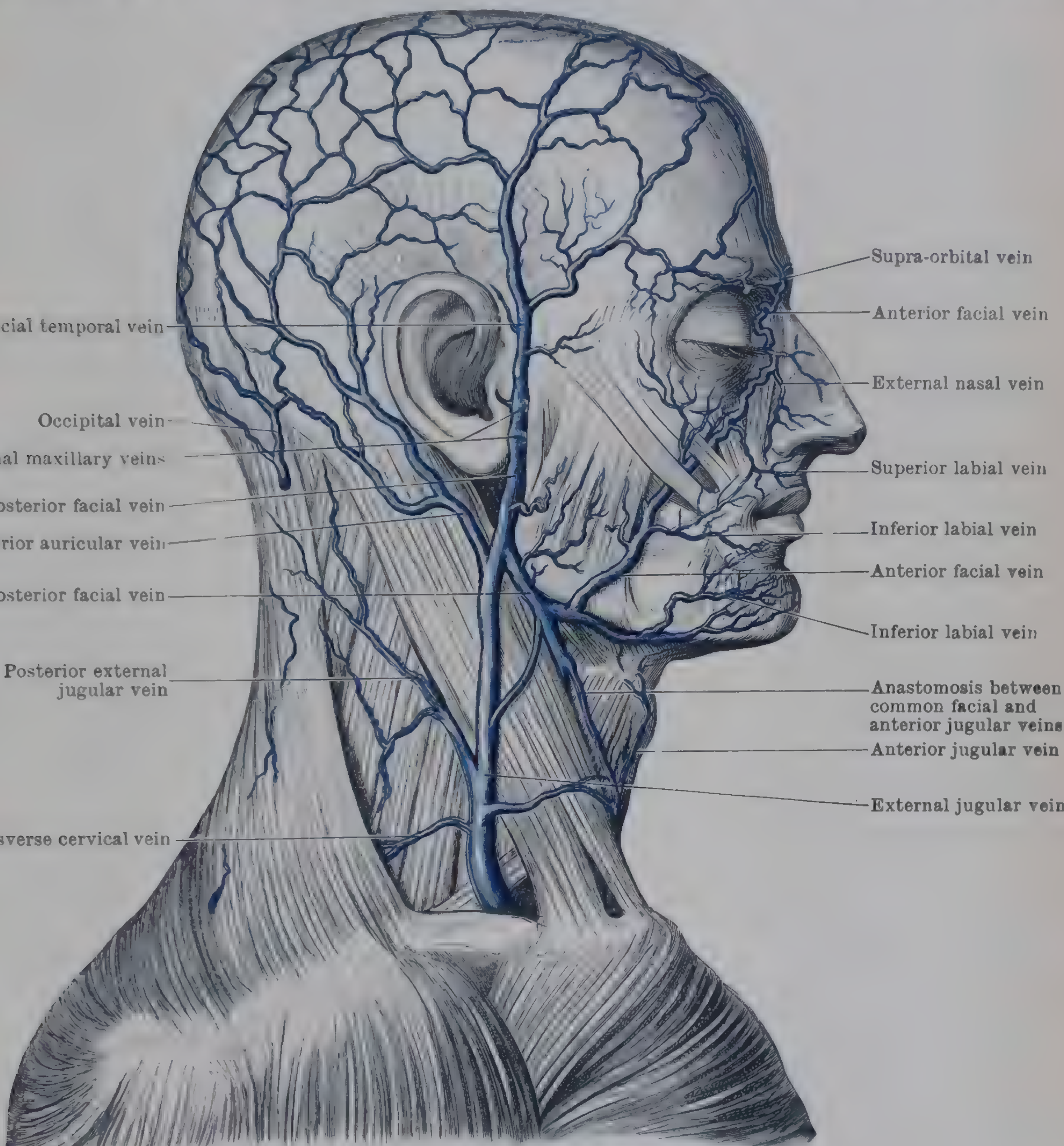

FIG. 1111.—SUPERFICIAL VEINS OF HEAD AND NECK.

artery, which there lies in a deeper plane. It ends, a short distance below the angle of the mandible, by uniting with the posterior facial vein to form the common facial vein.

The anterior facial vein receives tributaries corresponding with all the branches of the facial artery, except the ascending palatine and the tonsillar, which have no accompanying veins, the blood from the region which they supply being returned for the most part through the pharyngeal plexus. The anterior facial vein communicates with the cavernous sinus (p. 1347) through the superior ophthalmic vein, and also with the pterygoid plexus around the lateral pterygoid muscle by means of an anastomosing channel, called the **deep facial vein**, which passes backwards, between the masseter and buccinator muscles, into the infratemporal fossa.

The **posterior facial vein** is described on p. 1340.

Subclavian Vein.—The subclavian vein, of each side, is the direct continuation of the main vein of the upper limb, *i.e.*, the axillary vein; but through its

tributary, the external jugular vein, it receives blood both from the head and from the superficial parts of the neck.

From its commencement, at the outer border of the first rib, it runs medially, below and anterior to the corresponding artery, from which it is separated by the lower part of the scalenus anterior muscle, and it ends behind the medial end of the clavicle by joining the internal jugular vein to form the innominate vein. As it passes medially it forms a slight curve the convexity of which is directed upwards.

Each subclavian vein possesses a single bicuspid valve which is situated immediately to the lateral side of the opening of the external jugular vein.

Relations.—The subclavian vein is in relation *anteriorly* with the posterior layer of the clavi-pectoral fascia, which separates it from the subclavius muscle, and the nerve to the subclavius, and with the back of the medial part of the clavicle.

It is closely attached to the posterior surface of the clavi-pectoral fascia; consequently, it is expanded when the clavicle is moved forwards, an arrangement which constitutes a distinct danger when operations are being performed in the neighbourhood of the vein; for, in the event of the vessel being wounded, forward movement of the clavicle may cause air to be sucked into the vein, with fatal results.

Posterior to the vein, and on a higher plane, is the third part of the subclavian artery, but it is separated from the second part by the scalenus anterior. As soon as it reaches the medial border of the muscle it unites with the internal jugular vein.

The upper surface of the first rib is *below* the vein.

Tributaries.—Whilst the subclavian vein is the direct continuation of the axillary vein, and receives, therefore, the blood from the upper limb, it has, as a general rule, only one named tributary—the external jugular vein.

The **external jugular vein** (Fig. 1111) is formed on the superficial surface of the sterno-mastoid muscle, a little below and behind the angle of the mandible, by the union of the posterior auricular vein with a branch from the posterior facial vein. In many cases the branch from the posterior facial vein is so preponderantly large that it is more correct to describe the external jugular vein as its continuation. After its formation the external jugular vein descends across the sterno-mastoid to the supraclavicular part of the posterior triangle of the neck, where it pierces the deep fascia, crosses in front of the third part of the subclavian artery, and ends in the subclavian vein.

As it passes across the sterno-mastoid muscle it is covered by the superficial fascia and platysma muscle, and it lies in front of and parallel with the great auricular nerve; after crossing the anterior cutaneous nerve of the neck it reaches the posterior border of the sterno-mastoid, where it receives a tributary called the **posterior external jugular vein**, which drains the superficial tissues of the upper and back part of the neck, and runs downwards and forwards, across the roof of the upper part of the posterior triangle.

As the external jugular vein pierces the deep cervical fascia above the clavicle, its wall is closely attached to the margin of the opening through which it passes; and in the lowest part of the neck it is joined by the suprascapular, transverse cervical, and anterior jugular veins.

There are usually two valves in the lower part of the vein—one, which is generally incompetent, at or near its termination, and a second at a higher level.

Tributaries.—The **posterior auricular vein** (Fig. 1111) receives tributaries from the posterior parts of the parietal and temporal regions and from the medial surface of the auricle. It is considerably larger than the posterior auricular artery, which it accompanies only in the scalp. At the base of the scalp it leaves the artery and descends in the superficial fascia, over the upper part of the sterno-mastoid, to join the external jugular vein.

The **transverse cervical** and **suprascapular veins** accompany the corresponding arteries; not infrequently they open directly into the subclavian vein.

The **anterior jugular vein** begins in the submental region, and is formed by the union of small veins from the lower lip and chin. It descends, in the superficial fascia, at a variable distance from the median plane, perforates the outer layer of the deep fascia a short distance above the sternum, and enters the suprasternal space between

the first and second layers of the deep fascia. In the space it sometimes receives a communication from the common facial vein, and it is connected with its fellow of the opposite side by a transverse channel which lies in front of the trachea and is called the **jugular arch**. It then turns laterally, between the sterno-mastoid superficially and the sterno-hyoid, sterno-thyroid, and scalenus anterior muscles deeply, and ends in the external jugular vein at the posterior border of the sterno-mastoid.

The external jugular vein sometimes receives the occipital vein or a communication from it. Occasionally the cephalic vein also opens into it.

Variations.—The **subclavian vein** may pass behind the scalenus anterior instead of in front of it; and it has been seen passing between the clavicle and the subclavius muscle.

The **external jugular vein** is sometimes absent, or it may be smaller than usual; in both cases either the anterior or the internal jugular vein is enlarged. When the external jugular vein is small it sometimes receives no communication from the posterior facial vein, but is merely the continuation of the posterior auricular vein. On the other hand, it may be enlarged, and receive the whole of the posterior facial vein.

The **anterior jugular vein** may be absent, or it may be unusually large, especially in the lower part of its extent, and after it has received the occasional tributary from the common facial vein.

Veins of Scalp

The veins which drain the blood from the superficial parts of the scalp are the supratrochlear, the supra-orbital, the superficial temporal, the posterior auricular, and the occipital. The blood from the deeper part of the scalp, in the region of the temporal fossa, on each side, passes into the deep temporal veins, which are tributaries of the pterygoid plexus.

The **supratrochlear** and **supra-orbital veins** receive blood from the anterior part of the scalp. They unite together, near the medial angle of the eye, to form the *anterior facial vein*; before the union is effected the supra-orbital vein sends a branch backwards, through the supra-orbital notch, into the orbit, where it ends in the ophthalmic vein, and as that branch passes through the notch it receives the frontal diploic vein (p. 1341).

The **superficial temporal vein** (Figs. 1076, 1111) is formed by tributaries which accompany the anterior and posterior terminal branches of the superficial temporal artery. They drain the lateral frontal region, the superficial part of the temporal region, and the anterior part of the parietal region of the scalp, and unite to form a single trunk which descends to the upper border of the zygomatic arch, immediately anterior to the auricle, where it ends in the posterior facial vein (see p. 1340).

The **posterior auricular vein** has been described already (see p. 1338).

The **occipital vein** (Figs. 1076, 1111) receives tributaries from the parietal and occipital regions. As a rule it pierces the occipital origin of the trapezius, and passes into the suboccipital triangle to end in a plexus of veins which is drained by the vertebral and deep cervical veins. It sometimes communicates with the external jugular vein, and occasionally an offset from it accompanies the corresponding artery and ends in the internal jugular vein.

It usually receives the mastoid emissary vein; one of its tributaries receives the parietal emissary vein, and occasionally an emissary vein from the *confluence of the sinuses* opens into it.

Veins of Orbit, Nose, and Infratemporal Region

The veins of those three regions are closely associated together; for although the orbital blood is returned, for the most part, to the cavernous sinus by the ophthalmic veins, these veins are closely connected with the pterygoid plexus, which lies in the infratemporal region.

Veins of Orbit.—The veins of the orbit correspond with the branches of the ophthalmic artery, except the supra-orbital and supratrochlear, and they gradually converge, as they pass backwards in the orbit, until they form two main trunks—a **superior ophthalmic vein** and an **inferior ophthalmic vein**. The two trunks terminate separately, or by a single stem, in the anterior end of the cavernous sinus, to which they pass between the two heads of the lateral rectus muscle

through the superior orbital fissure. The *central vein of the retina* joins the superior ophthalmic or runs direct to the cavernous sinus.

The superior ophthalmic vein communicates, at the supero-medial angle of the orbit, with the anterior facial vein through its supra-orbital tributary. The inferior ophthalmic vein communicates through the inferior orbital fissure with the pterygoid plexus.

Veins of Nose.—The veins of the walls of the nasal cavity end partly in the ethmoidal tributaries of the superior ophthalmic vein, partly in the septal tributaries of the superior labial and in the *external nasal veins*, all of which pass to the anterior facial vein; but the majority of the *internal nasal veins*, both from the septal and lateral walls, join together to form a **spheno-palatine vein**, which passes through the spheno-palatine foramen and the pterygo-palatine fossa to the pterygoid plexus.

Pterygoid Plexus and **Maxillary Vein**.—The **pterygoid plexus** of veins lies in the infratemporal fossa. It covers the lateral surface of the medial pterygoid muscle and surrounds the lateral pterygoid. It receives tributaries which correspond with and accompany the branches of the maxillary artery—namely, spheno-palatine, pharyngeal, veins of pterygoid canal, infra-orbital, posterior superior dental, greater palatine, buccal, two or three deep temporal, pterygoid, masseteric, and inferior dental veins, and the middle meningeal vein. It communicates above with the cavernous sinus by emissary veins through the foramen ovale and the emissary sphenoidal foramen when present; in front with the inferior ophthalmic vein through the inferior orbital fissure; and between the masseter and the buccinator with the anterior facial vein by the deep facial branch. It also communicates behind and medially, on the medial side of the medial pterygoid, with the pharyngeal plexus, and it drains behind into the maxillary vein.

The **maxillary vein** is a short vessel which accompanies the first part of the maxillary artery between the spheno-mandibular ligament and the neck of the mandible. Between the neck of the mandible and the antero-medial surface of the parotid gland it joins the upper part of the posterior facial vein. Occasionally the maxillary vein is double, and sometimes it is represented by several channels.

The **posterior facial vein** is formed, immediately above the zygomatic arch, by the union of the superficial temporal vein with the middle temporal vein, which accompanies the middle temporal artery (p. 1262). It crosses the zygomatic arch, dips deep to the upper part of the parotid gland, and, between the antero-medial surface of the gland and the posterior border of the mandible, receives the maxillary vein or veins. Then it descends, through the substance of the parotid and divides into two parts—anterior and posterior—which emerge from its lower end.

The **anterior division** passes forwards and downwards and unites with the anterior facial vein to form the common facial vein. The **posterior division** forms one of the two tributaries of origin of the **external** jugular vein.

Variations.—The **posterior facial vein** may end entirely in the common facial vein, or in the external or the internal jugular vein. It may be very small or absent.

VENOUS SINUSES AND VEINS OF CRANIUM AND CONTENTS

The venous channels met with in the cranial walls and cranial cavity are:—

(1) The diploic veins, which lie in the spongy tissue of the cranial bones.

(2) The meningeal veins, which accompany the meningeal arteries in the outer layer of the dura mater.

(3) The veins of the brain, which lie in the folds of pia mater and in the subarachnoid space.

(4) The cranial venous sinuses, which are channels situated between the outer and inner layers of the dura mater; they receive blood chiefly from the brain but also from the membranes and bones, and cerebro-spinal fluid is transmitted into them from the arachnoid villi and granulations.

Diploic and Meningeal Veins

Diploic veins are anastomosing spaces, lined with endothelium, in the diploë of the flat bones of the skull. The number of efferent vessels which emerge from the diploic spaces is not constant, but usually there are at least four on each side—a frontal, two parietal (anterior and posterior), and an occipital (Jefferson & Stewart, 1928).

The **frontal diploic vein** is one of the most constant; it arises in the anterior part of the frontal bone, passes through a small aperture in the upper margin of the supra-orbital notch, and ends in the supra-orbital vein.

The **anterior parietal diploic vein** drains the posterior part of the frontal bone

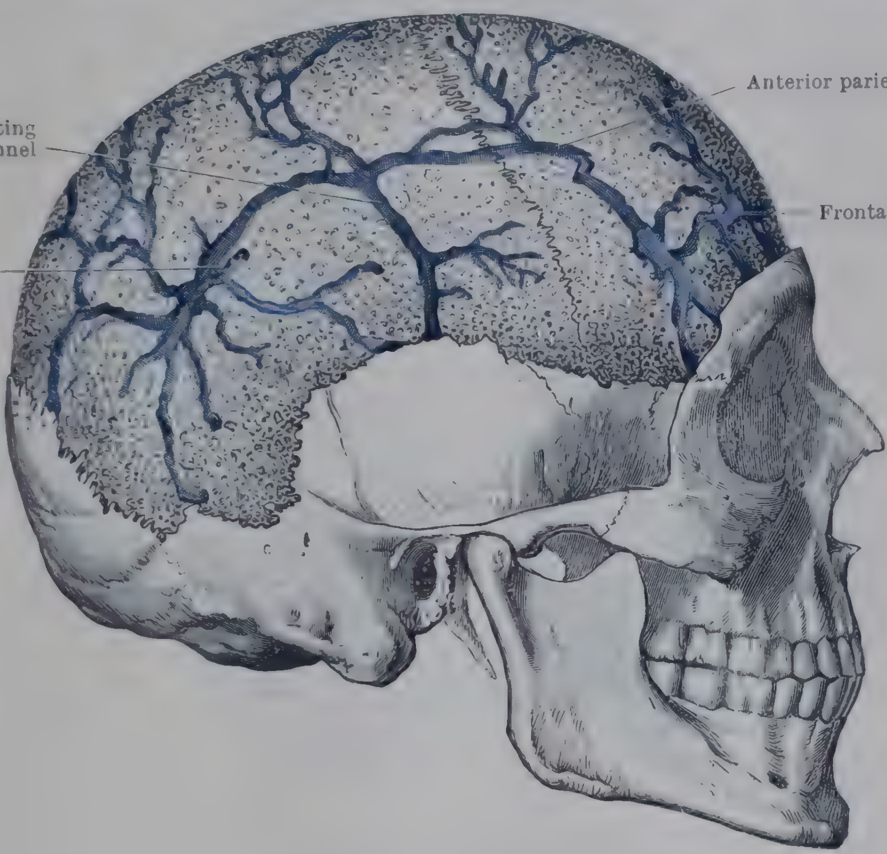

Fig. 1112.—Veins of the Diploë.

and the anterior part of the parietal bone; it emerges from the great wing of the sphenoid, and ends either in the spheno-parietal sinus or in the anterior deep temporal vein.

The **posterior parietal diploic vein** drains the posterior part of the parietal bone; it runs downwards through the posterior inferior angle of the parietal bone and ends either in the transverse sinus, or, more commonly, in the mastoid emissary vein.

The **occipital diploic vein** is usually the largest of the series; it drains the occipital bone, and ends either in the occipital emissary vein or internally in the transverse sinus.

The **meningeal veins** commence in two capillary plexuses—a deep and a superficial. The deep plexus is a wide-meshed network in the inner layer of the dura mater. Its efferent vessels pass to the superficial plexus. The superficial plexus lies in the outer layer of the dura mater. It consists of numerous vessels of uniform calibre which anastomose freely together and terminate in two sets of efferents; of those, one set ends in the cranial venous sinuses, and the other accompanies the meningeal arteries. The efferent meningeal veins are peculiar inasmuch as they do not alter much in size as they approach their terminations. They lie external to the arteries in the grooves in the bones, and are very liable to be torn when the bones are fractured (Wood Jones, 1912).

Veins of Brain

The veins of the brain include the veins of the cerebrum, mid-brain, cerebellum, pons, and medulla oblongata. They do not possess valves.

Veins of Cerebrum.—The **cerebral veins** are arranged in two groups—deep and superficial.

The deep veins issue from the interior of the brain. The superficial veins lie upon its surface in the pia mater and the subarachnoid space. The terminal trunks of both sets pierce the arachnoid membrane and the inner layer of the dura mater, and they open into the cranial venous sinuses.

The **deep cerebral veins** are the choroid veins, the thalamo-striate veins, the internal cerebral veins, the great cerebral vein, and the striate veins.

Each **choroid vein** is formed by the union of tributaries which issue from the choroid plexus in the central part and inferior horn of a lateral ventricle. It passes along the lateral border of the tela chorioidea of the third ventricle

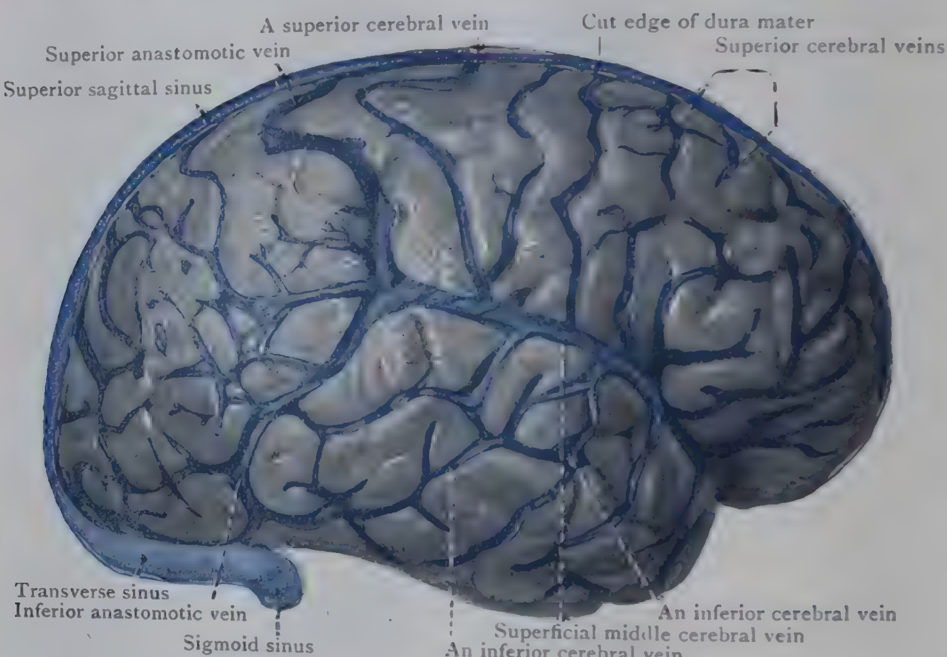

Fig. 1113.—Veins of Supero-Lateral Surface of Right Cerebral Hemisphere, seen through Arachnoid Mater.

to the interventricular foramen, where it receives efferents from the choroid plexus of the third ventricle, and unites with the thalamo-striate vein to form the internal cerebral vein.

The **thalamo-striate vein**, on each side, is formed by the union of tributaries which issue from the corpus striatum and from the thalamus. It runs forwards between the thalamus and the caudate nucleus, in a groove in the floor of the central part of the lateral ventricle, and, after receiving tributaries from the walls of the anterior horn of the ventricle and the septum lucidum, it ends at the apex of the tela chorioidea, where it joins the choroid vein to form the internal cerebral vein.

Each **internal cerebral vein** begins at the apex of the tela chorioidea, near the interventricular foramen, by the union of the thalamo-striate with the choroid vein. The two veins run backwards between the layers of the tela, receiving tributaries from the choroid plexuses of the third ventricle and from the fornix and corpus callosum, and they end beneath the splenium of the corpus callosum, by uniting to form the great cerebral vein.

The **great cerebral vein** (Galen) passes backwards and slightly upwards from its origin round the splenium of the corpus callosum. It ends in the anterior extremity of the straight sinus. In addition to the two internal cerebral veins, by the union of which it is formed, it receives tributaries from the posterior part of the gyrus cinguli of each side, from the pineal and quadrigeminal bodies, from the medial and inferior surfaces of the occipital lobes of the cerebral hemispheres,

and from the upper surface of the cerebellum. It receives also the basal vein of each side (see below).

One or two **striate veins** descend from the substance of the corpus striatum, through the anterior perforated substance, and end in the basal vein.

The **superficial cerebral veins** are more numerous and of larger calibre than the cerebral arteries. They lie upon the surface of the cerebrum, drain blood from the cerebral cortex, and they are divisible into two sets—the superior and the inferior.

The **superior cerebral veins**, six to twelve in number on each side, lie in the pia mater and subarachnoid space on the upper and lateral aspect of the cerebral hemispheres. They run upwards and medially to the margin of the longitudinal fissure where they receive tributaries from the medial surface of the hemisphere. They end in the superior sagittal sinus, and those that encounter the *lacunæ laterales* pass beneath them to reach the sinus (Sargent, 1911). The anterior veins of that set are small and run transversely, but the posterior are large and run obliquely forwards and medially; they are embedded for some distance in the wall of the sinus, and their orifices are directed forwards against the blood-stream.

The **inferior cerebral veins** lie on the lower and lateral aspects of the cerebral hemispheres; they end in sinuses which lie at the base of the skull—the cavernous, the superior petrosal, and the transverse sinuses. One of these veins, the **superficial middle cerebral vein**, runs along the posterior ramus and the stem of the lateral sulcus to the cavernous sinus; occasionally it is united by an anastomotic loop, known as the **superior anastomotic vein**, with the superior sagittal sinus, and sometimes by an **inferior anastomotic vein** with the transverse sinus. These anastomotic veins are persisting members of a series of channels which, in the fœtus, radiate from the superficial cerebral vein to the superior sagittal and transverse sinuses; they may be multiple, three superior and two inferior (O'Connell, 1934).

Each **anterior cerebral vein** lies in the longitudinal fissure, and accompanies the corresponding anterior cerebral artery; it receives tributaries from the corpus callosum and the gyrus cinguli. Turning downwards, round the genu of the corpus callosum, it reaches the base of the brain, and ends in the basal vein.

The **deep middle cerebral vein** lies deeply in the lateral sulcus; it anastomoses freely with the superficial middle vein, receives tributaries from the insula and the opercula, and ends in the basal vein.

The **basal vein** begins at the anterior perforated substance; it is formed by the union of the anterior cerebral vein with the deep middle cerebral vein and receives the striate vein or veins. It passes backwards around the cerebral peduncle and ends in the great cerebral vein. Its tributaries are derived from the tuber cinereum, the mamillary body, the posterior perforated substance, the uncus, the inferior horn of the lateral ventricle, and the cerebral peduncle.

Veins of Mid-Brain.—The veins of the mid-brain end for the most part either in the great cerebral vein or in the basal veins.

Cerebellar Veins.—Those veins also are divisible into two groups, the superficial and the deep. The former are quite independent of and much more numerous than the arteries. They form two sets, the superior and the inferior.

The **superior cerebellar veins** end in a median efferent vessel which is sometimes double, and in several lateral efferents. The median efferent vein runs forwards on the superior vermis and ends in the great cerebral vein. The lateral efferents end in the transverse sinuses and in the superior petrosal sinuses.

The **inferior cerebellar veins** also form a small median efferent and numerous lateral efferents: the former runs backwards on the inferior vermis and joins either the straight sinus or one of the transverse sinuses, and the latter end in the inferior petrosal and occipital sinuses.

The **deep cerebellar veins** issue from the substance of the cerebellum and join the superficial veins.

Veins of Pons.—The deep veins from the substance of the pons pass forwards to its anterior surface, where they become superficial and anastomose to form a

plexus which is drained by superior and inferior efferent veins. The superior efferent veins join the basal vein; the inferior efferent veins either unite with the cerebellar veins, or they open into the superior petrosal sinus.

Veins of Medulla Oblongata.—Deep veins of the medulla oblongata issue from its substance and end in a superficial plexus. This plexus is drained by an anterior and a posterior median vein and by radicular veins.

The *anterior median vein* is continuous below with the corresponding vein of the spinal cord; it communicates above with the plexus on the surface of the pons.

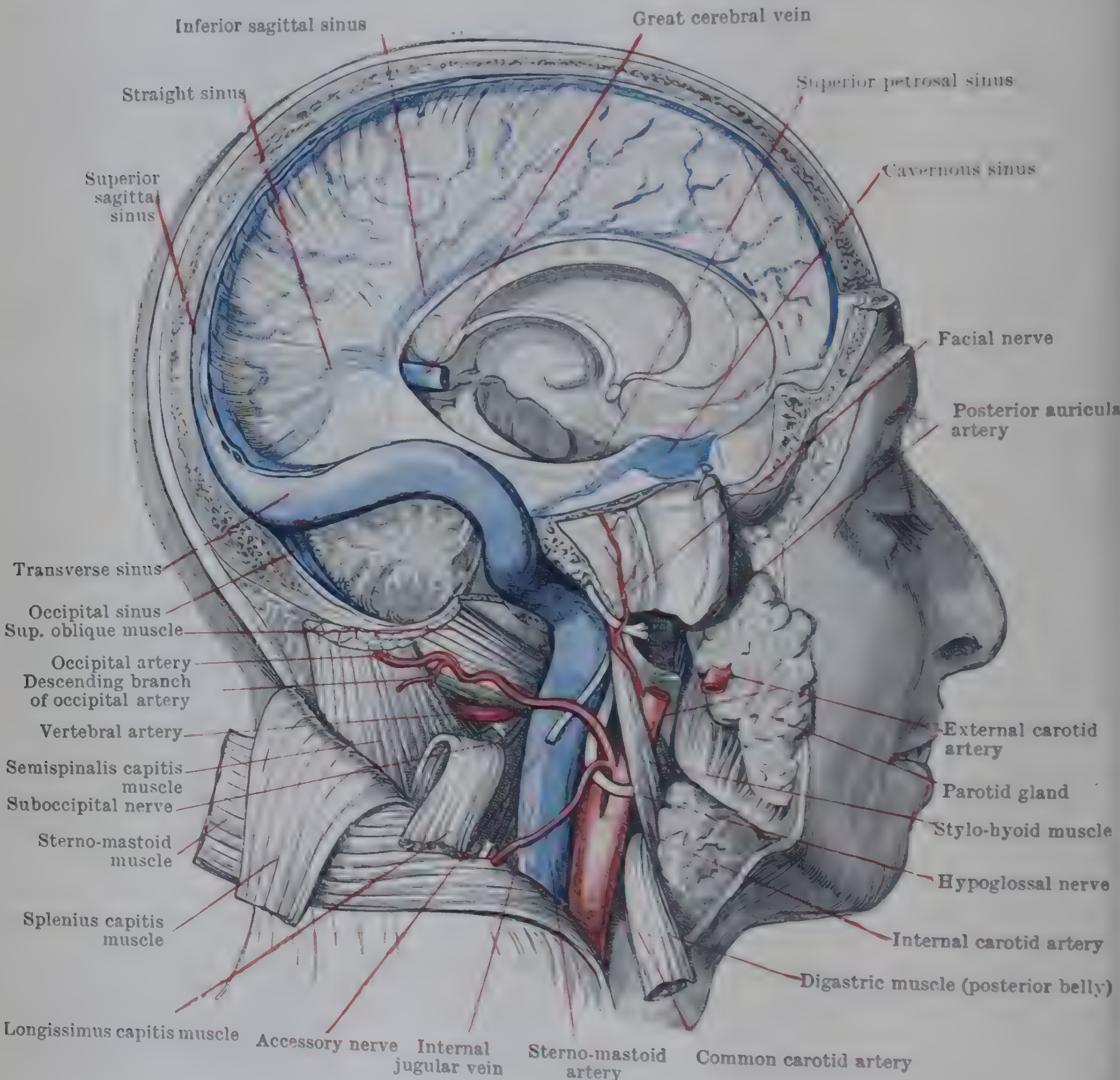

FIG. 1114.—DISSECTION OF HEAD AND NECK, SHOWING VENOUS SINUSES OF DURA MATER AND UPPER PART OF INTERNAL JUGULAR VEIN.

The *posterior median vein* is continuous below with the posterior median vein of the spinal cord, from which it ascends to the lower end of the fourth ventricle, where it divides into two branches which join the inferior petrosal sinuses or the network of basilar sinuses.

The *radicular veins* issue from the lateral parts of the plexus and run with the roots of the last four cranial nerves; they end in the inferior petrosal and occipital sinuses or in the upper part of the internal jugular vein.

VENOUS SINUSES OF DURA MATER

The **venous sinuses** of the cranium are spaces between the layers of the dura mater and they are lined with an endothelium which is continuous with the endothelium of the veins. They receive the veins of the brain, communicate frequently with the

meningeal veins and with veins external to the cranium, and end directly or indirectly in the internal jugular vein. Some of the sinuses are unpaired, others are paired.

Unpaired Sinuses.—These are the superior sagittal, the inferior sagittal, the straight, the intercavernous, and the basilar sinuses.

The **superior sagittal sinus** begins at the crista galli, where it communicates, through the foramen cæcum, frequently with the veins of the frontal sinus, sometimes with the veins of the nasal cavity, and more rarely with the anterior facial vein. It passes backwards in the convex margin of the falx cerebri, grooving the cranial vault. As it descends along the occipital bone it usually deviates slightly to the right, and it ends at the internal occipital protuberance by becoming the right transverse sinus. Instead of passing to the right it occasionally turns to the left and ends in the left transverse sinus, and sometimes it bifurcates and ends in both transverse sinuses. When it ends wholly in the right or the left transverse sinus its termination is associated with a well-marked dilatation, called the *confluence of the sinuses*, which is lodged in a depression at one side of the internal occipital protuberance. The confluence is connected, across the protuberance, by an anastomosing channel, with a similar dilatation which marks the junction of the straight sinus with the transverse sinus of the opposite side. Opening into the superior sagittal sinus are the superior cerebral veins; and it communicates on each side by slit-like openings with a series of spaces in the dura mater, called the **lacunæ laterales**, into which the arachnoid granulations project (see p. 1003 and Fig. 879). It communicates also, by emissary veins which pass through the parietal foramina, with the veins on the exterior of the cranium. Its cavity, which is triangular in transverse section, is crossed by several fibrous strands.

The **inferior sagittal sinus** runs in the posterior two-thirds of the free part of the lower margin of the falx cerebri. It ends behind by joining with the great cerebral vein to form the straight sinus. It receives tributaries from the falx cerebri and from the medial surface of the middle third of each cerebral hemisphere.

Around the hypophysis cerebri in the region of the sella turcica, there are intercommunicating channels which connect the two cavernous sinuses together. Two of these **intercavernous sinuses** lie in the anterior and posterior margins of the diaphragma sellæ; others pass across the floor of the hypophysial fossa (Fig. 707, p. 822).

The **network of basilar sinuses** is situated in the dura mater on the clivus of the skull. It connects the cavernous and the inferior petrosal sinuses together, and communicates below with the anterior longitudinal vertebral sinuses.

The **straight sinus** is formed by the union of the inferior sagittal sinus with the great cerebral vein. It runs downwards and backwards along the line of union between the falx cerebri and the tentorium cerebelli, and receives some of the superior cerebellar veins and a few tributaries from the occipital lobes and the falx cerebri. As a general rule it turns to the left at the internal occipital protuberance, dilates slightly, and becomes continuous with the left transverse sinus, its dilatation being united with the corresponding dilatation on the lower end of the superior sagittal sinus (the "confluence of the sinuses") by a transverse anastomosing channel. Occasionally the straight sinus ends in the right transverse sinus; in that case the superior sagittal sinus ends in the left transverse sinus; and sometimes it bifurcates to join both transverse sinuses.

Paired Sinuses.—There are six pairs of sinuses, viz., the transverse, the occipital, the cavernous, the superior petrosal, the inferior petrosal, and the spheno-parietal.

Each **transverse sinus** begins at the internal occipital protuberance, the right usually as the continuation of the superior sagittal, and the left as the continuation of the straight sinus. Each passes laterally in the postero-lateral part of the attached border of the tentorium cerebelli and in a groove on the occipital bone. From the lateral angle of the occipital bone it passes to the posterior inferior angle of the parietal bone, which it grooves; it then leaves the tentorium and turns

downwards on the cerebral surface of the mastoid portion of the temporal bone; from the latter it passes to the upper surface of the jugular process of the occipital bone; there it turns forwards and then downwards into the jugular foramen, where it becomes continuous with the internal jugular vein. The part which descends

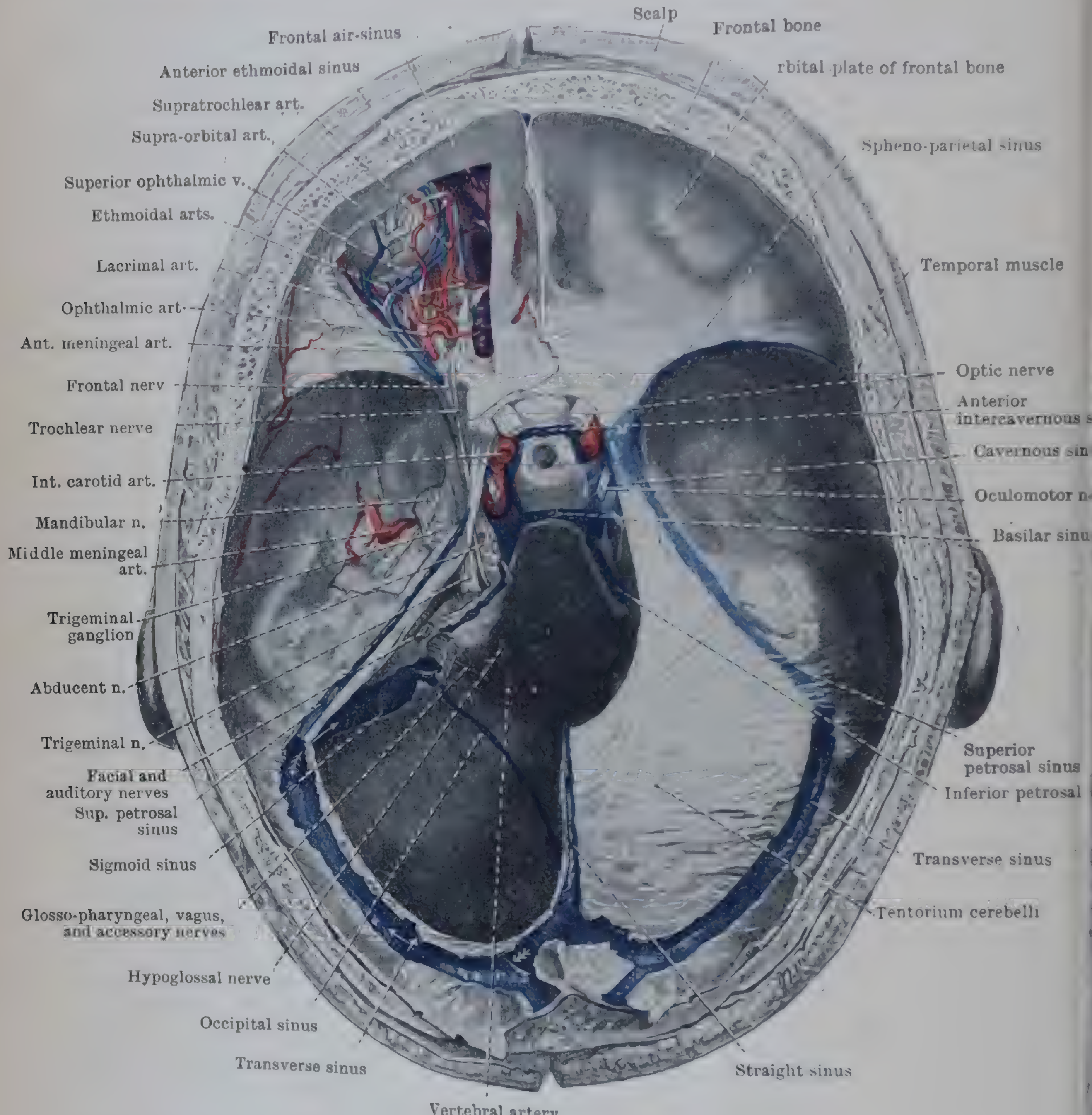

FIG. 1115.—LOWER VENOUS SINUSES OF DURA MATER.

In the specimen represented the superior sagittal sinus opened into both transverse sinuses and chiefly into the left. The straight sinus also opened into both transverse sinuses. The medial part of the left transverse sinus was divided by a horizontal septum into upper and lower parts. The arrow in the figure passes below the septum.

on the temporal bone and turns forwards on the jugular process of the occipital is called the **sigmoid sinus** (Fig. 1115).

Its tributaries are some of the inferior cerebral and superior and inferior cerebellar veins, a posterior parietal diploic vein, and the superior petrosal sinus. It is connected with the veins outside the cranium by emissary veins which pass through the mastoid foramen and the posterior condylar canal.

The **occipital sinuses** lie in the attached border of the falx cerebelli and in the dura mater along the postero-lateral boundaries of the foramen magnum; frequently they unite above and open by a single channel into the commencement of either

the right or the left transverse sinus, but their upper extremities may remain separate, and then each communicates with the transverse sinus of its own side. On the other hand, either the right or the left sinus may be absent. Each opens below into the corresponding sigmoid sinus, and both communicate with the posterior longitudinal vertebral sinuses. Each occipital sinus is an anastomosing channel between the transverse and sigmoid sinuses of the same side, and each receives a few inferior cerebellar veins.

The **cavernous sinuses** lie at the sides of the body of the sphenoid bone. Each sinus begins in front at the medial end of the superior orbital fissure, where it receives the corresponding ophthalmic veins, and it ends at the apex of the petrous portion of the temporal bone by dividing into the superior and inferior petrosal sinuses. Its cavity, which is irregular in size and shape, is so divided by numerous fibrous strands that it assumes the sponge-like appearance of cavernous tissue; and in its lateral wall are embedded the internal carotid artery with its sympathetic plexus, the oculomotor, the trochlear, the ophthalmic and the abducent nerves. Its tributaries are the ophthalmic vein, the spheno-parietal sinus, and inferior cerebral veins, including the superficial middle cerebral vein. It communicates with the opposite cavernous sinus through the intercavernous sinuses; with the pterygoid plexus by an emissary vein which passes either through the foramen ovale or through the sphenoidal emissary foramen; with the internal jugular vein by small venous channels which accompany the internal carotid artery through the carotid canal, and by the inferior petrosal sinus; with the transverse sinus by the superior petrosal sinus; and through the superior ophthalmic vein with the supra-orbital and anterior facial veins.

The **spheno-parietal sinuses** are lodged in the dura mater on the under surfaces of the lesser wings of the sphenoid bone close to their posterior borders. Each sinus communicates with the middle meningeal veins, receives veins from the dura mater, and ends in the anterior part of the cavernous sinus.

Each **superior petrosal sinus** begins at the apex of the petrous portion of the temporal bone in the posterior end of the cavernous sinus, and it runs backwards and laterally in the attached margin of the tentorium cerebelli above the trigeminal nerve. It grooves the superior margin of the petrous portion of the temporal bone, at the lateral end of which it ends in the transverse sinus at the point where it is turning down to become the sigmoid sinus. It receives inferior cerebral, superior cerebellar, and small tympanic veins.

An **inferior petrosal sinus** begins at the posterior end of each cavernous sinus; it runs backwards, laterally, and downwards, in a groove between the petrous part of the temporal bone and the basilar part of the occipital bone, to the anterior compartment of the jugular foramen, through which it passes. It crosses the glosso-pharyngeal, vagus, and accessory nerves either on their lateral or on their medial side, and it ends in the internal jugular vein. Its tributaries include inferior cerebellar veins and veins from the internal ear; the **internal auditory vein** reaches it through the internal auditory meatus, and small venules emerge from the cochlear canaliculus and the aqueduct of the vestibule to join it or the internal jugular vein.

Variations.—Variations of the venous sinuses are not numerous. One transverse sinus may be absent or very small, when, as a rule, that of the opposite side is enlarged. The inferior sagittal, the occipital, or the spheno-parietal sinuses may be absent, and there may be an additional petro-squamous tributary to the transverse sinus. The *petro-squamous sinus*, when present, runs in a groove (the posterior part of which may be a canal) along the line of the petro-sqaumous suture (p. 223) and opens behind into the transverse sinus. It is the remains of a fœtal channel which joined the primary head-vein (p. 1379); and in the human adult, in rare cases, it pierces the skull just above the posterior root of the zygoma (squamosal foramen) or through the root (post-glenoid foramen) above the lateral end of the squamo-tympanic fissure and ends in the external jugular *via* the posterior facial vein. That is the normal arrangement in some mammals.

Emissary Veins

The **emissary veins** are veins which connect the venous sinuses with the veins that lie outside the walls of the cranium, so that blood may pass in either direction. They may be single veins, or plexiform channels surrounding other structures which are passing through the

walls of the cranium ; individual emissary veins vary greatly in size and are not always present. They may communicate with the diploic veins.

In the child, and sometimes in the adult, a **frontal emissary vein** passes from the anterior end of the superior sagittal sinus through the foramen cæcum. Its lower end divides into two channels which either end in the veins of the frontal sinus or those of the roof of the nasal cavities, or they perforate the nasal bones and join the anterior facial veins.

The **parietal emissary veins**, one on each side, pass through the parietal foramina from the superior sagittal sinus to tributaries of the occipital vein.

An **occipital emissary vein** is only occasionally present. It passes from the confluence of the sinuses through the occipital protuberance to one of the tributaries of an occipital vein, and, when present, it receives the occipital diploic vein.

A **mastoid emissary vein** connects the sigmoid sinus, through the mastoid foramen, with the occipital or the posterior auricular vein.

A **posterior condylar emissary vein** passes through the posterior condylar canal when present, and connects the lower end of the sigmoid sinus with the plexus of veins in the sub-occipital triangle.

Emissary veins of the foramen ovale surround the mandibular nerve as it passes through the foramen ovale, and they connect the cavernous sinus with the pterygoid plexus. If the *sphenoidal emissary foramen* (*Vesalii*) is present, the plexus of the foramen ovale is replaced or supplemented by an emissary vein which passes through that foramen.

Emissary veins of the carotid canal accompany the internal carotid artery and connect the cavernous sinus either with the pharyngeal plexus or with the upper part of the internal jugular vein. A few small emissary veins also pass through the foramen lacerum to the pharyngeal veins and the pterygoid plexus.

As the hypoglossal nerve passes through the anterior condylar canal it is accompanied either by a venous plexus or by a large **anterior condylar emissary vein** which connects the veins of the medulla oblongata and the lower part of the occipital sinus with the upper end of the internal jugular vein, or with the extra-cranial part of the inferior petrosal sinus.

Not uncommonly there is a venous connexion between the cavernous sinus and the veins in the facial canal of the temporal bone.

Veins of Vertebral Column

The veins of the vertebral column are arranged in rich venous plexuses which extend along the whole length of the column both inside and outside the vertebral canal. All the plexuses anastomose freely with one another ; they are united by longitudinal channels ; and they are drained by the series of intervertebral veins.

Internal Vertebral Plexuses.—The veins in the interior of the vertebral canal form a continuous venous network which lies between the dura mater and the walls of the vertebral canal. The network communicates laterally with the intervertebral veins, behind with the posterior external venous plexuses, whilst in front it receives the basi-vertebral veins. It receives veins from the spinal cord also.

The **basi-vertebral veins** are venous channels, enclosed by endothelial walls, which lie in the substance of the bodies of the vertebræ. They communicate with the plexuses of veins on the anterior surfaces of the bodies of the vertebræ, and they converge towards the posterior surfaces of the bodies of the vertebræ, where they open into transverse anastomoses between the anterior longitudinal vertebral sinuses.

In the anterior part of the internal plexus, on the posterior surfaces of the bodies of the vertebræ and the intervertebral discs, at the sides of the posterior longitudinal ligament, there are two wide longitudinal channels, called the *anterior longitudinal vertebral sinuses*. They extend the whole length of the vertebral canal, are united together by transverse channels under cover of the posterior longitudinal ligament, and communicate above with the network of basilar sinuses, the terminal parts of the sigmoid sinuses, with the plexus of veins which accompanies each hypoglossal nerve through the anterior condylar canal and, through a plexus which surrounds the foramen magnum, with the occipital sinuses and the vertebral veins. Two less obvious longitudinal channels, called the *posterior longitudinal vertebral sinuses*, can sometimes be distinguished on the internal surfaces of the vertebral arches and the ligamenta flava.

External Vertebral Plexuses.—The **anterior external vertebral plexuses** are formed by anastomosing venous channels which lie on the anterior surfaces of the bodies of the vertebræ. They communicate with the basi-vertebral veins and with the intervertebral veins.

The **posterior external vertebral plexuses** lie on the postero-lateral surfaces

of the vertebræ, in the vertebral grooves, around the spines, the articular and the transverse processes of the vertebræ. They communicate with the internal plexuses and with the intervertebral veins, and they open into the vertebral, intercostal, and lumbar veins.

Intervertebral Veins.—The internal vertebral plexuses are drained not only above into the cranial venous sinuses by the longitudinal vertebral sinuses, but also by a series of **intervertebral veins** which pass through the intervertebral foramina. In the cervical region the intervertebral veins open externally into the vertebral veins, in the thoracic region into the intercostal veins, in the lumbar region into the lumbar veins, and in the sacral region into the lateral sacral veins. The intervertebral veins convey blood both from the internal and the external vertebral plexuses.

Veins of Spinal Cord

The **veins of the spinal cord** issue from its substance and end in a plexus in the pia mater. In that plexus there are six longitudinal channels—one *antero-median*, along the anterior fissure; two *antero-lateral*, immediately behind the anterior nerve-roots; two *postero-lateral*, immediately behind the posterior nerve-roots; and one *postero-median*, behind the posterior septum. Radicular efferent vessels issue from the plexus and pass along the nerve-roots to communicate with the internal vertebral venous network. The veins of the spinal cord vary very much in size, but they are largest on the lower part of the cord and on its posterior surface.

The postero-median and antero-median veins are continued above into the corresponding veins of the medulla oblongata.

The antero-lateral and postero-lateral veins pour their blood partly into the median veins and partly into the radicular veins; the greater part of the blood from the spinal cord is returned by the radicular veins.

VEINS OF UPPER LIMB

The veins of the upper limb are divisible into two sets — **superficial** and **deep**. Both sets open eventually into a common terminal trunk which is known as the **axillary vein**. That vein is continued as the subclavian vein to the innominate vein, through which its blood, together with that from the corresponding side of the head and neck, reaches the superior vena cava.

Deep Veins of Upper Limb

The deep veins of the upper limb, with the exception of the axillary vein, are arranged in pairs (**venæ comitantes**) which accompany the various arteries and are similarly named. So far as those veins are concerned, it is sufficient to state that they are provided with valves, that they are situated one on each side of the artery with which they are associated, and that they are usually united together by numerous transverse anastomoses which cross the artery. The axillary vein, however, requires more detailed consideration.

The **axillary vein** (Figs. 1087 and 1171) begins, as the direct continuation of the basilic vein, opposite the lower border of the teres major muscle. It passes upwards and medially, through the axilla, along the medial side of the axillary artery, and ends at the outer border of the first rib by becoming the subclavian vein. It possesses one or more bicuspid valves, of which one is usually situated opposite the lower border of the subscapularis muscle.

Relations.—Its *anterior* relations are similar to those of the axillary artery, but, in addition, the vein is crossed in front, under cover of the clavicular part of the pectoralis major, by the pectoral branches of the acromio-thoracic artery, and by branches of the medial pectoral nerve, and it receives anteriorly the cephalic vein.

Posterior to it are the muscles which form the posterior wall of the axilla, the axillary artery and the first serration of the serratus anterior. The nerve to the serratus anterior

intervenes between it and that muscle, and the subscapular nerves, the nerve to the latissimus dorsi, and the subscapular artery pass between it and the subscapularis.

It is separated from the third part of the axillary artery by the ulnar nerve and the medial cutaneous nerve of the forearm; from the second part of the axillary artery by the medial cord of the brachial plexus; and in the proximal part of the axilla, behind the clavi-pectoral fascia, it is separated from the first part of the artery by the medial

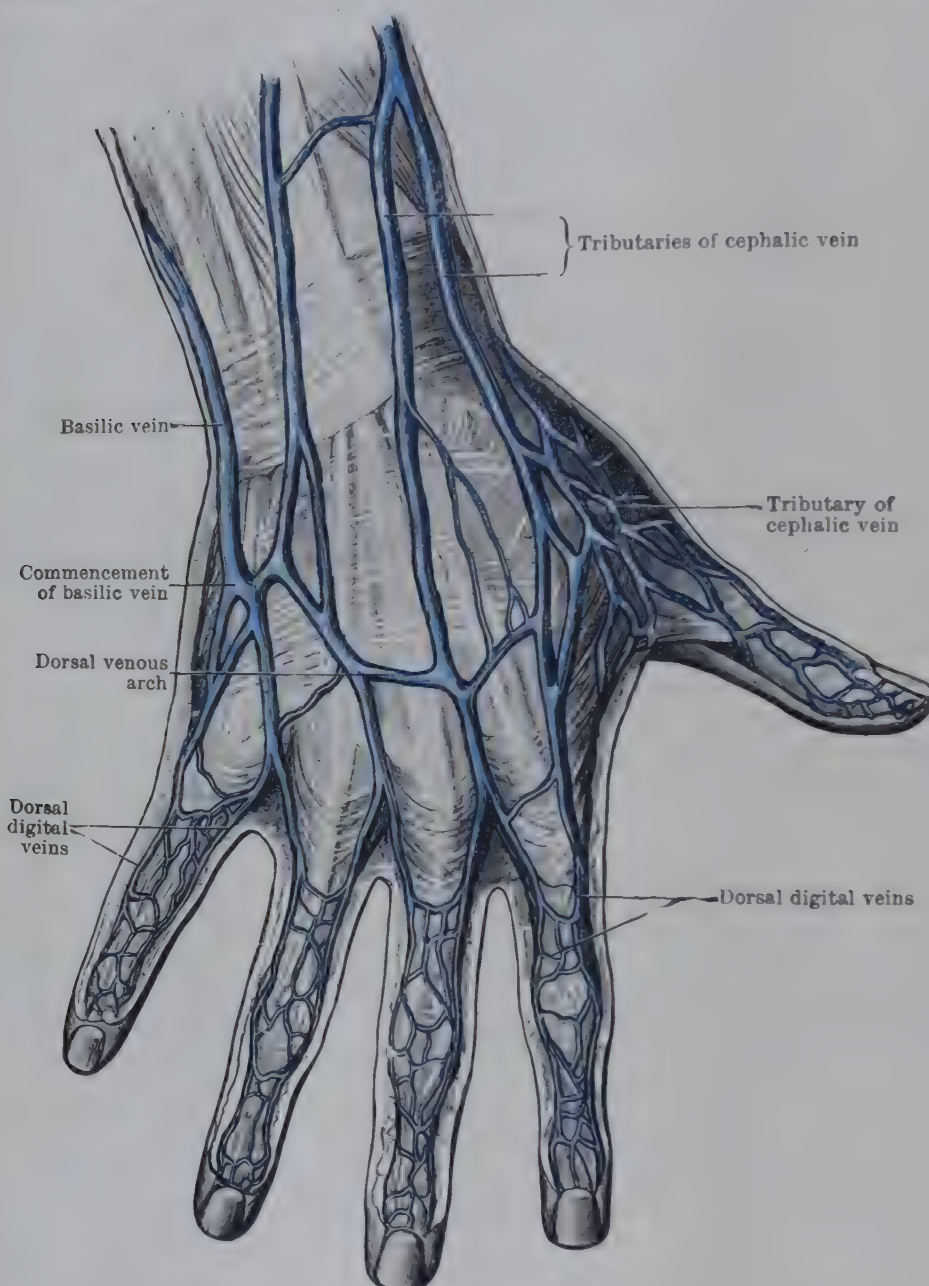

FIG. 1116.—SUPERFICIAL VEINS ON DORSUM OF HAND AND DIGITS.

pectoral nerve. To its medial side lie the lateral set of axillary lymph-glands and, in the distal part of the axilla, the medial cutaneous nerve of the arm.

Tributaries.—Its tributaries correspond with the branches of the axillary artery, except the acromio-thoracic. Besides these, it receives the venæ comitantes of the brachial artery at the lower border of the subscapularis; and the cephalic vein joins it above the upper border of the pectoralis minor muscle.

SUPERFICIAL VEINS OF UPPER LIMB

The superficial veins of the upper limb begin in the superficial fascia of the palm and dorsum of the hand and of the digits.

Veins of Digits and Hand.—The **palmar digital veins** are two or more fine longitudinal channels which lie in the superficial fascia of the palmar surfaces of the digits. They communicate, proximally, with a fine venous network which

lies in the superficial fascia of the palm, and, at the proximal ends of the inter-digital clefts, by means of anastomosing channels which pass backwards between the heads of the metacarpal bones, they open into the *dorsal digital veins.*

The **dorsal digital veins**, two in each digit, anastomose freely together on the dorsal surfaces of the digits. At the proximal ends of the interdigital clefts they communicate with the palmar digital veins, and then they unite together to form an indefinite series of *dorsal meta-carpal veins* which again unite on the lower part of the back of the hand in a **dorsal venous arch** which, however, is extremely variable in position and shape.

Veins of Forearm and Upper Arm.—The veins of the forearm emerge from the dorsal venous arch and from the palmar venous plexus, and they vary considerably in number and in size. As a rule there are two main longitudinal channels—the *cephalic vein* on the radial side and the *basilic vein* on the ulnar side. Sometimes there is a definite *median vein* on the front of the forearm.

The **cephalic vein** begins in the radial end of the dorsal venous arch. It receives the dorsal veins of the thumb, turns round the radial margin of the distal part of the forearm, and runs parallel with the anterior border of the brachio-radialis muscle to the front of the elbow. There, frequently much reduced in size, it turns laterally and runs along the lateral border of the prominence of the biceps to the interval between the deltoid and pectoralis major, along which, after piercing the deep fascia, it ascends to the infra-clavicular fossa. In the fossa, it crosses the pectoralis minor and passes medially under cover of the clavicular part of the pectoralis major in front of the clavi-pectoral fascia, which separates it from the first part of the axillary artery; then, turning backwards, it pierces that fascia and ends in the axillary vein. Occasionally, instead of piercing the clavi-pectoral fascia, it crosses the front of the clavicle, deep to the platysma, pierces the deep cervical fascia, and joins the lower part of the external jugular vein.

On the flexor aspect of the forearm a number of tributaries join its lateral border. Some of these arise from the dorsal venous arch of the hand and others in the superficial fascia of the dorsal aspect of the forearm.

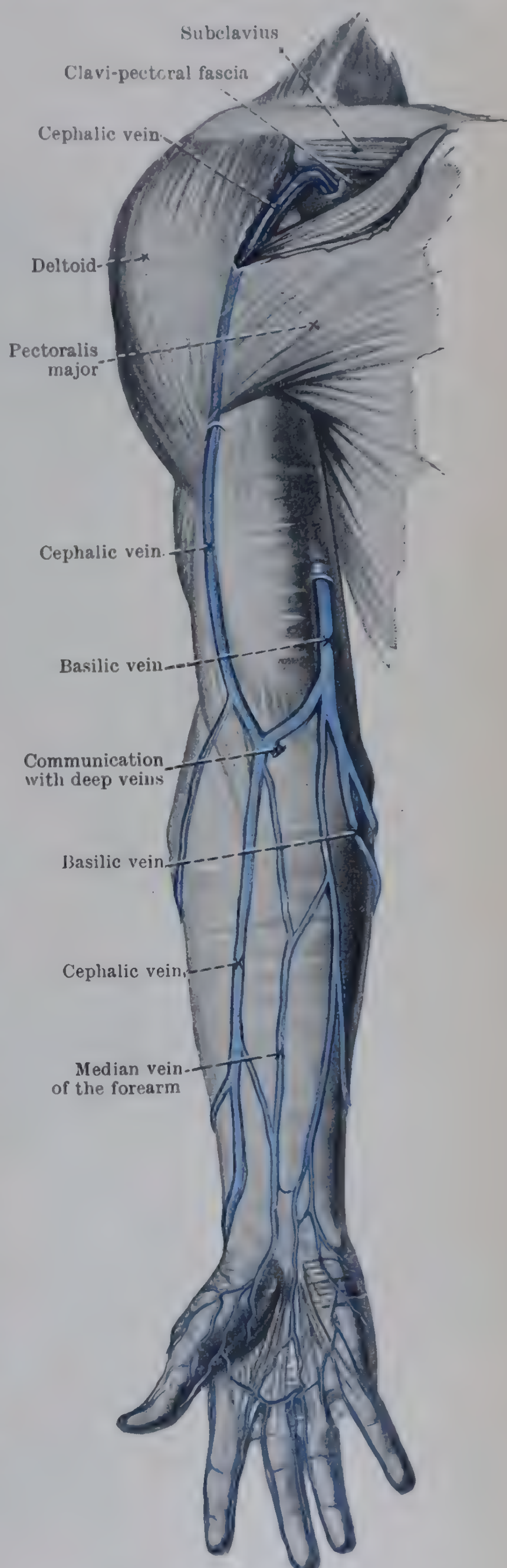

FIG. 1117.—SUPERFICIAL VEINS ON FLEXOR ASPECT OF RIGHT UPPER LIMB.

The median cubital vein connects the cephalic and basilic veins.

In front of the elbow it is connected with the basilic vein by a large obliquely placed anastomosing channel, called the *median cubital vein.* In the infra-

clavicular fossa it is joined by tributaries which correspond with the branches of the acromio-thoracic artery.

The **median cubital vein** (Fig. 1117) runs along the medial border of the distal part of the biceps-prominence, superficial to the bicipital aponeurosis which separates it from the brachial artery. It not only connects together the cephalic and basilic veins but it receives also a communicating tributary from the deep veins of the forearm, and one or more superficial veins of varying size which ascend on the front of the forearm.

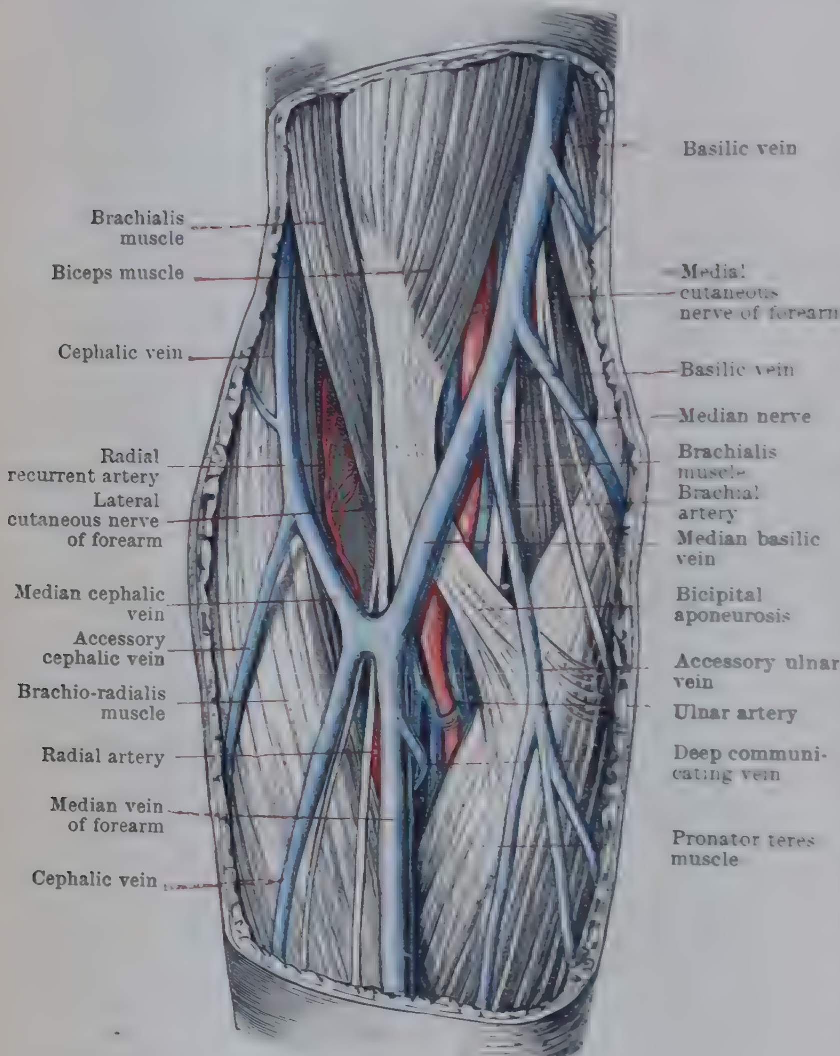

Fig. 1118.—Superficial Veins at Bend of Elbow in a Specimen in which the Median Vein was large.

Frequently the median cubital vein is relatively very large, and the upper part of the cephalic vein is then a comparatively small vessel.

The **basilic vein** begins in the ulnar end of the dorsal venous arch of the hand. It runs along the back of the forearm to the junction of the proximal and middle thirds, where it turns round the ulnar border of the forearm, and runs in front of the medial epicondyle of the humerus to the medial bicipital groove. At the middle of the upper arm it pierces the deep fascia. After piercing the fascia it runs along the medial border of the brachial artery to the axilla, and there becomes the axillary vein.

It is joined by tributaries from both surfaces of the forearm, and in front of the elbow by the median cubital vein, which connects it with the cephalic vein.

Median Vein of Forearm.—The median vein of the forearm, which begins in the palmar venous plexus and runs along the middle of the front of the forearm to the elbow, is occasionally a large vessel. At the bend of the elbow it receives the communication from the deep veins and then divides into two branches—the median cephalic and the median basilic veins (Fig. 1118). The *median cephalic vein* runs along the lateral bicipital sulcus and joins the cephalic vein. The *median basilic* passes along the medial bicipital sulcus and joins the basilic vein; it thus takes the place of the median cubital vein.

When venesection is performed in the forearm it is either the median cubital vein or the median basilic vein which is opened.

Variations.—The **superficial veins** of the forearm are extremely variable; any of them may be absent, but most commonly it is the median or the cephalic vein which is wanting. The median cephalic and the cephalic veins may be small or absent, and, on the other hand, the cephalic vein may be larger than usual. The cephalic vein may end in the external jugular vein, which was its original termination; or it may be connected with the external jugular vein

by an anastomosing channel which sometimes passes over the clavicle and sometimes through it. The basilic vein varies in size and in the level at which it pierces the deep fascia.

The **venæ comitantes** of the brachial artery usually end at the lower border of the subscapularis, where they join the axillary vein, but they may end above or below that level.

INFERIOR VENA CAVA

The **inferior vena cava** (Figs. 1119, 1120) is a large venous trunk which receives all the blood from the lower limbs, and the greater part of the blood from

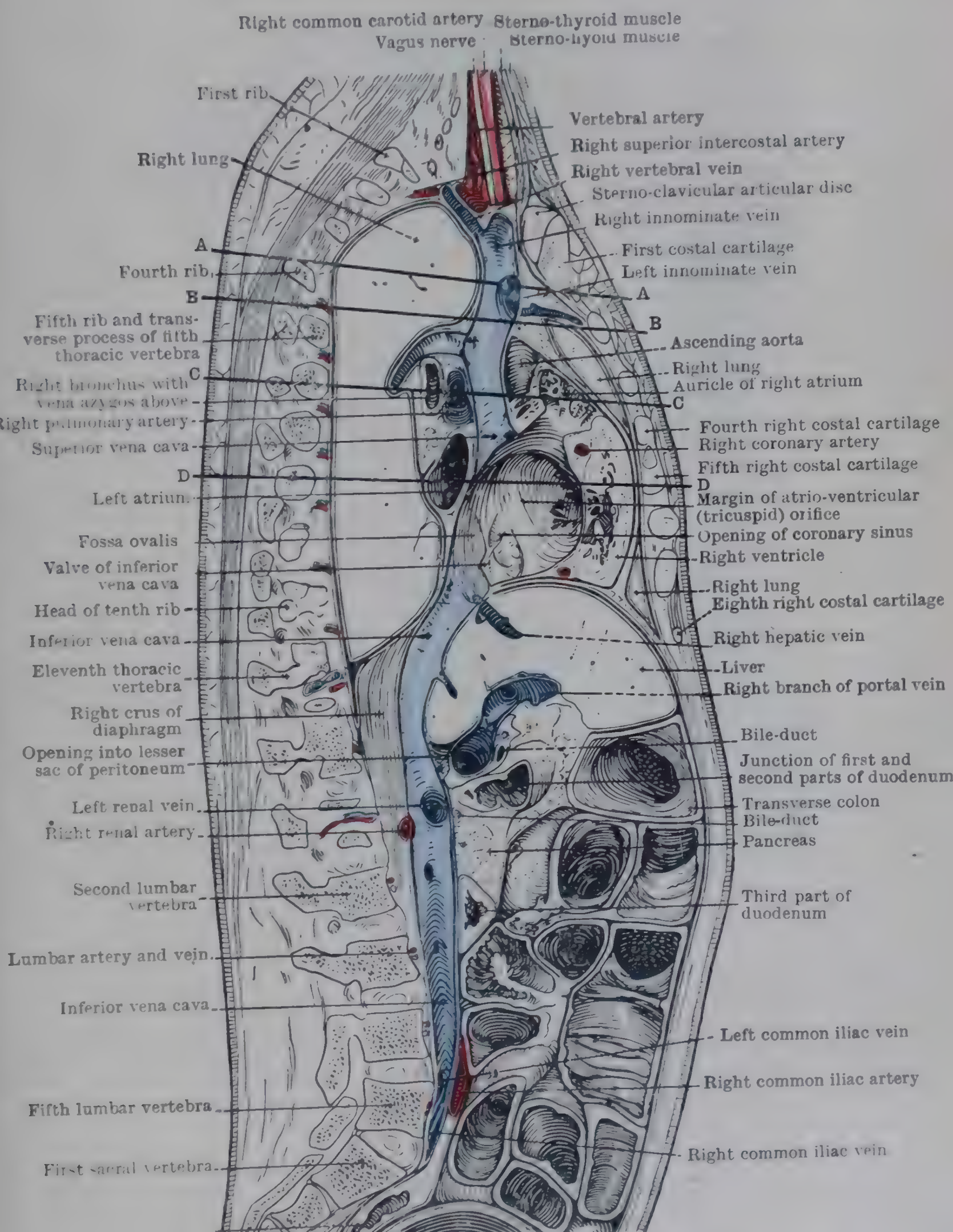

Fig. 1119.—Sagittal Section of Body of Young Man through Superior and Inferior Venæ Cavæ.

A-A. Plane of section of Fig. 1085.
B-B. Plane of section of Fig. 1110.
C-C. Plane of section of Fig. 1070.
D-D. Plane of section of Fig. 1063.

the walls and contents of the abdomen and pelvis. It begins on the body of the fifth lumbar vertebra, to the right of the median plane, behind the right common iliac artery. It ascends through the abdomen, over the front of the

vertebral column and the right crus of the diaphragm on the right of the median plane, and it pierces the central tendon of the diaphragm, between its middle and right leaflets, at the level of the lower part of the eighth thoracic vertebra. It then enters the middle mediastinum, pierces the fibrous pericardium, and terminates in the lower and posterior part of the right atrium of the heart. Its intrathoracic portion is very short, and its intrapericardial portion is covered in front and on its right and left sides by the parietal serous pericardium. Attached to the inferior and anterior margin of its atrial orifice is the *valve of the inferior vena cava*; that is a remnant of an important fold of endocardium by which, in the fœtus, the greater part of the blood from the inferior vena cava was directed through the foramen ovale into the left atrium.

Relations.—The inferior vena cava is in relation, *posteriorly*, with the bodies of the lower lumbar vertebræ and the corresponding part of the anterior longitudinal ligament, the anterior portion of the right psoas major muscle, the right lumbar sympathetic trunk, the trunks of the lower right lumbar arteries, the right crus of the diaphragm, the right renal artery, the right suprarenal artery, the right cœliac ganglion, the right phrenic artery, and the medial portion of the right suprarenal gland.

Anterior to it, from below upwards, are the following structures: the right common iliac artery, the lower end of the mesentery and the superior mesenteric vessels, the ileo-colic and right colic vessels, the right testicular or ovarian artery and the third part of the duodenum, the head of the pancreas and the bile-duct, the portal vein and the first part of the duodenum, the opening into the lesser sac of the peritoneum, and the liver—the vena cava being embedded in a deep groove on the back of that organ, so that the liver is to the right and left of it as well as in front. More superficially are coils of small intestine, the greater omentum, and the transverse colon and mesocolon.

To its *left side* are the aorta, the right crus of the diaphragm, and the caudate lobe of the liver.

On its *right side*, from below upwards, there are the right ureter, the right kidney, the right suprarenal gland (which is also behind), and the main part of the right lobe of the liver.

Variations and Abnormalities.—The lower part of the inferior vena cava is sometimes absent, in which case the common iliac veins ascend, one on the right of the aorta and the other on its left, to the level of the second lumbar vertebra, where the left common iliac vein receives the left renal vein and then crosses in front of or behind the aorta to join the corresponding vein of the right side; in such cases, therefore, the inferior vena cava begins at the level of the second lumbar vertebra, and it represents only the upper and last-formed part of the ordinary vessel; the common iliac veins, each of which receives the lumbar veins of its own side, are exceptionally long, and they may or may not be united at the pelvic brim by a small transverse anastomosing channel. Cases of this kind are sometimes described as partial doubling of the inferior vena cava.

Occasionally the inferior vena cava does not end in the right atrium but is continuous with the vena azygos, which is much enlarged, and all the inferior caval blood is then carried to the superior vena cava. In such cases the hepatic veins open into the right atrium by a channel which represents the upper end of the inferior vena cava (see p. 1289).

The lower part of the inferior vena cava sometimes lies to the left of the aorta instead of to the right of it; that condition is associated with a long right common iliac vein, which crosses obliquely from right to left to join the left common iliac vein. After receiving the left renal vein this misplaced inferior vena cava crosses in front of the aorta, reaching the right side at the level of the second or first lumbar vertebra. In other cases, however, the left inferior vena cava continues upwards through the left crus of the diaphragm, usurping the place of the inferior hemiazygos vein; having entered the thorax, it may cross to the opposite side and terminate in the vena azygos, or it may continue upwards on the same side, arch over the root of the left lung, and descend behind the left atrium to end in the right atrium in the situation of the coronary sinus. In that group of cases also the hepatic veins open separately into the right atrium.

The inferior vena cava may lie ventral instead of dorsal to the right testicular or ovarian artery.

The tributaries also of the inferior vena cava are subject to variation. Additional renal, testicular, ovarian, or suprarenal veins may be present. Two or three lumbar veins of one or both sides may unite into a common trunk which ends in the inferior vena cava, and the hepatic veins may open separately, or after fusing into a common trunk, into the right atrium near the opening of the inferior vena cava.

The variations of the inferior vena cava and its tributaries are due to persistence of portions of the primitive veins which usually disappear, and to the persistence of transverse anastomoses and tributaries which usually atrophy, or to other modifications of the embryonic veins which ordinarily take part in the formation of the inferior vena caval system (see p. 1384).

Tributaries.—In addition to the two common iliac veins, through which it receives blood from the pelvis and from the lower limbs, the inferior vena cava receives the following main tributaries: the hepatic veins, the right phrenic vein, the right suprarenal vein, the right and left renal veins, the right testicular or ovarian vein, and the third and fourth lumbar veins of both sides. It receives also a number of smaller tributaries, including one or two direct from the right ureter.

The **hepatic veins** (Fig. 1120) convey blood which has passed through the

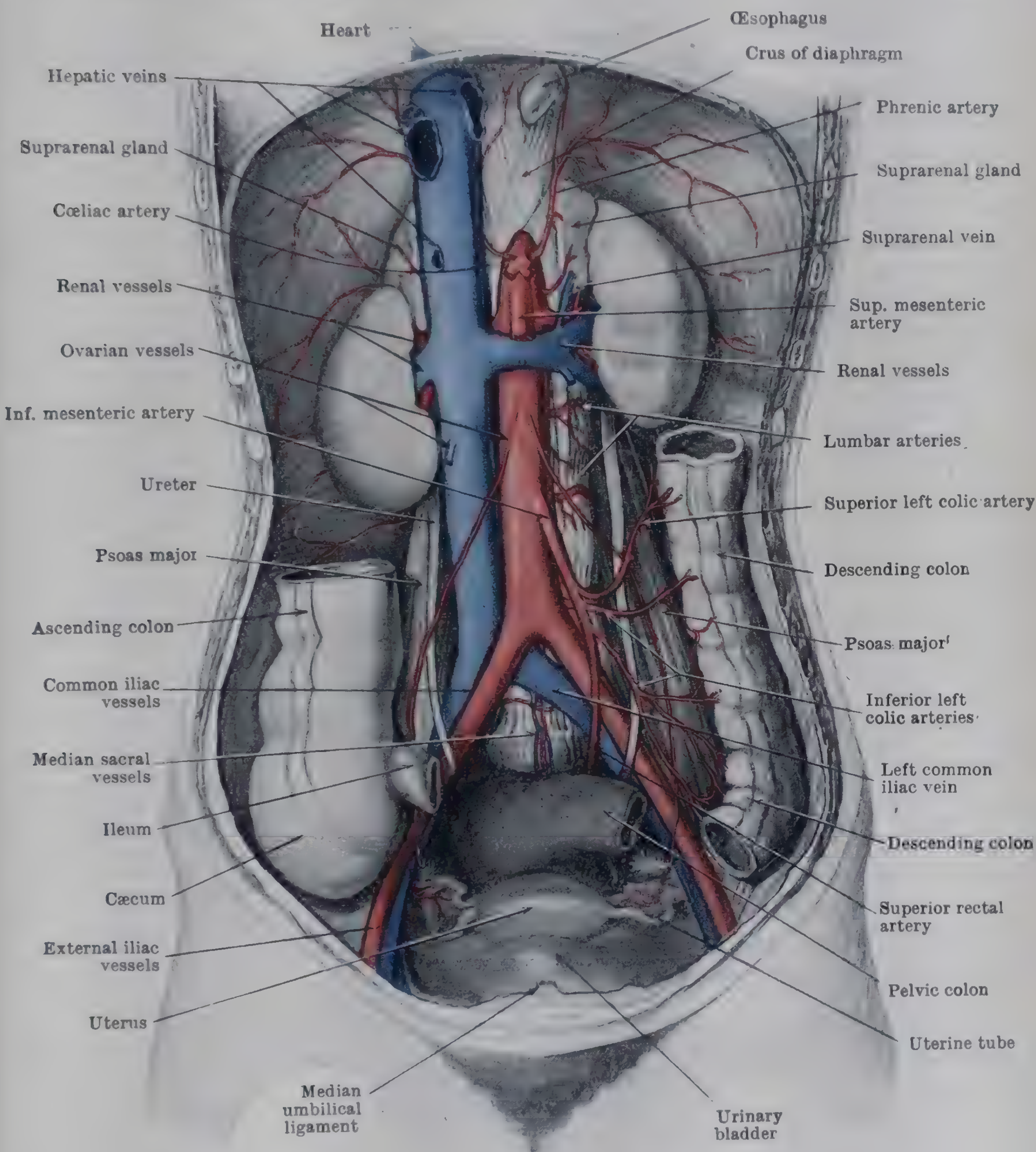

Fig. 1120.—Inferior Vena Cava and its Tributaries.

liver from the portal vein and from the hepatic artery, and they open into that portion of the inferior vena cava which lies immediately below the diaphragm and in the back of the right lobe of the liver. They form two groups, an upper group of two or three large trunks, and a lower group of smaller veins.

The upper group occasionally consists of only two veins, a right and a left; more frequently there are three vessels, a right, a left, and a middle vein, and in the latter case the middle vein issues from the caudate lobe.

The veins of the lower group vary in number from six to twenty; they return blood from the right and caudate lobes.

The hepatic veins begin as the *central* or *intralobular veins* of the lobules of

the liver; the central veins issue from the lobules, and unite together to form *sublobular veins*; and the sublobular veins unite with one another, as they converge towards the posterior surface of the liver, to form the larger hepatic veins.

The **phrenic veins** are formed by tributaries from the diaphragm and correspond to the phrenic arteries. The **right** vein ends in the upper part of the inferior vena cava. The **left** vein either descends to end in the left suprarenal or renal vein, or crosses behind or in front of the œsophagus to end in the inferior vena cava; both of these veins may be present.

A single **suprarenal vein** issues from the hilum of each suprarenal gland; the *right* vein is very short and runs slightly upwards to end in the back of the inferior vena cava; the *left* runs downwards and ends behind the body of the pancreas in the left renal vein.

The **renal veins** are formed by the union of five or six tributaries which issue from the hilum of each kidney, where they lie anterior to or are intermingled with the corresponding arteries.

The **right renal vein** is about 1 inch (25 mm.) long; it lies behind the second part of the duodenum, and ends in the right side of the inferior vena cava.

The **left renal vein** is about 3 inches (75 mm.) long. It crosses in front of the left psoas major, the left crus of the diaphragm, and the aorta immediately below the superior mesenteric artery. It lies behind the body of the pancreas and the fourth part of the duodenum, and runs above the third part of the duodenum to end in the left side of the inferior vena cava. The left testicular or ovarian vein, according to the sex, and the left suprarenal vein open into it.

The **testicular veins**, on each side, issue from the testis and epididymis and form the *pampiniform plexus*. The plexus is one of the constituents of the spermatic cord, and consists of from eight to ten veins, most of which lie in front of the vas deferens; it passes upwards through the scrotum and inguinal canal, and ends near the deep inguinal ring in two main trunks which ascend with the corresponding testicular artery, receiving tributaries from the ureter; the two veins soon unite together and a single terminal vein is formed. The terminal testicular vein on the right side opens into the inferior vena cava, that on the left side into the left renal vein. They are provided with valves, one of which usually lies near the termination of each vein, but occasionally the valve near the orifice of the left testicular vein is absent. The relations of the testicular veins are the same as those of the arteries (p. 1296), with the exception of the slight differences due to their modes of termination.

The much greater frequency of *varicocele* (see p. 1514) on the left side is associated with the fact that the left testicular vein joins the left renal at right angles; but it may be determined by the pressure of a loaded descending colon.

The **ovarian veins**, on each side, issue from the hilum in the mesovarian border of the ovary. They pass between the layers of the broad ligament, where they anastomose freely and form the *pampiniform plexus*, which extends to the brim of the pelvis. From the plexus two veins issue which accompany the ovarian artery and soon fuse together to form a single terminal vein which ends, on the right side, in the inferior vena cava, and on the left side in the left renal vein. As in the case of the testicular veins, the relations are the same as those of the arteries (p. 1297).

There are usually five **lumbar veins** on each side, one with each aortic lumbar artery and one with the lumbar branch of the median sacral artery. By their anterior and posterior tributaries the lumbar veins drain the lateral and posterior walls of the abdomen. The anterior tributaries begin in the lateral walls of the abdomen, where they communicate with the tributaries of the superior and inferior epigastric veins. The posterior tributaries issue from the muscles of the back in the lumbar region, and receive the intervertebral veins from the internal vertebral plexuses. The main stems pass forwards on the bodies of the vertebræ postero-medial to the psoas major muscle. The terminations of the lumbar veins are very variable. The upper two on each side may end in the ascending lumbar vein, or in the azygos or the hemiazygos vein. Usually the third

and fourth end in the inferior vena cava, those of the left side passing behind the aorta. The fifth ends in the ilio-lumbar vein. The lumbar veins of each side may all end in a median longitudinal channel (in the external vertebral plexus) which ascends behind the aorta in front of the vertebral bodies and branches to join the azygos and inferior hemiazygos veins; and they are all united together by a longitudinal anastomosing vessel—the ascending lumbar vein.

Each **ascending lumbar vein** passes upwards, between the psoas major and the roots of the transverse processes of the lumbar vertebræ. It begins in the lateral sacral vein of the same side, anastomoses with the ilio-lumbar vein, connects the lumbar veins together, receives tributaries from the anterior external vertebral plexus, and anastomoses with the inferior vena cava and the renal vein. The right ascending lumbar vein ends in the azygos vein and the left in the inferior hemiazygos vein.

Common Iliac Veins

The **common iliac veins** (Figs. 1097 and 1120), right and left, are formed by the union of the corresponding external and internal iliac veins. Each begins at the brim of the pelvis immediately behind the upper part of the internal iliac artery, and both veins pass upwards to the body of the fifth lumbar vertebra, at the right half of which, posterior to the right common iliac artery, they unite to form the inferior vena cava.

The **right common iliac vein** is much shorter than the left; it passes upwards anterior to the obturator nerve and the ilio-lumbar artery, and posterior to the corresponding common iliac artery.

The **left common iliac vein** is much longer than the right, and is placed more obliquely. It passes upwards and to the right, anterior to the body of the fifth lumbar vertebra and the median sacral artery. For some distance it runs along the medial side of the left common iliac artery, and then ends behind the right common iliac artery. Near its origin, it passes behind the mesentery of the pelvic colon and the superior rectal vessels.

Variations.—The **left common iliac vein** is short and the right long when the inferior vena cava lies on the left side. The common iliac veins may be absent, the internal iliac veins uniting to form the inferior vena cava, into which the external iliac veins open as lateral tributaries.

Tributaries.—Each common iliac vein receives the corresponding external iliac, internal iliac, and ilio-lumbar veins. The left common iliac vein receives, in addition, the median sacral vein.

The **ilio-lumbar vein** receives the fifth lumbar vein and tributaries from the iliac fossæ, from the lower parts of the vertebral muscles, and from the vertebral canal. It accompanies the corresponding artery only in the abdomen proper, for it passes behind the psoas major muscle and ends in the back of the corresponding common iliac vein.

The venæ comitantes of the median sacral artery begin by the union of tributaries which issue from the venous plexus on the pelvic surface of the sacrum, through which they communicate with the lateral sacral veins and receive blood from the interior of the sacral canal. They unite above into a single **median sacral vein**, which ends in the left common iliac vein.

The **internal iliac vein** (Fig. 1097) is a short trunk formed by the union of tributaries which correspond to all the branches of the internal iliac artery with the exception of the umbilical and the ilio-lumbar arteries.

It begins at the upper border of the greater sciatic notch and ascends to the brim of the pelvis; there it unites with the external iliac vein to form the common iliac vein. It lies immediately behind the internal iliac artery, is crossed laterally by the obturator nerve, and is in relation medially, on the left side with the pelvic colon, and on the right side with the lower part of the ileum.

Tributaries.—The tributaries, which are numerous, are conveniently divided into extra-pelvic and intra-pelvic groups.

The *extra-pelvic tributaries* are all **parietal**; they are the superior and inferior gluteal, the obturator, and the internal pudendal veins.

The **superior gluteal veins** are the venæ comitantes of the superior gluteal artery, formed by tributaries which issue from the muscles of the gluteal region. They accompany the artery through the greater sciatic foramen, and end in the internal iliac vein, often as a single trunk.

The **inferior gluteal veins** are the venæ comitantes of the inferior gluteal artery, which begin in the subcutaneous tissues on the back of the thigh; they ascend with the artery and pass into the buttock on the deep aspect of the gluteus maximus, where they receive numerous tributaries from the surrounding muscles. Entering the pelvis through the greater sciatic foramen, they unite into a single vessel which ends in the lower and anterior part of the internal iliac vein below the termination of the obturator vein.

The **obturator vein** is formed by the union of tributaries which issue from the hip joint and from the muscles of the proximal and medial part of the thigh. It enters the true pelvis through the obturator canal, runs backwards and upwards along the side-wall of the pelvis, medial to the obturator fascia, immediately below the corresponding artery, and passes lateral to the ureter and the descending branches of the internal iliac artery to end in the internal iliac vein.

The **internal pudendal veins** are the venæ comitantes of the internal pudendal artery: in the male they emerge from the lower part of the *prostatic plexus*, which lies below and behind the inferior pubic ligament. They follow the course of the internal pudendal artery, and usually join together into a single vessel which ends in the internal iliac vein. They receive blood from the corpus cavernosum by the deep vein of the penis or clitoris, veins from the bulb, perineal and inferior rectal veins, and veins from the muscles of the gluteal region.

The **inferior rectal veins** begin in the substance of the external sphincter of the anus and in the walls of the anal canal; they anastomose through the *rectal plexus* with the middle and superior rectal veins, and consequently connect the portal and vena caval systems together.

The *intra-pelvic tributaries* of the internal iliac vein are **parietal** and **visceral**: the former are the lateral sacral veins; the latter are the efferent vessels from the plexuses around the several pelvic viscera.

Lateral sacral veins accompany the lateral sacral arteries, and end on each side in the corresponding internal iliac vein. They are connected together by an *anterior sacral venous plexus.*

The **pelvic venous plexuses** form dense networks of thin-walled veins associated with the rectum, bladder, prostate, uterus, and vagina. They communicate freely with one another, and from them the visceral tributaries of the internal iliac veins arise.

The **rectal plexuses** lie in the submucous coat of the rectum and anal canal and on the outer surface of their muscular coats. They are drained by the superior, middle, and inferior rectal veins; the superior rectal vein joins the portal system; the middle and inferior are tributaries of the systemic veins. The rectal plexuses, therefore, form a link between systemic and portal veins.

The **middle rectal veins** are very irregular; sometimes they cannot be distinguished. When present they are formed by tributaries which begin in the submucous tissue of the rectum, where they communicate with the superior and inferior rectal veins in the rectal plexus; they pass through the muscular coat, and fuse together to form two middle rectal veins, right and left, each of which runs laterally beneath the peritoneum to end in the corresponding internal iliac vein. In the male each middle rectal vein receives tributaries from the seminal vesicle and vas deferens of its own side.

The **prostatic plexus** is situated mainly within the substance of the fascial sheath of the prostate (Fig. 651, p. 768). In front it receives the deep dorsal vein of the penis; its posterior part communicates with the vesical plexus and its extension around the seminal vesicles and vasa deferentia. Efferent vessels pass from it on each side to open into the internal iliac vein, but it drains mainly through the vesical plexus.

The **vesical plexus** *in the male* lies on the outer surface of the muscular coat of the bladder. It is densest round the neck of the bladder, where it is continuous with the prostatic plexus, and at the base, where it extends around the seminal vesicles and around the ends of the ureters and the vasa deferentia. Several **vesical veins** pass from it on each side to the internal iliac vein.

The **vesical plexus** *in the female*, which represents the vesical and prostatic plexuses of the male, surrounds the upper part of the urethra and the neck of the bladder. It communicates with the vaginal plexus and receives the dorsal vein of the clitoris; and its efferent vessels end in the internal iliac vein.

The **uterine plexuses** lie along the borders of the uterus; they receive tributaries,

which are entirely devoid of valves, from the uterus; and they communicate above with the ovarian pampiniform plexuses, and below with the vaginal plexuses.

The **uterine veins**, usually two on each side, issue from the lower parts of the uterine plexuses, above their communications with the vaginal plexuses. At first the uterine veins lie in the medial part of the root of the broad ligament above the lateral fornix of the vagina and the ureter; they then pass backwards with the artery and end in the internal iliac vein. For their relation to other venous plexuses in the pelvis, see p. 1367.

The **vaginal plexuses** lie at the sides of the vagina. They receive tributaries from the walls of the vagina. They communicate with the uterine plexuses above; with the veins of the bulb below; in front with the vesical plexus; and behind with the veins which issue from the middle and lower parts of the rectal plexus. A single **vaginal vein** issues from the upper part of the vaginal plexus on each side; it accompanies the corresponding artery, and ends in the internal iliac vein.

Dorsal Veins of Penis and Clitoris.—There are two dorsal veins of the penis—the superficial and the deep.

The **superficial dorsal vein** receives tributaries from the prepuce, and runs backwards, immediately beneath the skin, to the pubic symphysis, where it divides into right and left branches which end in the superficial external pudendal veins.

The **deep dorsal vein** lies on the dorsum of the penis, deep to the deep fascia. It begins in the sulcus behind the glans by the union of numerous tributaries from the glans and the anterior parts of the corpora cavernosa; and it runs backwards in the mid-dorsal line in the sulcus between the corpora cavernosa, from which it receives many additional tributaries. At the root of the penis the vein passes between the two layers of the suspensory ligament, and then between the inferior pubic ligament and the transverse ligament of the perineum; and it ends by dividing into two branches which join the lower part of the prostatic plexus.

The **dorsal vein of the clitoris** in the female has a similar course to that of the deep dorsal vein of the penis in the male. It ends in the lower part of the vesical plexus and communicates with the internal pudendal veins.

The **external iliac vein** (Figs. 1097, 1100, and 1120) is the upward continuation of the femoral vein. It begins, on the medial side of the end of the external iliac artery, immediately behind the inguinal ligament, and ascends along the brim of the pelvis to end, opposite the sacro-iliac joint and immediately behind the internal iliac artery, by joining the internal iliac vein to form the common iliac vein. It lies, at first, on the medial side of the external iliac artery but on a slightly posterior plane, and then directly posterior to the artery, whilst just before its termination it crosses the lateral side of the internal iliac artery and separates that vessel from the medial surface of the psoas major muscle. In its whole course the vein lies anterior to the obturator nerve. It is usually provided with one or sometimes two bicuspid valves; but both are usually incompetent. Its tributaries correspond to the branches of the external iliac artery; that is, the deep circumflex iliac and inferior epigastric veins open into it close to its commencement. In addition, it frequently receives the pubic vein.

The **pubic vein** forms a communication between the obturator vein and the external iliac vein. It varies in size, and may form the main termination of the obturator vein, from which it arises. It begins in the obturator canal and ascends alongside the pubic branch of the inferior epigastric artery to reach the external iliac vein.

VEINS OF LOWER LIMB

The veins of the lower limb, like those of the upper limb, are arranged in two groups, the **superficial** and the **deep**; and in the lower limb as in the upper the deep veins are associated with the arteries as venæ comitantes, whilst the trunks of the superficial veins, which lie at first in the subcutaneous tissues, ultimately end in the deep veins. There is therefore a general similarity in the arrangement of the veins of the upper and lower limbs, but there are differences in detail which are of some importance. Thus, in the upper limb, there are two deep veins with each artery from the fingers to the root of the limb, where a single trunk, the axillary vein, is formed; but in the lower limb each main artery has two venæ comitantes only as far as the knee, where a single trunk

is usually formed. That vessel, the **popliteal vein**, is the commencement of the main venous stem of the lower limb; it is continued upwards through the thigh, as the **femoral vein**, and along the brim of the pelvis as the **external iliac vein**.

In the upper limb all the blood which passes through the superficial veins is poured into the efferent trunk at the root of the limb—the axillary vein; but in the lower limb the superficial veins of the lateral parts of the leg and foot join the popliteal vein at the knee, whilst those of the medial part of the limb join the femoral vein near the root of the limb in the femoral triangle.

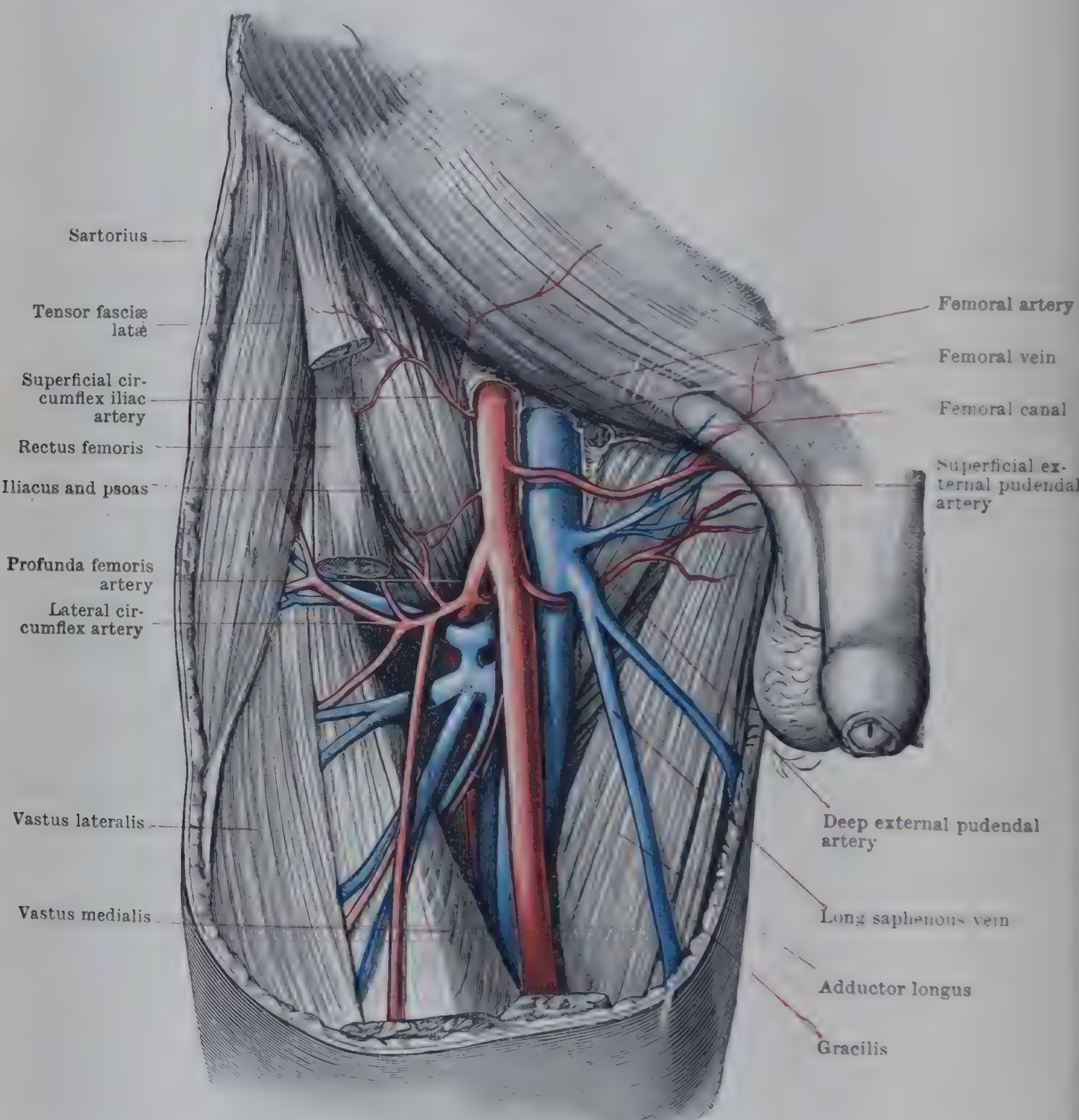

Fig. 1121.—Femoral Vessels in the Femoral Triangle.

In addition to these differences in the general arrangement of the veins of the limbs, it must be noted also that in the upper limb all the blood, from the shoulder-girdle region as well as from the free portion of the limb, is returned to the main efferent vein; but in the lower limb the greater part of the blood from the region of the pelvic girdle, and a considerable portion from the thigh, is returned by the gluteal, obturator, and internal pudendal veins to the internal iliac vein, which is not the main efferent vein of the limb.

Deep Veins of Lower Limb

Two *venæ comitantes* accompany all the arteries of the lower limb, except the popliteal and femoral trunks and the profunda femoris. They usually lie one on

each side of the artery; they are connected with one another by transverse channels which pass across the artery, and they are provided with numerous valves.

The **popliteal vein** (Figs. 1099, 1103, 1104) is formed, at the distal border of the popliteus muscle, by the union of the venæ comitantes of the anterior and posterior tibial arteries. At its commencement it lies to the medial side of, and slightly superficial to, the popliteal artery, and to the lateral side of the medial popliteal nerve; as it runs through the popliteal fossa it inclines laterally, and in the middle of the space it is directly posterior to the artery, separating the artery from the nerve which is still more posterior; and at the proximal part of the space it is postero-lateral to the artery, and still between it and the nerve. It then passes through the opening in the adductor magnus muscle and becomes the femoral vein.

The popliteal vein, which is provided with two or three bicuspid valves, is closely bound to the artery by a dense fascial sheath. Not uncommonly there are one or more additional satellite veins which anastomose with the popliteal vein, and in those cases the artery is more or less completely surrounded by venous trunks.

Tributaries.—In addition to venæ comitantes of the anterior and posterior tibial arteries, it receives tributaries which correspond with the branches of the popliteal artery, and it receives also one of the superficial veins of the leg—the short saphenous vein.

The **femoral vein** is the direct continuation of the popliteal vein. It begins at the junction of the middle and distal thirds of the thigh, at the opening in the adductor magnus muscle. It then ascends through the subsartorial canal and through the femoral triangle, and it ends a little medial to the middle of the inguinal ligament by becoming the external iliac vein.

In the subsartorial canal it lies at first postero-lateral to the femoral artery and then posterior to it, and it is anterior to the adductors magnus and longus, separated by the latter muscle from the profunda vessels. In the distal part of the femoral triangle it is still behind the artery, and immediately in front of the profunda vein which separates it from the profunda artery; but in the proximal part of the femoral triangle it is on the medial side of the femoral artery. About one and a quarter inches (30 mm.) below the inguinal ligament it enters the middle compartment of the femoral sheath, through which it ascends to its termination, lying between the compartment for the femoral artery on the lateral side and the femoral canal on the medial side. It usually contains two bicuspid valves—one near its termination and the other just proximal to the entrance of its profunda tributary.

Tributaries.—It receives: (1) the profunda femoris vein; (2) the long saphenous vein, which enters the femoral vein where that vessel lies in the middle compartment of the femoral sheath; (3) venæ comitantes of small unnamed arteries, of the descending genicular artery, of the lateral and medial circumflex arteries (branches of the profunda femoris), and of the deep external pudendal artery.

The **profunda femoris vein** lies in front of its artery and separates it from the adductor longus and the femoral vein. It receives the venæ comitantes of the muscular and perforating branches of its artery, but only occasionally those of the circumflex arteries, for they usually join the femoral vein direct. It is connected through the *perforating veins* with the veins of the back of the thigh.

Superficial Veins of Lower Limb

The superficial veins of the lower limb terminate in two trunks, one of which, the **short saphenous vein**, passes from the foot to the back of the knee; whilst the other, the **long saphenous vein**, extends from the foot to the groin. These veins are often enlarged and tortuous—the condition known as 'varicose veins'.

The superficial veins of the sole of the foot form a fine plexus, immediately under cover of the skin, from which anterior, medial, and lateral efferents pass. The anterior efferents end in a transverse **plantar venous arch** which lies in the furrow at the roots of the toes, and the medial and lateral efferents pass round the sides of the foot to the long or the short saphenous vein. The venous arch receives also small *plantar digital veins* from the toes, and it communicates between the heads of the metatarsals with the veins on the dorsum of the foot.

The superficial veins on the dorsal aspect of each toe unite to form two **dorsal digital veins**, which run along the borders of the dorsal surface. The dorsal digital veins of the adjacent borders of the interdigital clefts unite, at the apices of the clefts, to form four **dorsal metatarsal veins** which end in the dorsal venous arch of the foot. The dorsal digital vein from the medial side of the big toe ends in the long saphenous, and that from the lateral side of the little toe in the short saphenous vein.

FIG. 1122.—LONG SAPHENOUS VEIN AND ITS TRIBUTARIES.

The dorsal venous arch lies in the subcutaneous tissue, between the skin and the dorsal digital branches of the musculo-cutaneous nerve, opposite the anterior parts of the shafts of the metatarsal bones. It ends, medially, by uniting with the medial dorsal digital vein of the big toe to form the long saphenous vein, and laterally by joining the lateral dorsal digital vein of the little toe to form the short saphenous vein. The dorsal venous arch receives the dorsal metatarsal veins and interdigital efferents from the plantar venous arch; and numerous tributaries from the dorsum of the foot, which anastomose freely together forming a wide-meshed *dorsal venous network*, open into it from behind.

The **long saphenous vein** is formed by the union of the medial end of the dorsal venous arch with the medial dorsal digital vein of the big toe. It passes in front of the medial malleolus, crosses the medial surface of the distal third of the shaft of the tibia obliquely, and ascends, immediately behind the medial margin of the tibia, to the knee, where it lies medial to the posterior end of the medial condyle of the femur; continuing upwards, with an inclination forwards and laterally, it gains the proximal part of the femoral triangle, where it perforates the cribriform fascia and the femoral sheath and ends in the femoral vein. In the foot and leg it is accompanied by the saphenous nerve, and for a short distance distal to the knee by the saphenous branch of the descending genicular artery. In the thigh, branches of the medial cutaneous nerve lie in close relation with it. It has from eight to twenty bicuspid valves, but these become incompetent if the vein is varicose.

Tributaries.—It communicates freely, through the deep fascia, with the deep, intermuscular veins. In the foot it receives tributaries from the medial part of the sole and from the dorsal venous plexus. In the leg it is joined by tributaries from the

dorsum of the foot, the medial and ,posterior parts of the heel, the front of the leg and the calf; and it anastomoses freely with the short saphenous vein. In the thigh it receives numerous unnamed tributaries and superficial veins from the groin, which are the last tributaries to enter the long saphenous vein. They are the **superficial circumflex iliac**, **superficial epigastric**, and **superficial external pudendal veins**. They accompany the corresponding arteries, and end in the long saphenous vein immediately before it perforates the cribriform fascia. The superficial circumflex iliac vein receives blood from the lower and lateral part of the abdominal wall and the proximal and lateral parts of the thigh. The superficial epigastric vein drains the lower and medial part of the abdominal wall. The superficial external pudendal vein receives blood from the dorsum of the penis and the scrotum or from the labium majus.

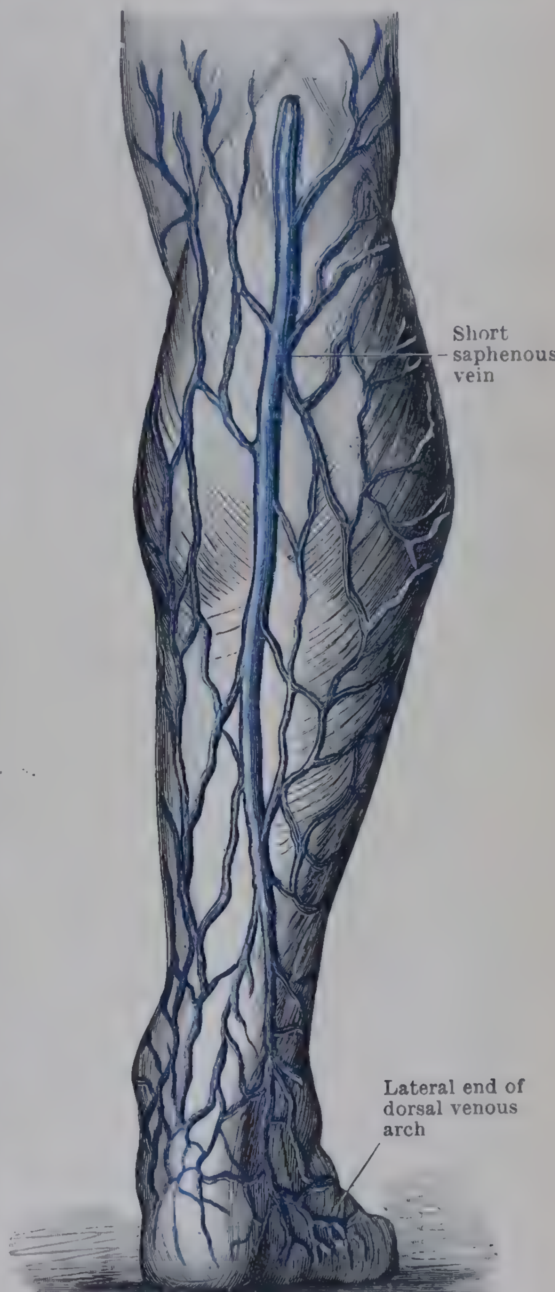

Fig. 1123.—Short Saphenous Vein and its Tributaries.

The tributaries of the superficial epigastric vein communicate above with the tributaries of the lateral thoracic veins which join the axillary vein. These communications thus unite main vessels which pass to the inferior vena cava and the superior vena cava respectively; and they may enlarge if there is any obstruction to the flow of blood in either of the venæ cavæ.

The **short saphenous vein** is formed by the union of the lateral end of the dorsal venous arch with the lateral dorsal digital vein of the little toe. At first it passes backwards in company with the sural nerve, along the lateral side of the foot and below the lateral malleolus, lying on the peroneal retinacula; then it ascends behind the lateral malleolus, and along the lateral border of the tendo calcaneus, still in company with the nerve, to the middle of the calf, whence it proceeds between the heads of the gastrocnemius to the popliteal fossa, where it pierces the deep fascia and ends in the popliteal vein. It communicates, round the medial side of the leg, with the long saphenous vein, and through the deep fascia with the deep veins. It contains from six to twelve bicuspid valves.

Tributaries.—It receives tributaries from the lateral side of the foot, the lateral side and back of the heel, the back of the leg, and, occasionally, a descending tributary from the back of the thigh. Just before it pierces the popliteal fascia it frequently gives off a small branch which ascends round the medial side of the thigh and unites there with a vein of some size to form the *accessory saphenous vein*, a channel through which a communication is established between the long and short saphenous veins. This communication may become enlarged and constitute the main continuation of the short saphenous vein.

Variations.—The **venæ comitantes** are generally described as ending at the distal part of the popliteal fossa, but they may ascend as far as the femoral triangle; one or more small additional veins usually accompany the popliteal and femoral arteries, although, as a rule, there is only one large popliteal and one large femoral vein. In a few cases the popliteal vein does not pass through the opening in the adductor magnus, but ascends behind that muscle and becomes continuous with the profunda vein, the femoral artery being unaccompanied by any large vein during its passage through the subsartorial canal.

The **long saphenous vein** is not subject to much variation, but the **short saphenous vein**

may end by joining the long saphenous, or, after piercing the deep fascia in the distal part of the thigh, it may ascend and join the inferior gluteal vein or one of the tributaries of the profunda vein.

PORTAL SYSTEM OF VEINS

The veins which form the **portal system** are the portal, the superior and inferior mesenteric and the splenic veins and their tributaries. They convey blood to the liver: (1) from the whole of the abdominal and pelvic parts of the alimentary canal, except the terminal part of the anal canal, (2) from the pancreas, and (3) from the spleen. The right branch of the portal vein receives the vein from the gall-bladder; and its left branch receives para-umbilical veins which pass along the round ligament of the liver and constitute one of the anastomoses between the portal and systemic veins. The tributaries of origin of the portal vein correspond with the branches of the splenic and the superior and inferior mesenteric arteries, after which they are named and which they accompany for a considerable distance. The larger or terminal veins leave their associated arteries; the **inferior mesenteric vein** joins the **splenic vein**, and the latter unites with the **superior mesenteric vein** to form the **portal vein**, which passes to the liver. All the larger vessels of this system, including the superior rectal vein, are devoid of valves, but valves are present in the tributaries in the fœtus, and some of them may remain in an imperfect condition in the smaller tributaries in the adult.

Unlike other veins, the portal vein ends like an artery by breaking up into branches which ultimately terminate in the sinusoidal capillaries in the substance of the liver; from the capillaries, which receive also the blood conveyed to the liver by the hepatic artery, the hepatic veins arise; and, as the hepatic veins open into the inferior vena cava, the portal blood ultimately reaches the general systemic circulation.

The portal vein conveys products of digestion to the liver, and, in addition to this important function, the whole portal system also acts as a reservoir of blood for the needs of the general circulation. It has been calculated that the portal system can contain about one-third of the total amount of blood in the body; and the amount of blood present can be varied by contraction or relaxation of the arteries by which it enters the system and of the terminal parts of the hepatic veins by which it leaves it. The spleen may be regarded as a specialized portion of the portal reservoir.

The **portal vein** is a wide venous channel, about three inches long (75 mm.). It begins by the union of the superior mesenteric and the splenic veins behind and to the left of the neck of the pancreas, at the level of the body of the first lumbar vertebra, and either anterior to the left border of the inferior vena cava, or in front of the upturned extremity of the uncinate process of the head of the pancreas. It ascends in front of the inferior vena cava and behind the neck of the pancreas and the first part of the duodenum, to the lower border of the opening into the lesser sac of the peritoneum, where it passes forwards above the duodenum and enters the lesser omentum. Continuing its upward course, it lies behind the bile-duct and hepatic artery, and in front of the opening into the lesser sac; it ultimately reaches the right end of the porta hepatis, where it ends by dividing into a short and wide right branch and a longer and narrower left branch.

The **right branch** generally receives the **cystic vein** and then enters the right lobe of the liver, in which it breaks up into numerous branches which end as *interlobular veins*, which are connected to the *sublobular* rootlets of the hepatic veins by the sinusoidal capillaries in the substance of the liver lobules (Fig. 563, p. 662).

The **left branch** runs from right to left, in the porta hepatis, giving off branches to the caudate and quadrate lobes; it crosses the fissure for the ligamentum teres, and it ends in the left lobe of the liver in the same manner as the right branch.

As it crosses the fissure, the left branch of the portal vein is joined in front

by the **round ligament** of the liver and some small accompanying veins, and behind by the **ligamentum venosum**. The round ligament is a fibrous cord which passes from the umbilicus to the left branch of the portal vein. It is the remains of the umbilical vein of the fœtus. The small *para-umbilical veins* which accompany it connect the left branch of the portal vein with the superficial veins round the umbilicus. The ligamentum venosum connects the left branch of the portal vein

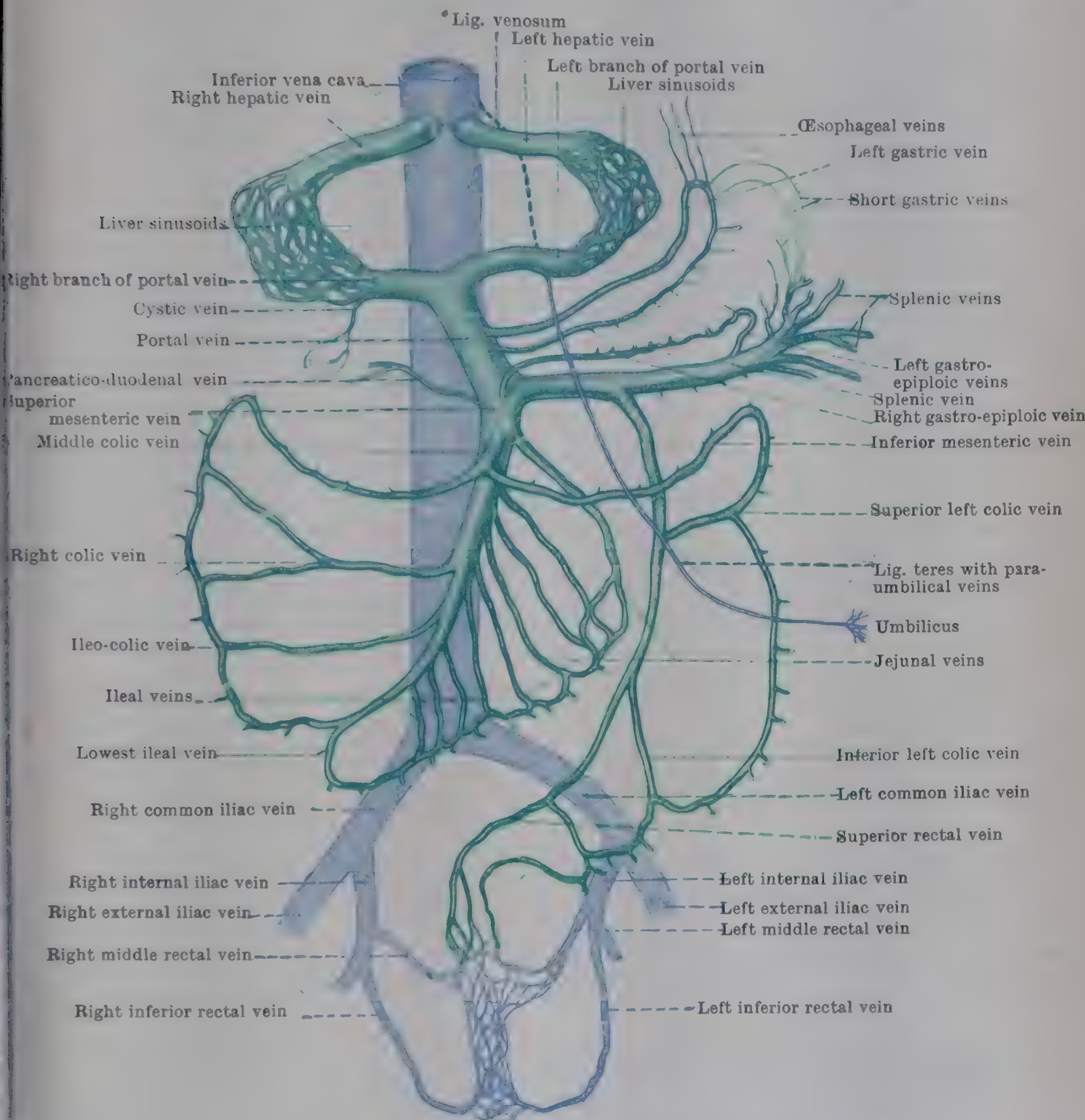

FIG. 1124.—SCHEME OF PORTAL SYSTEM OF VEINS (*green*) AND ITS CONNEXIONS WITH SYSTEMIC VEINS (*blue*).
It must be remembered that systemic blood carried by the hepatic artery also enters the liver capillaries ; therefore the hepatic veins contain both portal and systemic blood.

with the upper part of the inferior vena cava. It is the remains of a fœtal blood-vessel—the **ductus venosus**—through which blood, carried from the placenta by the umbilical vein, passed to the inferior vena cava without going through the liver. The portal vein is accompanied by numerous lymph-vessels, and it is surrounded, in the lesser omentum, by filaments of the hepatic plexus of nerves.

Tributaries.—Soon after its formation the portal vein receives the left and right gastric veins, and the cystic vein opens into its right branch.

The **left gastric vein** begins in the lesser omentum by the union of tributaries from both surfaces of the stomach. It runs with the left gastric artery along the lesser curvature of the stomach to the œsophagus, from which it receives tributaries. It then turns backwards and reaches the posterior wall of the abdomen, where it again changes its direction to run from left to right behind the lesser sac of the peritoneum to open into the portal vein as it passes forwards into the lesser omentum.

The **right gastric vein** is a small vessel which is formed by the union of tributaries from the upper parts of both surfaces of the pyloric portion of the stomach. It runs from left to right along the lesser curvature, between the layers of the lesser omentum, and ends in the portal vein after that vessel has entered the lesser omentum. It receives the **pre-pyloric vein** which marks the position of the pylorus (see p. 610).

The **cystic vein** is formed by the union of tributaries which accompany the branches of the cystic artery on the anterior and posterior surfaces of the gall-bladder; it ascends along the cystic duct and ends as a rule in the right branch of the portal vein. Some small veins pass directly from the gall-bladder into the substance of the liver.

The **superior mesenteric vein** begins in the right iliac fossa, and ascends along the right side of the superior mesenteric artery. In the greater part of its course it lies in the root of the mesentery, and crosses the right ureter and testicular or ovarian vessels, the inferior vena cava and the third part of the duodenum. There, it leaves the mesentery, ascends in front of the uncinate process of the pancreas, and, crossing behind the root of the transverse mesocolon, it ends behind the neck of the pancreas by uniting with the splenic vein to form the portal vein.

Tributaries.—It receives the veins that accompany the branches of the superior mesenteric artery, and also the right gastro-epiploic vein and pancreatico-duodenal veins, which enter it near its termination The **appendicular** and **anterior** and **posterior cæcal** veins unite to form it. The **ileal** and **jejunal** veins run from the small intestine to the root of the mesentery to join it. The **ileo-colic** and **right colic** veins enter it below the duodenum. It receives the **middle colic** vein where it crosses the root of the mesocolon.

The **right gastro-epiploic vein** runs from left to right along the greater curvature of the stomach, between the anterior two layers of the greater omentum. It receives tributaries from both surfaces of the stomach. Near the pylorus it turns backwards, and ends in the superior mesenteric vein.

The **pancreatico-duodenal veins** receive tributaries from the head of the pancreas and the adjacent parts of the duodenum; the lower vein may join the right gastro-epiploic; the upper vein ascends along the superior pancreatico-duodenal artery, and, before it ends in the upper part of the superior mesenteric vein or in the portal vein, receives a fairly large tributary that runs upwards on the left of the bile-duct.

The **splenic vein** is formed by the union of five or six tributaries which issue from the hilum on the gastric surface of the spleen. It passes backwards and medially, in the lieno-renal ligament, to the kidney, turns to the right and runs behind the body of the pancreas and below the splenic artery; it crosses the front of the abdominal aorta immediately below the origin of the cœliac artery, and ends behind the neck of the pancreas by joining the superior mesenteric vein to form the portal vein.

Tributaries.—It receives the short gastric veins, the left gastro-epiploic vein, the pancreatic veins, and the inferior mesenteric vein. Occasionally the left gastric vein ends in it.

The **short gastric veins** are a series of small vessels which gather blood from the region of the left portion of the greater curvature of the stomach; they pass backwards towards the spleen, in the gastro-splenic ligament, and end either in the trunk of the splenic vein or in its main tributaries.

The **left gastro-epiploic vein** runs from right to left along the greater curvature of the stomach between the anterior two layers of the greater omentum. It enters the gastro-splenic ligament, through which it passes towards the hilum of the spleen, and ends by joining the commencement of the splenic vein. It receives tributaries from both surfaces of the stomach.

The **pancreatic veins** issue from the pancreas, and end at once in the splenic vein.

The **inferior mesenteric vein** is the continuation of the **superior rectal vein**, and it receives the **inferior left colic veins** from the pelvic colon and iliac portion of the descending colon, and the **superior left colic vein** from the upper part of the descending colon and the left flexure. It begins on the middle of the left common iliac artery. It runs upwards along the left side of its own artery and the aorta, to the right of the ureter, on the front of the left psoas major muscle, crossing superficial to the left testicular or ovarian vessels, and superficial or deep to the inferior and superior left colic arteries. In most of its course it is directly behind the peritoneum, but near its upper end it passes behind the duodeno-jejunal flexure, and then, crossing in front of the left renal vein, it ends in the splenic vein behind the pancreas. Occasionally it bends to the

right to end in the junction of the splenic and superior mesenteric veins. It is longer than its companion artery, as it ascends to a higher level than the origin of the artery.

The **superior rectal vein** drains the greater part of the blood from the rectum. It arises by the union of tributaries from the rectal venous plexuses, through which it communicates with the middle and inferior rectal veins. It ascends, in company with the superior rectal artery and between the layers of the pelvic mesocolon, to the inlet of the pelvis, where it ends on the front of the left common iliac artery by becoming the inferior mesenteric vein.

Communications between Portal and Systemic Veins.—Important venous anastomoses take place between the outlying tributaries of the portal system and systemic veins. The most notable of these communications occur at the lower end of the œsophagus (between the left gastric vein and œsophageal veins which join the azygos system) and in the rectal plexus of veins (between the superior rectal vein and the middle and inferior rectal veins, which pass to the internal iliac). In both of these situations the communicating veins may enlarge; in the region of the anal canal such varicose enlargements of the veins are known as *hæmorrhoids* or piles. Owing to the free anastomoses between the venous plexuses in the pelvis, portal obstruction may affect plexuses other than those of the rectum; this may be of clinical importance in the case of the uterine veins (Wermuth, 1939).

The communication with superficial veins around the umbilicus by para-umbilical veins which reach the left branch of the portal vein along the round ligament of the liver has been mentioned already. Obstruction to the passage of blood through the liver is often indicated by the appearance of enlarged superficial veins radiating from the umbilicus—the so-called *caput medusæ*. Enlarged veins may also appear in the falciform ligament or on the "bare area" of the liver and communicate with the veins of the diaphragm and the internal mammary veins. Other communications occur on the posterior wall of the abdomen between intestinal tributaries of the portal vein and the renal or lumbar veins or small retroperitoneal tributaries of the inferior vena cava.

DEVELOPMENT OF BLOOD-VASCULAR SYSTEM

DEVELOPMENT OF HEART AND ARTERIES

In the general account of the development of the embryo (pp. 89-92) it has been pointed out that the primitive vascular system, from which the main blood-vessels of the adult are derived, consists of :—

(1) A tubular heart, separated by constrictions into six parts named, from the caudal to the cephalic end, the sinus venosus, the atrium, the atrio-ventricular canal, the ventricle, the bulbus cordis, and the truncus arteriosus.

(2) Two ventral aortæ.

(3) Two dorsal aortæ fused in parts of their extent to form a median descending aorta.

(4) Six pairs of aortic arches, of which four pairs, the first to the fourth, connect the ventral aortæ with the unfused portions of the dorsal aortæ; one pair, the fifth, connects the ventral aortæ, for a short time, with the dorsal parts of the sixth arches; and the remaining pair, the sixth, connects the truncus arteriosus with the unfused parts of the dorsal aorta.

(5) Seven pairs of venous trunks, the vitelline, the umbilical, the anterior cardinal, the posterior cardinal, the ducts of Cuvier (common cardinals), the subcardinals, and the supracardinals, of which only three pairs—the vitelline veins, the umbilical veins, and the ducts of Cuvier—open directly into the venous sinus of the heart (Fig. 104, p. 90).

It was noted also : (*a*) that the dorsal aortæ give off a series of paired branches through which blood passes from the aortæ to networks of capillary vessels from which it is collected into the veins; (*b*) that the venous trunks are connected with their fellows of the opposite side, across the median plane, by transverse anastomoses; and (*c*) that anastomoses are formed between the posterior cardinal, the subcardinal, and the supracardinal veins (p. 91).

The further changes in the development of the heart and the blood-vessels have now to be considered.

Development of Heart.—The development of the heart is a complex process of which only an outline is given here. Full accounts, with bibliographies, are provided in special works on Human Embryology (see list of References, p. 101); and the models of His (1886) and Born (1889), illustrating their classical accounts, are to be found in most Anatomical Museums. For the early stages, consult Davis (1927); for the external form of the heart and the separation of its chambers, Waterston (1918); and for a standard general account, see Tandler (1912, 1913).

In the early part of the fourth week, when the embryo is about 2 mm. long, the heart is formed, in the septum transversum and the dorsal wall of the pericardium, by the fusion of the caudal parts of the ventral aortæ (Figs. 102, 103, p. 89).

The sinus venosus lies for a time in the septum transversum, where it receives the ducts of Cuvier, the vitelline veins, and the umbilical veins; and, after a short period, it begins to project out of the septum transversum into the dorsal part of the pericardium.

After its formation the heart elongates more rapidly than the pericardium and therefore

bends into the form of a loop, of which the cephalic limb is formed by the truncus arteriosus and the bulbus cordis, the apex, which lies ventrally, by the ventricle, and the caudal limb by the atrium and the sinus venosus (Fig. 1125). The interval between the cephalic and caudal limbs is filled by a fold of the lining pericardium which constitutes the mesocardium.

As the heart folds longitudinally it is also bent in the transverse plane, so that, for a time, the more cephalic part of the ventricle, with the bulbus cordis and the truncus arteriosus, lies towards the right of the more caudal part of the ventricle and the atrium and sinus venosus, and the atrio-ventricular orifice enters what, for a period, is the left limb of the ventricle (Fig. 1125).

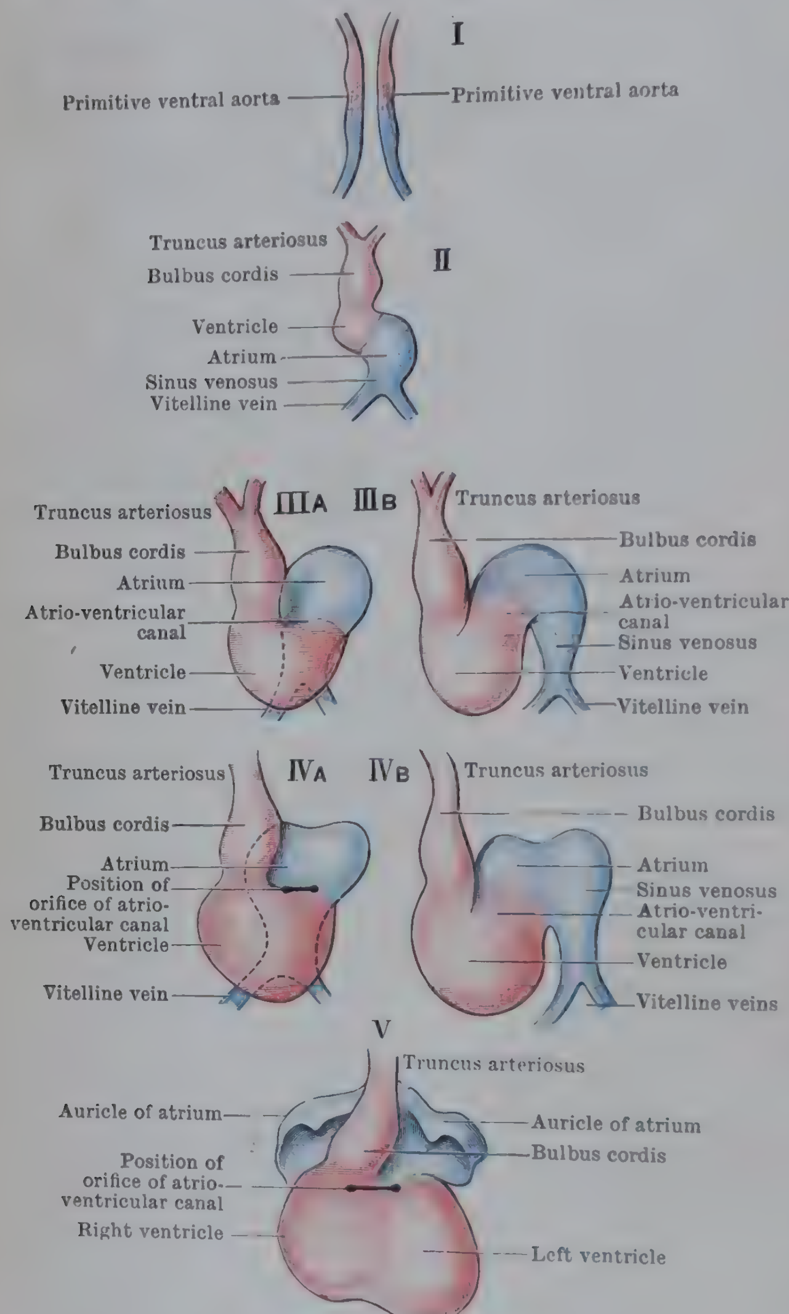

FIG. 1125.—DEVELOPMENT OF THE HEART.

Diagrams showing the changes in form and relation of parts at different stages. Modified from His's models. IIIB and IVB are side views; the other figures represent the heart as seen from the front.

Afterwards, as the ventricle enlarges mainly ventrally, laterally, and headwards, the atrio-ventricular orifice is transposed to the middle of its dorsal wall, the right segment of the sinus venosus is absorbed into the atrium, and the atrium, thus reinforced, expands round the sides of the bulbus cordis and the truncus arteriosus (Fig. 1125).

Subsequently the bulbus cordis is absorbed, partly into the ventricle and partly into the truncus arteriosus, and thereafter the truncus itself is divided into the pulmonary trunk and the ascending part of the aorta, whilst the mesocardium, which lay in the angle between the truncus arteriosus and the atrium, disappears, leaving an aperture—the transverse sinus of the pericardium—through which the right and left halves of the pericardial cavity communicate with each other on the dorsal and cephalic side of the ventricle, on the dorsal side of the ascending aorta and the pulmonary trunk, and on the ventral side of the atrium.

While the changes in position and shape of the heart, the disappearance of the mesocardium, and the division of the truncus arteriosus are taking place, the cavities of the atrium, the atrio-ventricular canal, and the cavity of the ventricle are all being divided into right and left halves by means of septa, which it is convenient to consider separately although they are formed simultaneously and fuse with one another in parts of their extent.

Division of Atrio-Ventricular Canal.—After the longitudinal folding of the primitive cardiac tube has occurred, the atrio-ventricular canal runs dorso-ventrally (from behind forwards in the erect posture) from the atrium to the ventricle. At first it is cylindrical in form, but gradually its cephalic and caudal walls are thickened to form *endocardial cushions*, which project into the middle of the lumen of the canal and convert it into a cleft (Figs. 1126, 1128). Finally the cushions fuse, forming an atrio-ventricular septum but leaving the right and left margins of the canal intact as the *right* and *left atrio-ventricular orifices*.

Later, partly by invagination into the ventricle and partly by the growth of the margins of the atrio-ventricular orifices into the ventricles, the cusps of the atrio-ventricular valves are formed (Fig. 1128).

Occasionally, the atrio-ventricular cushions obliterate not only the middle of the lumen of the atrio-ventricular canal but also one of its margins. In such cases only a single atrio-ventricular

orifice is found in the later stages, right or left as the case may be. When such an abnormality occurs it is usually associated with incomplete formation of the atrial and ventricular septa.

Division of Atrium.—The division of the primitive atrium into right and left atria is brought about by the formation and fusion of two septa—the septum primum and the septum secundum — and the fusion of both with the atrial end of the septum of the atrio-ventricular canal.

The *septum primum* is so called because it appears and partially disappears before the septum secundum is developed. It grows ventrally from the dorsal and cephalic walls of the atrium until it meets and fuses with the septum of the atrio-ventricular canal, and, as it grows, the area of communication between the right and left parts of the atrium is gradually reduced to an aperture. The aperture is called the *ostium primum* (Fig. 1126). It is obliterated when the septum primum fuses with the septum of the atrio-ventricular canal, but, before that fusion occurs, an aperture called the *ostium secundum* (Born, 1889) or *foramen ovale* appears in the dorsal and caudal part of the septum primum (Fig. 1126).

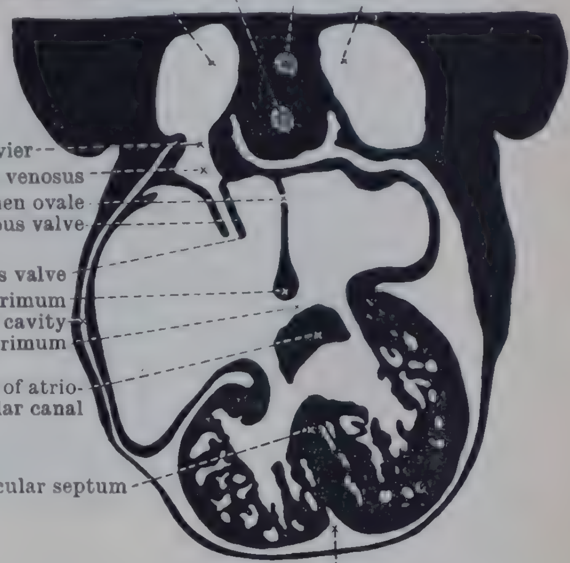

Fig. 1126.—Section of Heart of Human Embryo, showing Development of Septa. (Edinburgh University collection.)

The *septum secundum* grows from the cephalic and ventral walls of the atrium, immediately to the right of the septum primum.

When the growth of the septum secundum has caused its dorsal margin to pass beyond the dorsal margin of the foramen ovale, the latter margin acts as a flap-valve which permits blood to pass through the foramen ovale, from the right to the left atrium, but prevents its return. That condition is retained until a short time after birth, when the right surface of the septum primum fuses with the left surface of the septum secundum and the orifice is permanently closed.

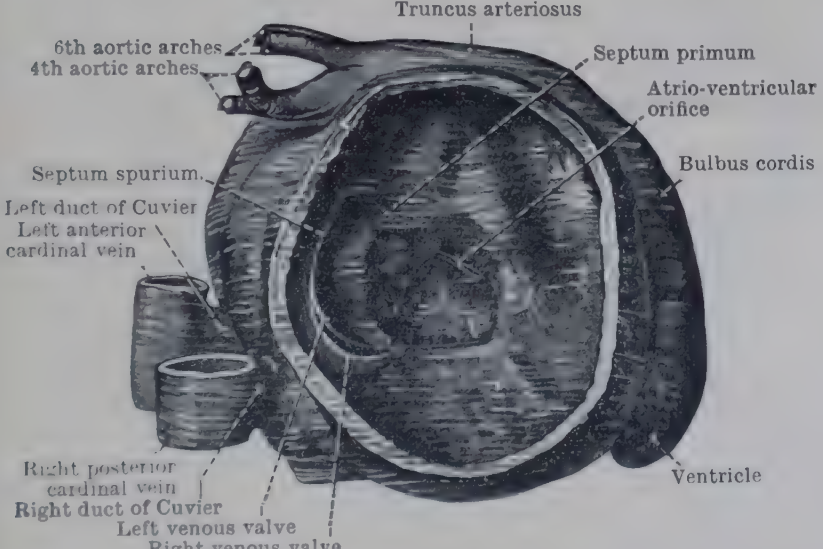

Fig. 1127.—Interior of Right Atrium of Human Embryo, 5·5 mm. long. (Edinburgh University collection. Reconstruction model by C. C. Wang.)

As a result of incomplete development the atrial septum may be absent and the common atrium then communicates with both ventricles. In other cases the septum is incompletely formed, and one or other, or both, of the interatrial foramina persist to adult life.

If the ventral end of the septum primum fails to fuse with the septum of the atrio-ventricular canal, the ostium primum persists, and is found as an aperture which lies between and immediately dorsal (posterior in the erect posture) to the atrio-ventricular apertures.

If the right surface of the septum primum fails to fuse with the left surface of the septum secundum, a more or less reduced foramen ovale persists. Such a condition is found in 10 per cent of adults examined in the post-mortem room.

Division of Truncus Arteriosus and Cranial Part of Bulbus Cordis.—It has already been noted that the bulbus cordis is absorbed partly into the truncus arteriosus and partly into the ventricular segment of the heart. As the absorption proceeds, endocardial cushions develop in the truncus arteriosus and pass spirally along its inner wall into the ventricle. At the apex of the truncus, where it gives off the ventral aortæ and the sixth aortic arches, four endocardial cushions are found. They are placed ventrally, dorsally, and right and left.

The ventral and dorsal cushions disappear in normal cases, but the right and left cushions

pass spirally along the vessel into the ventricle, and they fuse together to form a septum which divides the lumen of the truncus arteriosus into two passages.

At the apex of the truncus, the septum (formed from right and left cushions) divides the arterial trunk into a ventro-cranial (anterior in the erect posture) or aortic passage, which communicates with the ventral aortæ, and a dorso-caudal or pulmonary passage, which remains continuous with the sixth pair of aortic arches, which become parts of the pulmonary arteries.

At that level the septum has ventro-cephalic and dorso-caudal surfaces and right and left borders. But as it passes towards the ventricle it twists like a right-handed spiral, its right border first becoming dorsal, next left lateral, and finally ventral; consequently the surface which was originally dorso-caudal becomes ventro-cephalic, and as a result, when the ventricular end of the septum passes into the ventricle, the blood from the right part of that chamber is directed into the sixth pair of aortic arches, which become parts of the pulmonary arteries, and that from the left part into the ventral aortæ and the four anterior aortic arches, which help to form the main arterial trunks of the head, neck, and upper limbs of the adult.

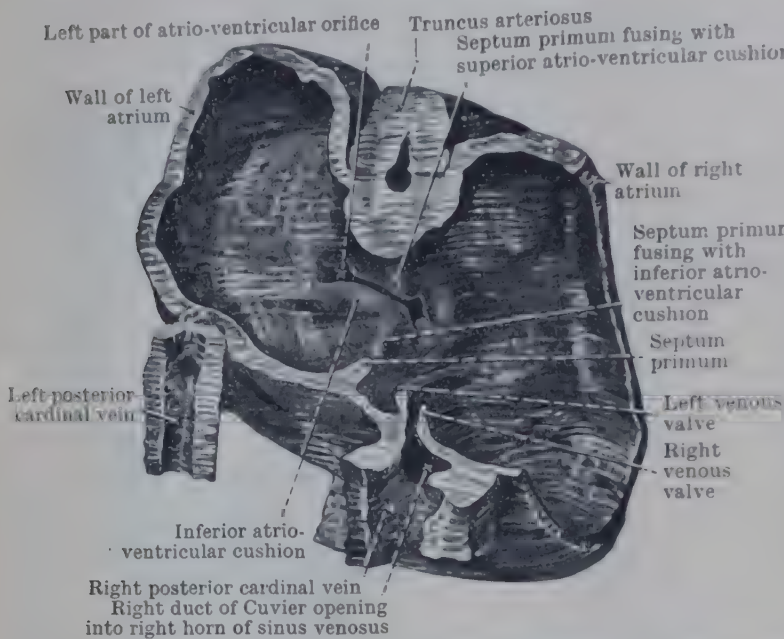

FIG. 1128.—INTERIOR OF ATRIA OF HUMAN EMBRYO 5·5 MM. LONG, VIEWED FROM BEHIND. (Edinburgh University collection. Reconstruction model by C. C. Wang.)

After the septum is completed it is split longitudinally, and so the truncus arteriosus is divided into the ascending aorta and the pulmonary trunk.

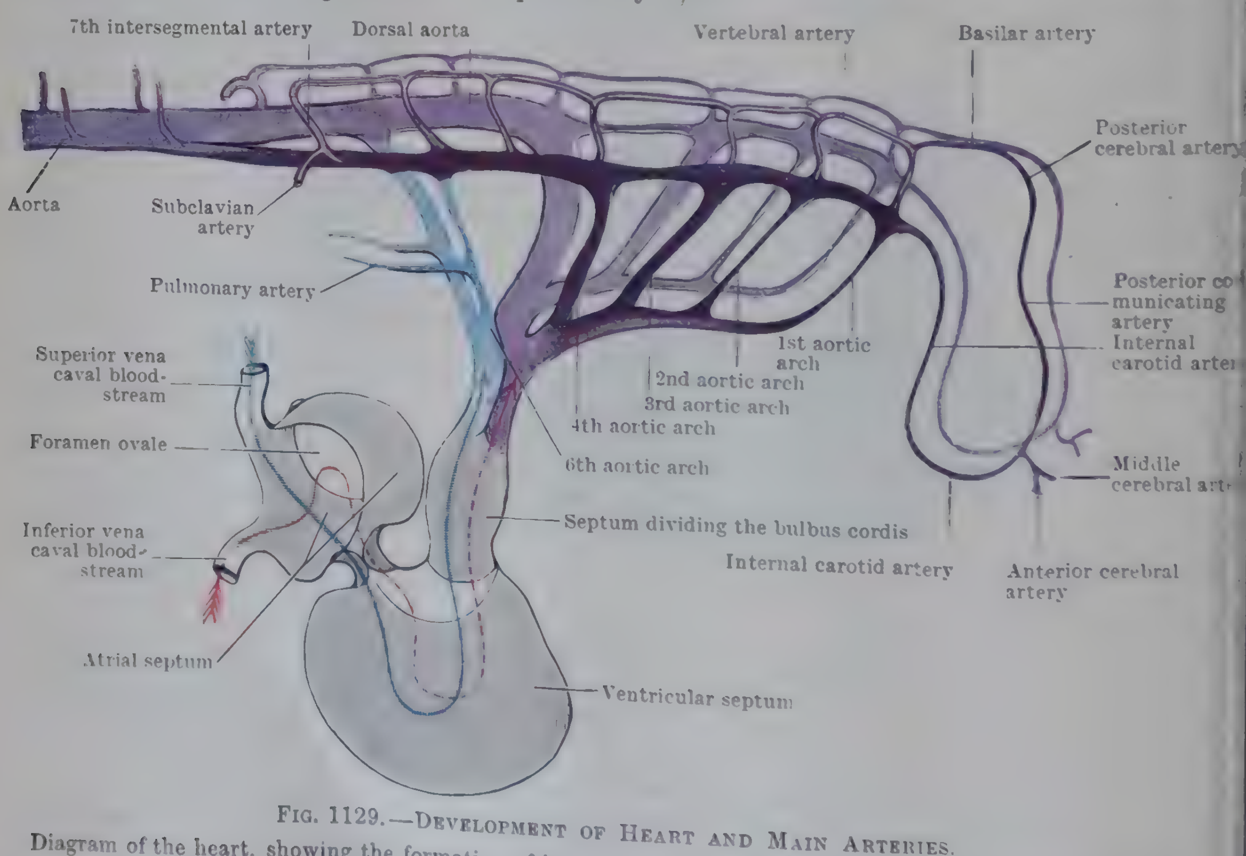

FIG. 1129.—DEVELOPMENT OF HEART AND MAIN ARTERIES.
Diagram of the heart, showing the formation of its septa, and of the cephalic portion of the arterial system.

Division of Ventricle.—As the bulbus cordis is absorbed (p. 1368), and the cavities of the truncus arteriosus and the atrium are divided by the formation of septa, the septum which divides the ventricle into right and left parts also appears.

It begins as a fold of the ventricle wall, immediately to the right of its most ventral

point, and its position is indicated on the surface by a sulcus (Fig. 1126) which sometimes remains to produce a bifid apex of the heart. The fold takes form mainly as a result of the active outgrowth of the right and left ventricles; it consists of the muscular substance as well as the endocardial lining, and it projects into the cavity not only from its ventral but also from its cephalic and caudal walls; hence the septum, in the early stages, is semilunar in form.

The cephalic horn of the semilune advances along the wall of the ventricle until it meets the cephalic margin of the ventricular part of the septum of the truncus arteriosus, with which it fuses. The caudal margin travels along the caudal wall of the ventricle until it meets and fuses with the septum of the atrio-ventricular canal (Fig. 1129). The concave margin of the semilunar septum lies ventral to the aperture leading into the truncus arteriosus; therefore, for a time, there exists an aperture, ventral to the truncus, through which the right and left ventricles communicate with each other. The aperture is closed by proliferation of the atrio-ventricular cushions to meet and fuse with the dorsal concave margin of the ventricular septum below and the septum of the truncus arteriosus above (Odgers, 1938).

The ventricular septum of the adult consists, therefore, of two parts—a ventral and larger muscular part, formed from the wall of the ventricle, and a dorsal and smaller membranous part (pars membranacea), formed from an extension of the atrio-ventricular cushions.

The more common abnormalities which result from the non-completion or the modification of the developmental processes in the ventricular area are :—

(1) The proliferation of the atrio-ventricular cushions may fail, in which case the pars membranacea septi is absent and an interventricular foramen exists through which the cavities of the two ventricles communicate with each other, and each ventricle opens into both the aorta and the pulmonary artery.

(2) The muscular part of the ventricular septum may be absent. There is then only one ventricular cavity, which receives blood from both atria and projects it into both the pulmonary trunk and the aorta.

(3) The septum of the truncus arteriosus may form a left-handed instead of a right-handed spiral, with the result that the pulmonary trunk communicates with the left ventricle and the aorta with the right ventricle.

(4) The spiral twist of the septum of the truncus arteriosus may be incomplete, so that its ventral margin meets the dorsal margin of the ventricular septum more or less at right angles, then the pulmonary trunk and the aorta both communicate with each of the ventricles.

Many other abnormalities, due to interference with or alterations of the ordinary processes of development, occur; for accounts of them readers who are interested must consult monographs on malformation of the heart (Keith, 1909; Walmsley, 1929; Abbott, 1936).

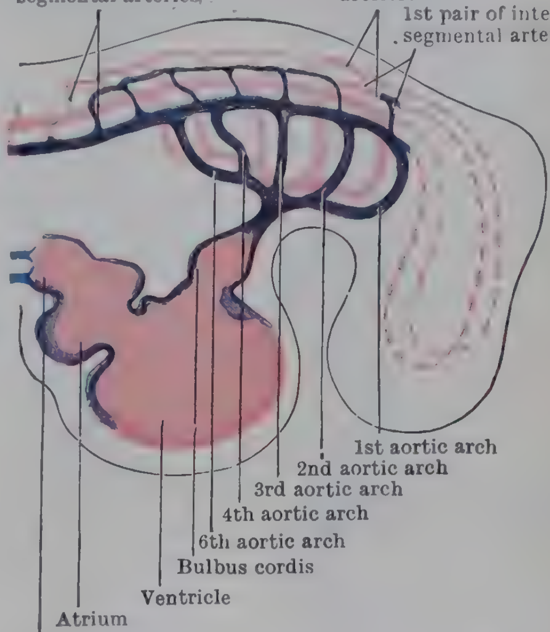

Fig. 1130.—Scheme of Stage of Five Aortic Arches. The cardinal veins and ducts of Cuvier are not shown.

Fate of Sinus Venosus.—The sinus venosus, which constituted the most caudal part of the primitive heart, was formed, in the septum transversum, by the fusion of the terminal parts of the common vitello-umbilical venous trunks. It consists of a single chamber possessing a right and a left horn and a middle section.

Each horn, at that time, receives a duct of Cuvier, a vitelline vein and an umbilical vein. Later, as the longitudinal folding of the cardiac tube occurs, the sinus venosus emerges from the septum transversum and appears in the caudal part of the pericardium. There it lies dorsal to the atrium into which its right horn opens through an orifice guarded by right and left venous valves (Figs. 1127, 1128) which fuse with each other at their cephalic and caudal ends.

As development proceeds, the right horn of the sinus venosus is absorbed into the right atrium, the whole of the left and the cranial part of the right venous valves disappearing, whilst the caudal part of the right valve becomes the valve of the inferior vena cava, which is the modified termination of the right vitelline vein (see Development of the Portal System, p. 1377).

The left horn of the sinus venosus remains as the coronary sinus of the fully developed heart, and the dorsal wall of the middle section is projected ventrally towards the right atrium, to form the valve of the coronary sinus, which lies at the right margin of the opening through which the coronary sinus communicates with the right atrium (Fig. 1060, p. 1229).

Fate of Ventral Aortæ, Aortic Arches, and Unfused Parts of Dorsal Aortæ.—When five pairs of aortic arches have developed (p. 91), the first and second pairs connect the ventral aortæ with the unfused parts of the dorsal aortæ, whilst the third, fourth, and sixth pairs—the transitory fifth pair appear later—arise from a common stem which springs from the apex of the truncus arteriosus and also join the unfused dorsal aortæ (Fig. 1130).

As the embryo increases from 5 mm. to 9 mm. in length: (1) the third and fourth pairs of arches are transferred to the ventral aortæ; (2) a transitory fifth pair of arches appears and for a time connects the ventral aortæ with the dorsal parts of the sixth pair of arches; (3) the first two pairs of arches have begun to disappear; and (4) the right and left pulmonary arteries have grown from the corresponding sixth pair into the rudiments of the lungs (Fig. 1131).

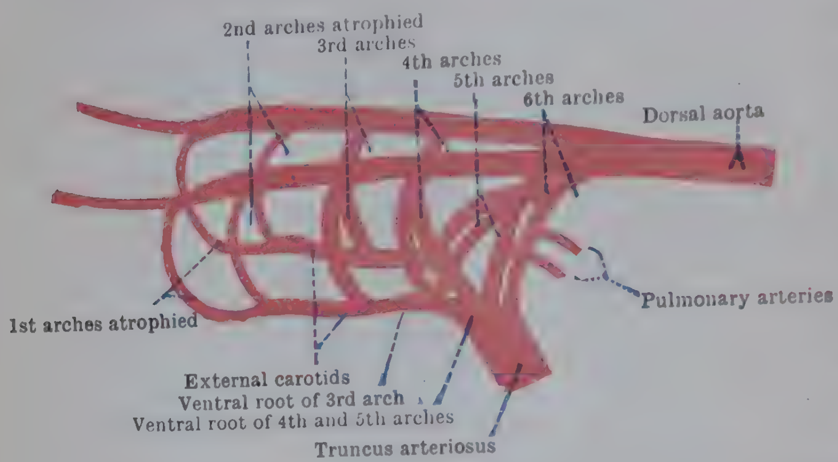

FIG. 1131.—SCHEME OF AORTIC ARCHES OF EMBRYO 9 MM. LONG. (After Tandler, 1909, modified.) The first and second arches have atrophied and the transitory fifth has appeared.

As soon as two or more arches arise from the ventral aortæ it is customary, for convenience of description, to speak of the parts of the ventral aortæ which lie caudal to the various arches as the ventral roots of those arches, and the corresponding parts of the dorsal aortæ are called the dorsal roots of the arches; therefore, at the 9 mm. stage, if the fifth pair of arches are left out of consideration on account of their very transitory and unimportant nature, it may be said that the first four pairs of arches have ventral roots. The sixth pair of arches spring from the apex of the truncus arteriosus, and therefore are devoid of ventral roots; but all the arches have dorsal roots, and the dorsal roots of the sixth pair end in the descending aorta, which was formed by the fusion of the more caudal portions of the primitive right and left dorsal aortæ.

The main events of the subsequent changes which occur before the embryo is 15 mm. long may be summarized as follows:—

(1) The following parts have disappeared:

(*a*) The dorsal roots of the third pair of arches.
(*b*) The dorsal roots of the right fourth and sixth arches.
(*c*) The dorsal part of the right sixth arch.

(2) In the meantime the truncus arteriosus has been divided into the ascending aorta, which passes from the left ventricle to the ventral roots of the fourth pair of arches, and the pulmonary trunk which connects the right ventricle with the sixth pair.

(3) The ventral root of the right fourth arch has become the innominate artery.

(4) The ventral root of the left fourth arch and the fourth arch itself have been converted into part of the arch of the aorta.

(5) The right fourth arch has become the right subclavian artery.

(6) The ventral roots of the third pair have become the common carotid arteries.

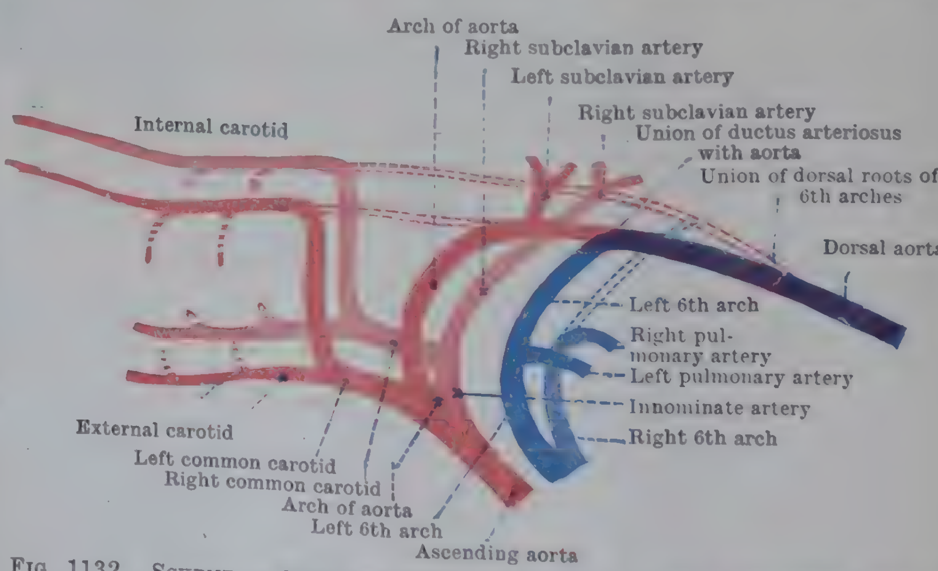

FIG. 1132.—SCHEME OF PART OF ARTERIAL SYSTEM OF FŒTUS SEEN FROM LEFT SIDE. Parts of the first and second arches, the dorsal roots of the third arches, the dorsal part of the right sixth arch, and the dorsal roots of the right fourth and fifth arches have atrophied. The position of the fifth arch is not indicated; see Fig. 1131.

(7) The ventral roots of the first and second pair have become the external carotid arteries.

(8) The third pair of arches and the dorsal roots of the first and second pairs of arches have formed the internal carotid arteries.

(9) The dorsal root of the left fourth arch has become part of the arch of the aorta.

(10) The dorsal root of the left sixth arch has become the first part of the descending aorta.

(11) The dorsal part of the left sixth arch has become the ductus arteriosus, through which blood, which has passed from the right ventricle into the pulmonary trunk, is transmitted into

the aortic arch until birth; then the dorsal part of the left sixth arch becomes the ligamentum arteriosum; the ventral part of the left sixth arch becomes the extra-pulmonary part of the left pulmonary artery.

(12) The dorsal part of the right sixth arch disappears and the ventral part becomes the extra-pulmonary portion of the right pulmonary artery.

For the transformation of the system of aortic arches, consult Congdon (1922), and for the development of the cranial arteries, Padget (1948).

Many variations of the main stems of the adult arterial system are the result of modifications of the ordinary developmental changes which have been noted. Parts which usually disappear may remain; parts which usually remain may disappear; and fusions and absorptions of parts which usually remain distinct may occur.

If the dorsal roots of the right fourth and sixth arches persist, in addition to the persistence of the same parts of the left side, both right and left aortic arches are formed, and the more cephalic part of the descending aorta is doubled, an arrangement which is found in adult reptiles.

If the dorsal roots of the right fourth and sixth arches persist and the corresponding parts on the left side disappear, the arch of the aorta is transposed from the left to the right side. That is the regular occurrence in birds.

If the right fourth arch disappears, and the dorsal roots of the right fourth and sixth arches persist—a not uncommon variation—then the right subclavian artery arises from the descending aorta caudal to the origin of the left subclavian artery.

If the ventral roots of the fourth pair of arches fuse, a common stem is formed, which arises from the arch of the aorta and gives origin to the right subclavian and both common carotid arteries.

If the ventral roots of the third and fourth pairs of arches all fuse, a common stem is formed, which springs from the arch of the aorta; it gives off the right subclavian artery and the external and internal carotid arteries of both sides.

High division of the common carotid, on either side, may be due to the disappearance of the third arch and the dorsal roots of the second and third arches, and the persistence of the second arch.

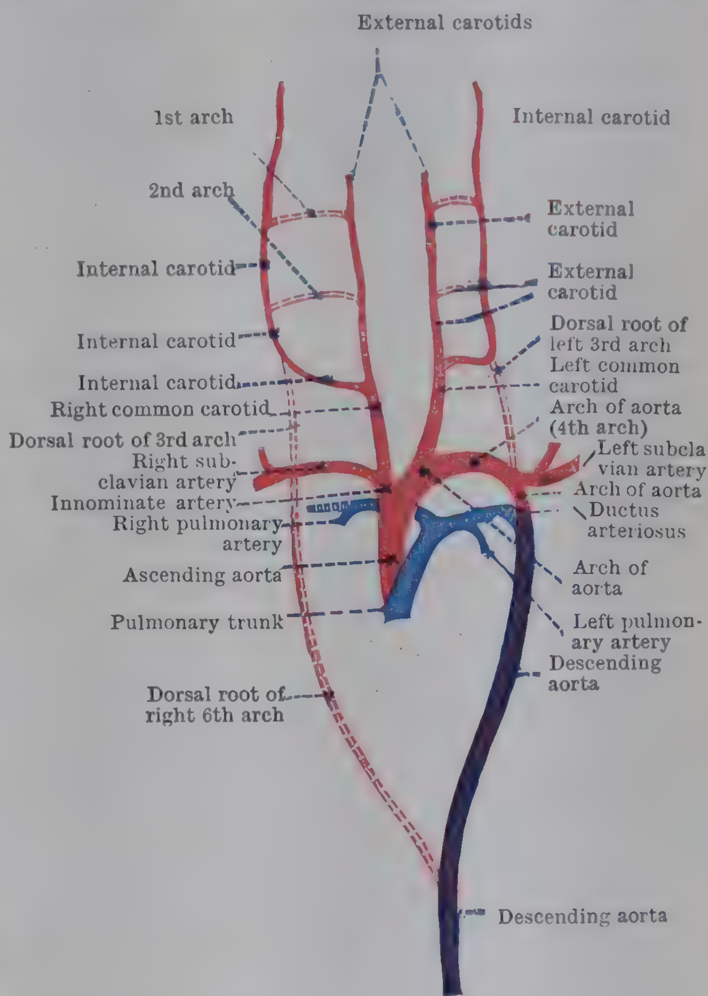

FIG. 1133.—SCHEME OF PART OF ARTERIAL SYSTEM OF FŒTUS SEEN FROM THE FRONT. The positions of the first and second arches, the dorsal roots of the third arches on both sides, and the dorsal roots of the fourth and sixth arches on the right side are shown by dotted lines. The positions of the fifth arches are not shown.

Branches of External Carotid Artery.—All the typical branches of the external carotid artery are present in embryos about 15 mm. long; little is known, however, regarding the details of their development. It is probable that the maxillary artery and its branches are evolved partly from the ventral part of the first aortic arch and partly from an anastomosis with the branches of a temporary *stapedial artery*, which develops from the dorsal end of the second arch; but it is not known whether the other branches of the external carotid spring as offsets from the ventral roots of the first or second arches or from the ventral parts of the arches themselves.

Descending Aorta.—The greater part of the descending aorta is formed by the fusion of the primitive dorsal aortæ. In embryos with twenty-three mesodermal somites the primitive dorsal aortæ are fused together from the tenth to the sixteenth segment (Fig. 104, p. 90). At a later period the fusion is continued caudalwards to the twenty-third body segment—the level of the fourth lumbar vertebra—where the common iliac arteries arise. Still later the small terminal portions of the primitive dorsal aortæ fuse together to form the median sacral artery, which runs to the end of the coccygeal region.

If the three somites which lie nearest the head-end, in embryos possessing twenty-three somites, are cephalic somites, then the point of commencement of the median aorta would be situated at the level of the seventh body somite, that is, at the situation of the future seventh cervical vertebra. The position of the anterior point of fusion of the primitive dorsal aortæ is indicated in the adult by the origin of the abnormal right subclavian artery, and is situated at the level of the fifth thoracic vertebra; therefore the anterior end of that part of the descending

aorta which is formed by the fusion of the primitive dorsal aortæ must move tailwards during the developmental period.

Branches of Dorsal Aortæ.—The branches given off from the primitive dorsal aortæ are dorsal, lateral, and ventral.

Some of the **dorsal branches** arise in the head region, cephalic to the point where the first mesodermal somite is formed, and hence are presegmental. The others arise more caudally in the head, and in the neck and trunk regions, where they lie opposite the intervals between the mesodermal somites, and are therefore *intersegmental.*

They supply the neural tube and its surroundings, the tissues of the head and neck, the body wall and the limbs. But they do not send branches to the viscera; therefore they are somatic arteries. They anastomose with one another by a series of longitudinal channels which lie ventral and dorsal to the dorsal portions of the costal elements of the skeleton, and dorsal to the transverse processes of the vertebræ.

An account of their branches and anastomoses and the transformations which affect them, and more especially of those which result in the formation of the vertebral arteries and the arteries of the limbs, is given in the description of the morphology of the vascular system (see pp. 1387 ff.). But it may be stated here that the main arteries of the adult which are derived from the dorsal branches of the primitive dorsal aortæ and their anastomoses and branches, are: (1) the intercostal and lumbar arteries and their posterior (dorsal) branches; (2) parts of the subclavian arteries; (3) the axillary arteries and their continuations in the upper limbs; (4) the vertebral arteries; (5) the spinal arteries; (6) the basilar artery; (7) the superior intercostal arteries; (8) the internal mammary and the superior and inferior epigastric arteries.

As a rule, the dorsal branches of the primitive dorsal aortæ remain separate from each other, even in the regions where the primitive dorsal aortæ themselves fuse, but occasionally in the thoracic and lumbar regions they fuse, with the result that intercostal and lumbar arteries of opposite sides arise from common stems.

The **lateral branches of the dorsal aortæ** are distributed to organs developed from the intermediate cell-masses: that is, to the pronephros and mesonephros (p. 788), which form the temporary kidneys; to the metanephros, which becomes the permanent kidney; and to the suprarenal and genital glands. They become the renal, testicular, and ovarian arteries.

The **ventral branches of the dorsal aortæ** are neither definitely segmental nor intersegmental. They pass to the walls of the entodermal portion of the alimentary canal and its diverticula, and also, in the early stages of development, to the walls of the yolk-sac and the chorion and its placental derivative. They are connected together by longitudinal anastomosing channels which lie in the dorsal mesentery of the gut and also upon the wall of the gut itself. As the yolk-sac atrophies, the prolongations of the ventral branches to its walls disappear, and simultaneously the portions of the corresponding vessels of opposite sides, which lie in the mesentery, dorsal to the gut, and the longitudinal anastomoses which connect them, fuse together to form unpaired stem-trunks from which the three great vessels of the abdominal part of the alimentary canal are derived, namely, the cœliac, the superior mesenteric, and the inferior mesenteric arteries. But the original stem of each of these three important vessels is not that which eventually forms its origin from the abdominal part of the aorta; for the cœliac artery, which originally arose opposite the seventh cervical segment, wanders tailwards to the twelfth thoracic segment as the roots of origin of the ventral vessels, which are situated nearer the head, disappear; and, in the same manner, the superior mesenteric is transposed from the level of the second thoracic to the level of the first lumbar segment, and the inferior mesenteric wanders from the twelfth thoracic to the third lumbar segment.

Of the three arteries mentioned, the superior mesenteric retains longest its connexion with the yolk-sac, and it occasionally happens that a fibrous strand, representing the original channel, extends from one of the ileal branches of the superior mesenteric past the side of the intestine to the umbilicus.

Umbilical and Iliac Arteries.—The umbilical arteries arise, when the embryo is less than 1·5 mm. long, about the level where the fourth cervical mesodermal somite is developed at a later stage. They spring from plexuses formed, on the lateral walls of the caudal part of the primitive gut, by the anastomoses of some of the most caudally situated ventral or vitelline branches of the primitive dorsal aorta (Fig. 1101). The origins of the arteries are gradually moved tailwards as the embryo grows, until, eventually, they spring from the primitive dorsal aorta opposite the twenty-third body somite, that is, the fourth lumbar segment. As each umbilical artery passes from its origin on the ventral wall of the primitive dorsal aorta to the body-stalk it lies to the medial side of the pronephric duct. The ventral origin is, however, but temporary; for, by the time the embryo has attained a length of 5 mm., and the primitive dorsal aortæ have fused to form the permanent descending

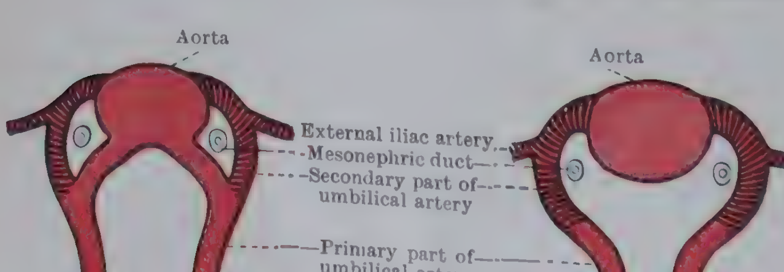

FIG. 1134.—DIAGRAMS SHOWING FORMATION OF SECONDARY PART OF PRIMITIVE UMBILICAL ARTERY.

aorta, a new vessel has arisen, on each side, from the lateral part of the caudal end of the aorta. This new vessel passes ventrally to the lateral side of the mesonephric duct, and then unites, on a plane ventral to the aorta, with the primitive umbilical artery of the same side. After the union has taken place the ventral origin of the umbilical artery disappears, and the primitive umbilical artery then arises from the side of the caudal end of the aorta. From the newly formed vessel, which now constitutes the only origin of the umbilical artery, the **inferior gluteal artery**, which is the primitive main artery of the lower limb, arises. At a later period, and at a more dorsal level, a second branch arises from the dorsal root of origin of the umbilical artery; this is the second main vessel of the lower limb, which becomes the **external iliac** and the **femoral arteries** of the adult. As soon as the external iliac artery is formed, that portion of the umbilical stem which lies dorsal to it becomes the **common iliac artery**, and the more ventral part, which descends into the true pelvis, becomes the **internal iliac artery**. But that portion of the original umbilical artery which runs along the side of the true pelvis to the ventral wall of the abdomen, then to the umbilicus and through the umbilicus to the placenta, is still called the umbilical artery. After birth, when the placental circulation ceases, the greater part of the intra-abdominal portion of the umbilical artery atrophies and becomes converted into the **lateral umbilical ligament**; but a portion of the part which lies in the pelvis remains pervious, and from it springs the **superior vesical artery**.

Arteries of Upper Limb.—It appears probable that, in the earliest stages of development,

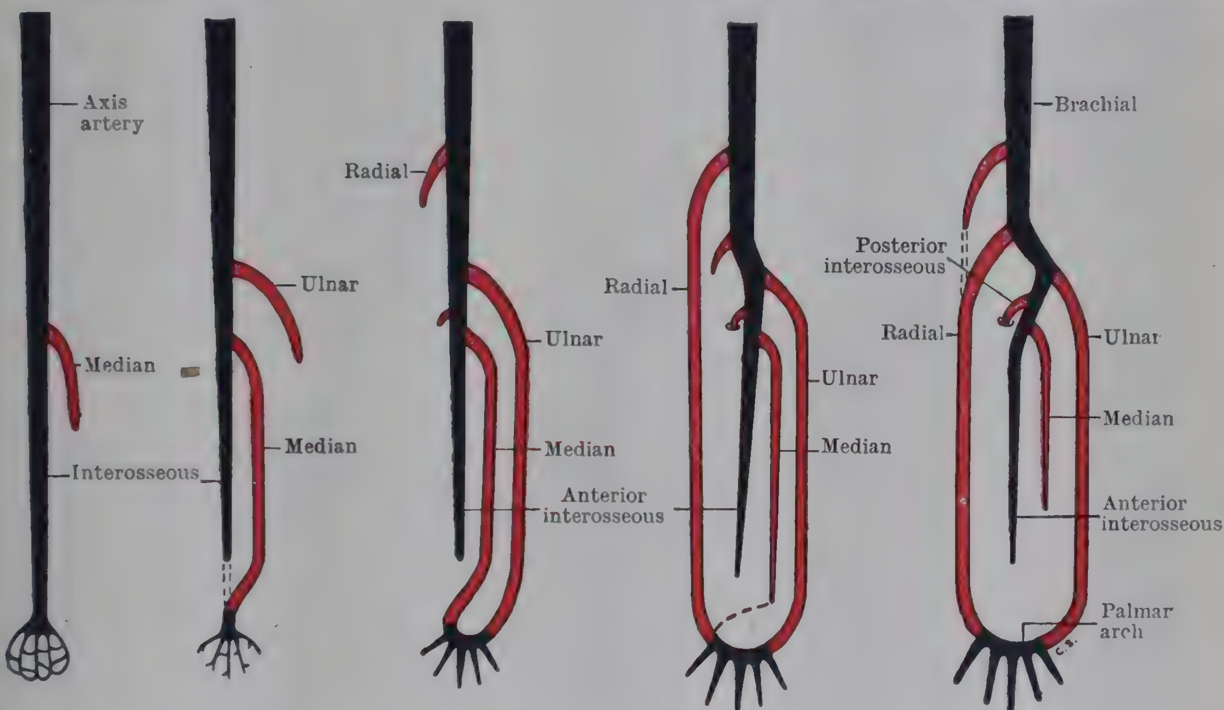

Fig. 1135.—Diagrams of Stages in Development of Arteries of Upper Limb. (After Arey, 1946.)
The original axial artery is *black* and the later-formed arteries *red*.

a number of branches arise from the sides of the primitive dorsal aortæ and pass to the rudiments of the upper limbs, where they end in vascular plexuses which are drained into the anterior cardinal veins.

At a later period the number of connexions with the aorta, on each side, is reduced to one, and that is transferred from the aorta to the ventral branch of the seventh intersegmental artery, whilst, at the same time, the original plexus in the limb is reduced to a single trunk or **axial artery**, which is divisible into subclavian, axillary, brachial, and interosseous segments. The first secondary vessel to be formed is the **median artery** which appears as a branch of the part of the axial artery that becomes the **anterior interosseous**. The median artery joins the hand-plexus but is replaced by the ulnar and radial arteries. The origin of the **radial artery** is moved distally; its final point of origin from the axial artery becomes the bifurcation of the brachial, and the portion of the **ulnar artery** which lies between that point and the origin of its common interosseous branch is part of the original stem vessel (Fig. 1113).

Arteries of Lower Limb.—The development of the arteries of the lower limb has been investigated by Senior (1919, 1920), and readers who wish to follow the details of an intricate process, in order to understand the evolution of the arterial variations met with in the lower limbs, should refer to his work; only a general outline of the phenomena can be given here (Fig. 1136).

In the first place, a primary **axial artery** is developed. It springs from the secondary umbilical artery, leaves the pelvis through the greater sciatic foramen, descends through the thigh between the rudiments of the hamstring and adductor muscles, passes through the popliteal fossa, where its distal part is in front of the rudiment of the popliteus muscle, and descends along the interosseous membrane to the foot, where it ends in a capillary plexus.

gluteal artery and its sciatic branch (which becomes the companion artery of the sciatic nerve), the proximal or femoral part of the popliteal artery, and the distal part of the peroneal artery.

After the axial artery is established, a new branch springs from the secondary umbilical artery above the origin of the axial artery. This new vessel—the external iliac artery—runs along the inlet of the pelvis, passes above the superior pubic ramus, and enters the front part of the thigh, where it becomes the **femoral artery** and is joined by a recurrent branch of the axial artery (*ramus communicans superior*) which pierces the rudiment of the adductor magnus so that the continuity between femoral and popliteal arteries is established.

All the arteries of the leg and foot of the adult, except the distal part of the peroneal artery and a small segment of the anterior tibial artery, are formed by branches of the primitive axial artery and anastomosing channels between them (Fig. 1136).

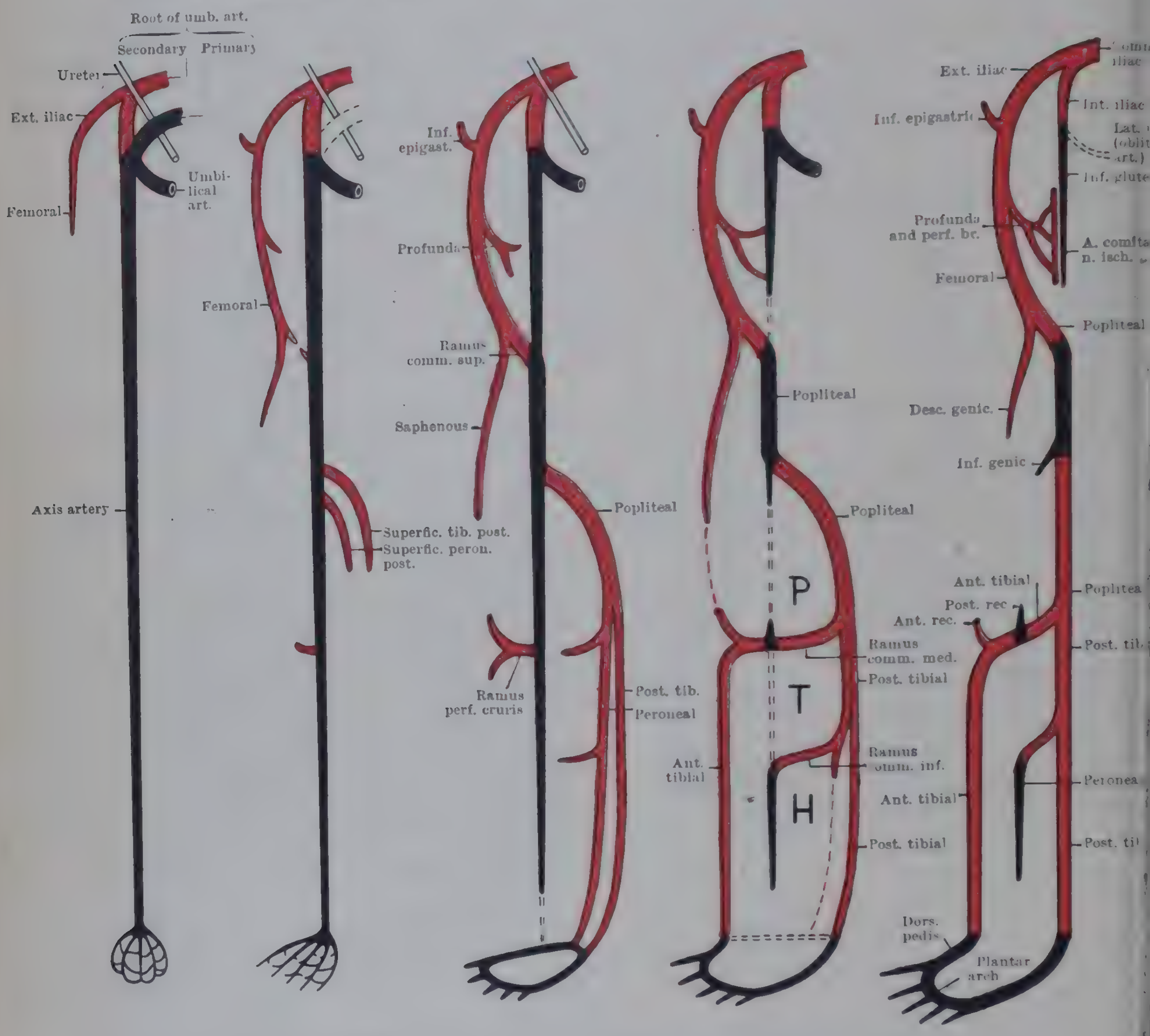

FIG. 1136.—DIAGRAMS OF STAGES IN DEVELOPMENT OF ARTERIES OF LOWER LIMB. (After Senior, 1919, and Arey, 1946.)

The original umbilical artery and the axial artery are *black*, the later-formed arteries *red*. The development of the arteries of the foot is schematic and details are not shown. P, T, and H = position of popliteus, tibialis posterior and flexor halluois longus muscles.

The distal part of the **popliteal artery** and the proximal part of the **posterior tibial artery** are produced by the fusion of two branches of the axial artery. The **anterior tibial artery** arises from the "perforating" branch of the axial artery and is joined to the popliteal by the *ramus communicans medius*. The **peroneal artery**, the distal part of which is derived from the axial artery itself, obtains its connexion with the posterior tibial through the *ramus communicans inferior* (Fig. 1136).

DEVELOPMENT OF VEINS

During the period of embryonic life many venous plexuses and veins appear: some of them are represented in the adult as parts of permanent vessels, others by fibrous cords, and some disappear leaving, in ordinary circumstances, no trace of their existence.

Those which appear may be classified in two groups: (1) Those which are partly extra-

embryonic and partly intra-embryonic. (2) Those which are entirely intra-embryonic. The main features of the history of the first group are well established, but there is considerable difference of opinion regarding the history of those members of the second group which lie in the lower part of the thorax and in the abdomen. It must be understood, therefore, that the account here given is based on a previous tentative, personal summary of knowledge and opinion (Robinson, 1931).

Veins Partly Intra-Embryonic and Partly Extra-Embryonic

It has previously been noted (p. 82) that the earliest veins to appear are the *vitelline veins*, which return blood from the yolk-sac, and the *umbilical veins*, which return purified blood from the placenta. Their further history may now be considered. They are paired veins, right and left, and between them there are transverse anastomoses.

Vitelline and Umbilical Veins, Portal Vein, Hepatic Veins, and Cardiac End of Inferior Vena Cava.—In the early stages of development the **vitelline veins**, right and left, convey blood from the yolk-sac part of the entodermal vesicle first to the caudal ends of the corresponding primitive ventral aortæ, and next, after the caudal parts of the primitive ventral aortæ have fused, to the sinus venosus of the primitive heart.

After the entodermal vesicle is separated into the embryonic alimentary canal, the yolk-sac, and the vitello-intestinal duct, each vitelline vein passes along the duct to the corresponding side of the cephalic margin of the umbilical orifice, where it enters the embryo, passing at once into a mass of mesoderm called the septum transversum; there it unites, for a time, with the cardiac end of the corresponding umbilical vein to form a common vitello-umbilical trunk, which terminates in the sinus venosus (Figs. 102, 103, p. 89). At that period the sinus venosus also is situated in the septum transversum.

Subsequently, as the sinus venosus leaves the septum transversum and passes into the pericardial cavity, the common vitello-umbilical trunk is absorbed into it, and each vein thus acquires its own separate opening into the sinus.

The septum transversum is a mass of mesoderm which intervenes between the pericardium and the ventral portion of the abdominal cavity along the line of the cephalic border of the umbilical orifice. From it are derived the caudal (lower) wall of the pericardium, the ventral part of the central and lateral parts of the diaphragm, the falciform ligament of the liver, the areolar tissue and vascular parts of the liver, and the lesser omentum.

The liver is developed from the branchings of a diverticulum from the ventral wall of the duodenum in the mesoderm of part of the septum transversum. Therefore the portions of the vitelline and umbilical veins which lie in the liver area of the septum transversum are expanded as the liver tissue grows, and at the same time broken up into a great number of anastomosing channels, which form for a period the main part of the liver substance and constitute what is called **sinusoidal tissue**.

The sinusoidal tissue consists of relatively wide anastomosing blood-vessels whose walls are formed at first of endothelium surrounded by areolar tissue. Intervening between the channels of adjacent sinuses, and spreading through the areolar tissue, there are ramifying strands of liver cells which multiply and increase in size and invade the sinusoidal blood-spaces until they are, for the main part, reduced to the size of capillaries, and the liver becomes a comparatively solid organ. At the same time the endothelial lining of the spaces loses its continuity so that liver cells come into direct contact with the blood.

While the formation of the sinusoidal spaces is taking place in the liver area the parts of the fore-gut are defined, and as the duodenal and gastric parts recede from the liver the lesser omentum is evolved from the caudal part of the septum transversum. As the duodenum is delimited, the vitelline veins pass along its sides on their way to the liver, and become connected around the duodenum by three transverse anastomoses, two of which lie ventral and one dorsal to it. On the liver side of the anastomoses each vitelline vein is broken up into: a caudal part, the *vena advehens*, which enters the liver substance; an area of sinusoidal channels in the liver substance; and a cephalic part, the *vena revehens*, which passes from the liver to the heart. After a time the **left vena revehens** loses its direct connexion with the heart, moves across towards the right, and opens into the cephalic end of the right vena revehens. When that change has occurred, all the blood passing to the liver by the vitelline veins reaches the heart by the **right vena revehens,** which now becomes the terminal part of the inferior vena cava. This also receives the ductus venosus—a new channel, which is evolved from the sinusoidal spaces, and which carries the major part of the blood from the left umbilical vein to the inferior vena cava.

In the meantime degeneration takes place in the ventral and caudal parts of the vitelline veins and in parts of the two loops formed by the three transverse anastomoses between them. The ventral parts of the veins disappear with the degeneration of the yolk-sac, and the right half of the caudal loop and the left part of the cephalic loop also disappear (Fig. 1137). Simultaneously the superior mesenteric vein, which has been evolved in association with the formation of the intestine from the mid-gut, opens into the left vitelline vein, caudal to the dorsal transverse anastomosis, and, a little later, the splenic vein enters at the same point. The final result is the formation of the permanent **portal vein,** which is formed from: (1) the cephalic end of the left limb of the caudal loop between the vitelline veins; (2) the dorsal anastomosis between the vitelline veins; (3) the right limb of the cephalic loop formed by the vitelline veins. The

formed from the left vena advehens, and the more cephalic of the two ventral anastomoses between the vitelline veins. It is connected with the ligamentum teres of the liver, because the left umbilical vein, which opened at one time into the left horn of the sinus venosus of the heart, and afterwards into the sinusoids of the liver, finally becomes connected with the left vena advehens, at the level of the cephalic ventral anastomosis between the two vitelline veins; at the same point it is connected with the ductus venosus so that a channel may exist by which the blood from the placenta can pass to the right vena revehens without much admixture with the venous blood passing to the liver through the left branch of the portal vein and the left vena

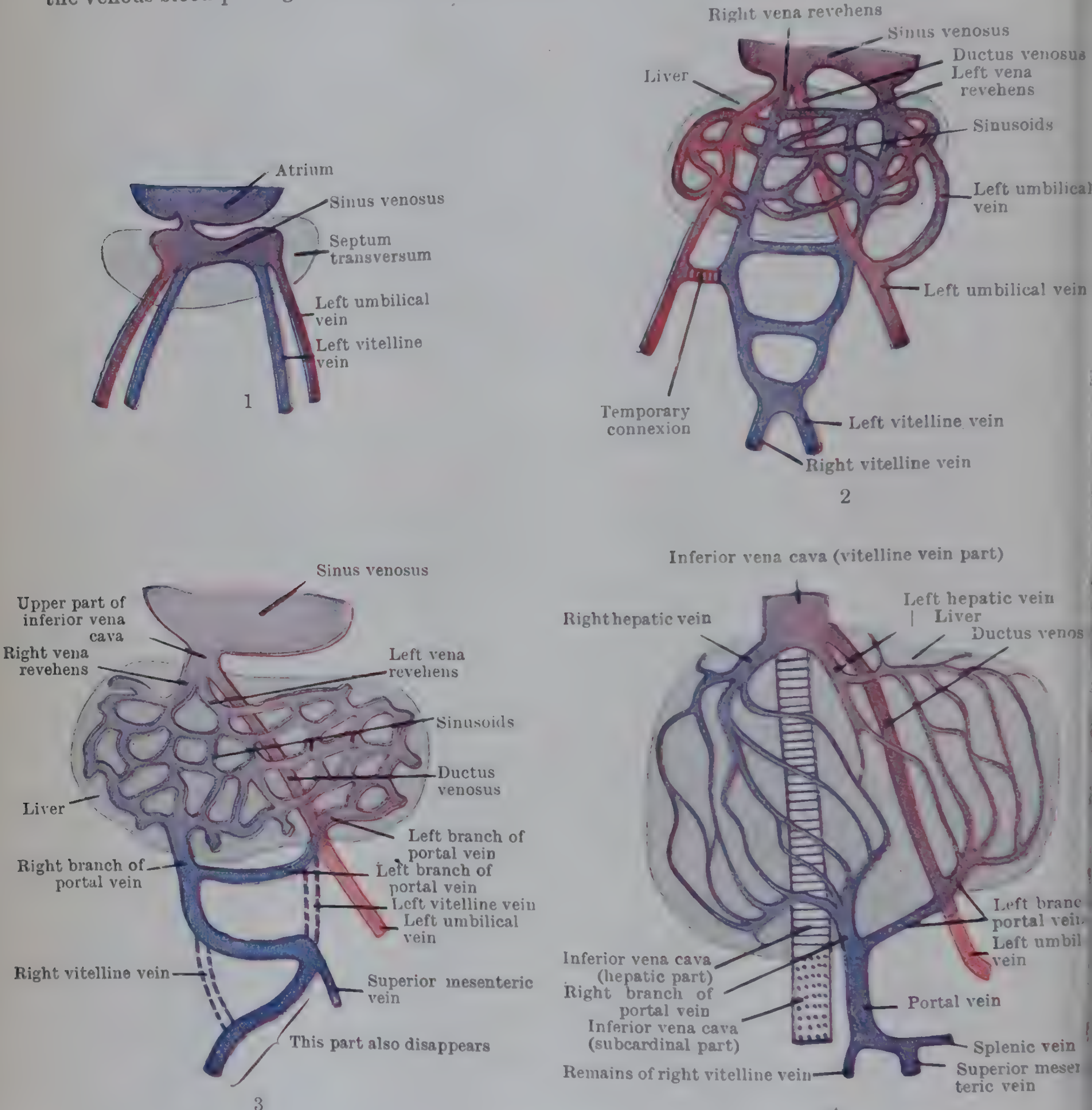

Fig. 1137.—Diagrams showing Four Stages of Development of Portal System and Parts of Inferior Vena Cava.

advehens. But it should be noted that the left branch of the portal vein and the vessels to the liver that ultimately belong to it appear in the fœtus to be branches of the umbilical vein; and it is probable that the umbilical vein dominates the circulation through the liver to a greater extent than is indicated in Fig. 1137, 4.

The **venæ revehentes**, which transfer the blood from the liver to the heart, are the cephalic ends of the primitive vitelline veins. The left vena revehens, as already stated, eventually loses its connexion with the heart and ends in the right vena revehens, which receives the ductus venosus also. The right vena revehens thus becomes the only channel by which blood is returned to the heart from the alimentary canal and from the placenta: that is, it becomes the anterior or cephalic end of the inferior vena cava. The intrahepatic part of the stem of the right vena revehens becomes the **right hepatic vein**, and the left vena revehens becomes the **left hepatic vein**, which are the two vessels which pour, into the inferior vena cava, the blood which was carried from the alimentary canal to the liver by the portal vein and its branches.

As the cephalic part of the right vitelline vein is transformed from the right vena revehens into the anterior end of the inferior vena cava, some of the sinusoids in the dorsal part of the liver are fused together to form the hepatic part of the inferior vena cava, from the caudal end of which an outgrowth passes caudally to anastomose with the right subcardinal vein and to take part in the formation of the pre-renal part of the inferior vena cava (see p. 1384).

Umbilical Veins.—In the earliest stages of development there are three umbilical veins, the vena umbilicalis impar and its branches the left and right umbilical veins. The vena umbilicalis impar and the left umbilical vein persist until birth; the right umbilical vein disappears entirely at an early stage of development.

The vena umbilicalis impar passes from the placenta to the caudal boundary of the umbilical orifice, where it divides into the left and right umbilical veins. Each of the latter unites, for a time, with the corresponding vitelline vein in the septum transversum; then it becomes directly connected with the corresponding horn of the sinus venosus of the heart, and still later with sinusoidal spaces of the liver. The right umbilical vein has also a temporary secondary connexion with the right vitelline vein, but at an early period it undergoes atrophy and all parts of it completely disappear.

The left umbilical vein, which is connected first with the left vitelline vein, next with the heart, still later with the liver, and finally with the left vitelline again, at the point where the latter becomes the left vena advehens, persists until birth, and, after the disappearance of the right umbilical vein, it conveys the blood from the placenta to the liver, where part of the placental blood passes into the left vena advehens and so through the left vena revehens to the inferior vena cava, and part passes into the ductus venosus, by which it reaches that portion of the cephalic part of the right vena revehens which becomes the cephalic or anterior end of the permanent inferior vena cava.

After birth, when the placental circulation ceases, the left umbilical vein becomes the ligamentum teres of the liver.

Ductus Venosus.—The ductus venosus is developed as the left umbilical vein loses its direct connexion with the liver and becomes united to the left vena advehens. It is formed from the sinusoidal spaces of the rudimentary liver and connects the commencement of the left vena advehens with the cephalic part of the right vena revehens. It forms the more direct channel by which the greater part of the blood from the placenta is passed to the heart through that part of the right vena revehens which becomes the upper end of the inferior vena cava. After birth it is converted into the fibrous *ligamentum venosum*, which connects the left branch of the portal vein with the upper end of the inferior vena cava.

Intra-Embryonic Veins

The consideration of the history of the veins of the second group—the intra-embryonic veins—and especially of those members of the group which appear in the lower part of the thorax and in the abdomen, is complicated by the names which have been given to them, and by insufficient definition of the exact positions of the vessels to which the names are applied; it is thus sometimes difficult to decide whether or not the vessel which two different observers describe under the same term is really the same vessel, and whether or not the same vessel has been described under different names.

The main terms used to indicate the vessels which have been noted are *anterior cardinal veins*, *posterior cardinal veins*, *subcardinal veins*, *supracardinal veins*, *thoraco-lumbar veins*, the *prevertebral* (*subvertebral*) *plexus*, and the *azygos venous lines*.

In the subsequent account the embryo and fœtus are considered as being in the quadruped position. Therefore the terms *anterior* and *posterior* are equivalent to *cephalic* and *caudal*, and to *upper* and *lower* in the erect posture; and the prefixes *sub-* and *supra-* are equivalent to *ventral* and *dorsal*, and to *anterior* and *posterior* in the erect posture.

Anterior Cardinal Veins.—The history of the anterior cardinal veins is relatively simple; they are the first purely intra-embryonic longitudinal veins to appear, and they extend from the region of the eye to the sinus venosus of the heart, one on each side. Each anterior cardinal vein is separable into three parts—a cephalic part, and nuchal and thoracic parts. In the earliest stages the *cephalic part* extends from the optic stalk, along the medial side of the trigeminal ganglion, the otic vesicle, and the seventh to the eleventh cranial nerves into the neck. At a later period the part which lies medial to the otic vesicle and the seventh to the eleventh cranial nerves disappears and is replaced by a new vessel which lies lateral to the vesicle and the nerves. The new vessel follows the course of the facial nerve, and in part of its course is extracranial. At the anterior end of the neck it ends in the nuchal portion of the anterior cardinal vein which has now become the internal jugular vein. After the secondary channel is established the stem-vessel of the head is termed the **primary head-vein**. Its anterior part, which lies medial to the trigeminal ganglion, becomes the cavernous sinus; its posterior part disappears, but before that disappearance occurs many changes take place in the tributaries of the primary head-vein.

The most anterior tributaries of the primary head-vein are derived from the region of the optic vesicle and remnants of them become converted into the ophthalmic vein. But in addition to the anterior tributaries there are numerous dorsal or upper tributaries which become arranged in three main groups: an *anterior plexus* associated with the regions of the fore-brain and the mid-brain; a *middle plexus* associated with the cerebellar region of the hind-brain; and a

The vessels of each plexus tend to run together as they approach the stem of the primary head-vein and so three *stems* are formed, the *anterior*, *middle*, and *posterior* (Fig. 1138); they were described by Mall in 1904. That condition persists until the embryo attains a length of about 18 mm. when an anastomosis forms, above the otic vesicle, between the stems from the middle and posterior plexuses (Fig. 1139), and at the same time that part of the primary head-vein which lay lateral to the otic vesicle and the 7th, 8th, 9th, 10th, and 11th cranial nerves disappears (Fig. 1139).

By the time the embryo has become 21 mm. long the anastomosis mentioned has become very important, and a separation has occurred between the lower and the upper portions of

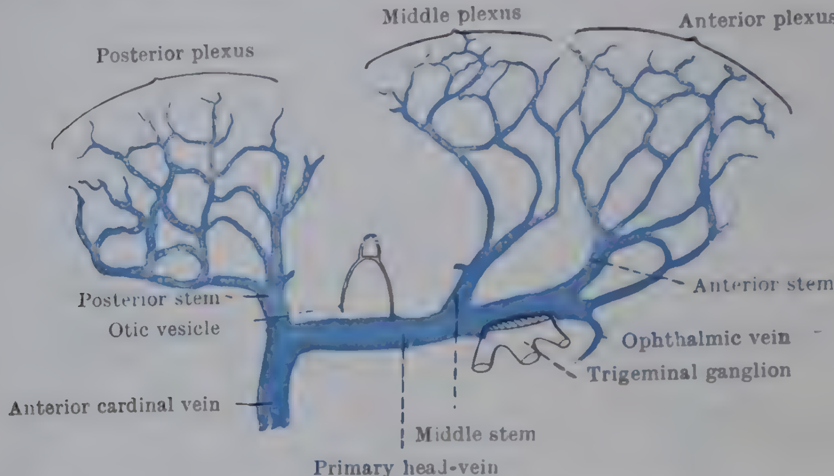

Fig. 1138.—Diagram of Primary Head-Vein and its Tributaries. (After Streeter, 1915.)

the anterior stem tributary; therefore, at that period, the blood from the eye-region flows backwards to the anterior end of the primary head-vein, then upwards along what was the lower part of the middle stem tributary, next backwards along the anastomosis above the otic region to the posterior stem tributary, down which it passes to the nuchal portion of the anterior cardinal vein which has now become the internal jugular vein (Fig. 1139). At

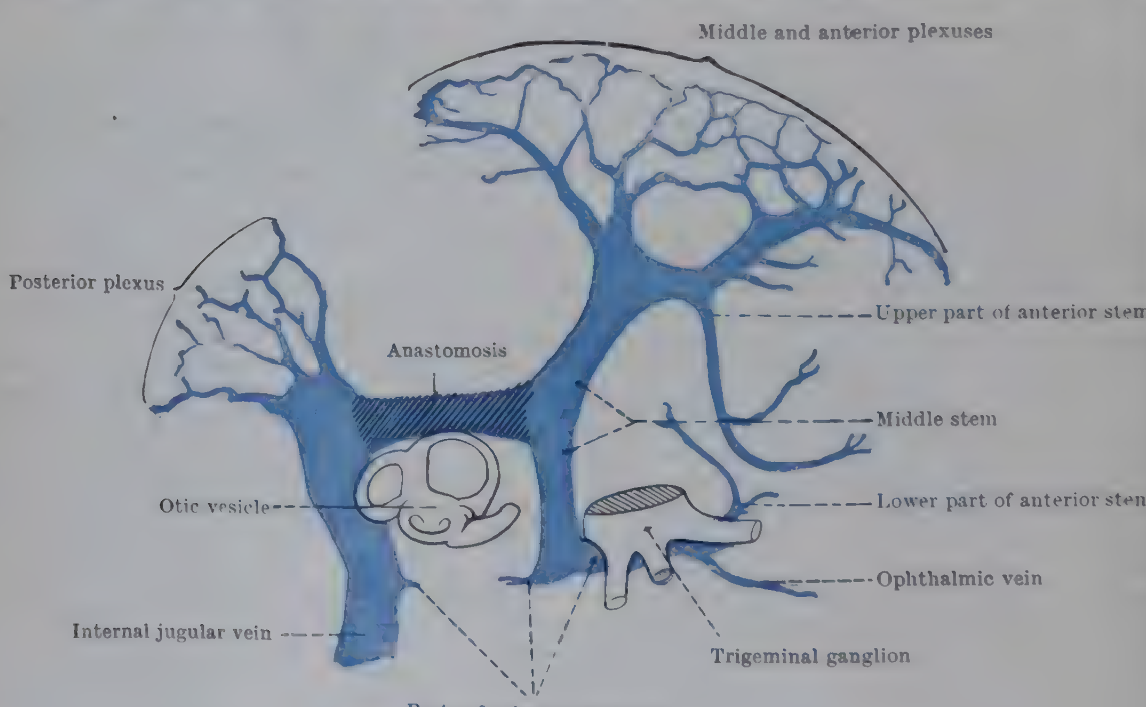

Fig. 1139.—Diagram of Head-Veins of 21 mm. Embryo. (After Streeter, 1915.)

this time the blood from the anterior and middle plexuses reaches the supra-otic anastomosis through the upper or dorsal part of the middle stem tributary (Fig. 1139).

With the formation of the subdural and subarachnoid spaces the main parts of the venous plexuses are carried away from the brain, with the membrane which will be transformed into the dura mater; but in part the plexuses still retain their connexions with the pia mater, and they afterwards establish new connexions with the veins which appear on the surfaces of the developing cerebral hemispheres. In the meantime, on each side, the upper or dorsal tributaries of the anterior and the middle plexus anastomose together (Fig. 1140 B).

When the cerebral hemispheres increase in size the dura-matral tissue is compressed between

them, and between the cerebral hemispheres above and the mid- and hind-brain below, in the form of folds (Figs. 1141 A and B). As the folds are formed the conjoined anterior and middle plexuses of one side are carried into relation with those of the opposite side in the median plane of the head; there the vessels of opposite sides unite together and are finally resolved into the superior and inferior sagittal sinuses and the straight sinus (Figs. 1141 A and B); at the same time some of the smaller vessels of the plexuses which retain their connexion with the pia mater are transformed into the internal cerebral veins and the great cerebral vein; and from some of the lower or ventral tributaries, on each side, is produced the inferior cerebral vein of the embryo which probably becomes the basal vein of the adult (Figs. 1141 A and B).

While the changes last mentioned are taking place, the growth of the hemispheres forces the upper part of the middle stem tributary on each side backwards and then downwards until it becomes the transverse sinus (Fig. 1142); and the anastomosis above the otic region and the posterior stem tributary are converted into its continuation—the sigmoid sinus (Fig. 1142).

By the time this stage is attained the anterior portion of the primary head-vein which lies to the medial side of the trigeminal ganglion has become the cavernous sinus, and the lower or ventral part of the middle stem tributary has been converted into the superior petrosal sinus (Fig. 1142).

The inferior petrosal sinus appears to be an independently formed anastomosis which

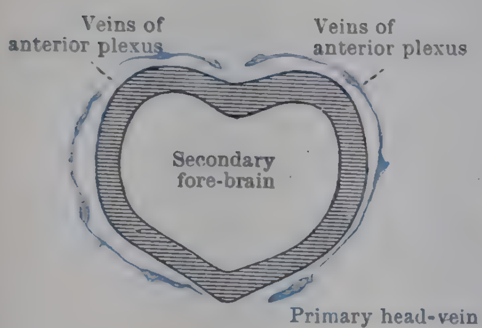

Fig. 1140 A.—Diagram of Transverse Section of Secondary Fore-Brain and Venous Plexuses.

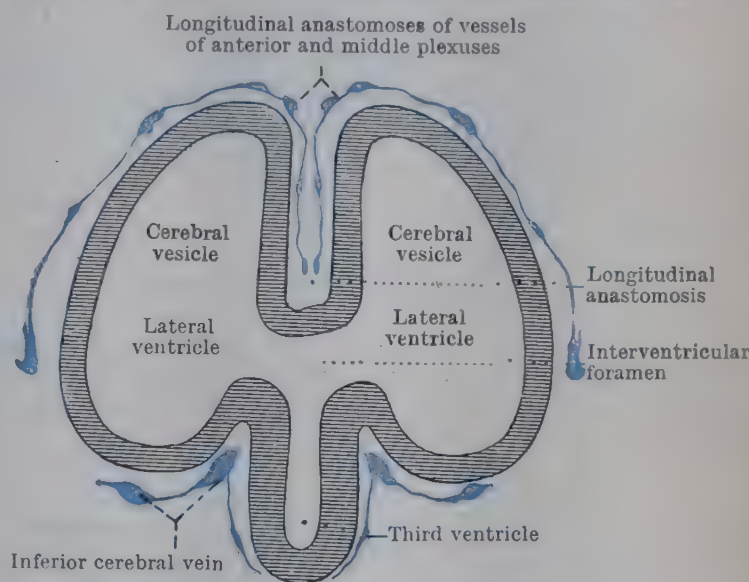

Fig. 1140 B.—Diagram of Transverse Section of Brain, showing Folding of Upper Parts of Plexuses between Cerebral Hemispheres.

connects the posterior end of the cavernous sinus with the upper end of the internal jugular vein across the medial side of the otic region (Fig. 1142).

The history of the *nuchal* and *thoracic* parts of the anterior cardinal veins is different, to a certain extent, on opposite sides. On both sides the anterior cardinal vein is joined, at the root of the neck, by the chief vein of the upper limb. The part cephalic to the junction becomes the internal jugular vein. Caudal to the junction, in the cephalic part of the thorax, a transverse anastomosis forms between the two anterior cardinal veins. The part cephalic to the anastomosis and caudal to the junction with the vein of the limb, on the right side, becomes the right innominate vein; on the left side it becomes part of the left innominate vein, the remainder of the left innominate vein being formed by the transverse anastomosis. On the right side the part caudal to the transverse anastomosis is joined, after a time, by the posterior cardinal vein of that side. The part cephalic to that junction becomes the extrapericardial part of the superior vena cava. The part caudal to the junction is a *common cardinal vein* and is generally called the *duct of Cuvier*; it becomes the intrapericardial part of the superior vena cava. On the left side the part of the anterior cardinal vein caudal to the transverse anastomosis opens, at first, into the left horn of the sinus venosus of the heart; after the anterior cardinal is joined by the posterior cardinal its caudal part becomes the left duct of Cuvier (represented by the ligament of the left vena cava and oblique vein of the left atrium), whilst the cephalic part becomes part of the left superior intercostal vein, which opens into the left innominate vein.

The **external jugular vein** is a new formation which receives for a time the cephalic vein of the upper limb; but the cephalic vein, which is a secondary vessel, is eventually transposed to the axillary vein, which is a part of the primitive upper limb vein.

Posterior Cardinal, Subcardinal, and **Supracardinal Veins, Thoraco-Lumbar Veins, Prevertebral Venous Plexus, Azygos Venous Lines,** and **Inferior Vena Cava.** All these veins extend from the abdomen into the thorax; and all of them, with the exception of the posterior cardinals, are evolved from more or less well-marked venous plexuses. They communicate freely with one another, and they receive in turn, as they supplant one another, the intersegmental veins which open first into the posterior cardinals, and finally in the thoracic region and in some cases, and to a variable extent, in the lumbar region into the adult

The **Posterior Cardinal Veins** appear shortly after the anterior cardinals. They extend from the pelvic region along the dorsal wall of the abdomen, dorsal to the mesonephros and the remnants of the pronephros, into the septum transversum, where they unite with the anterior cardinals. They receive the intersegmental veins and the veins from the mesonephros, and, for a time, the veins of the upper limbs. When the subcardinal veins appear they form numerous anastomoses with the posterior cardinals; but the two most important anastomoses are situated—(1) near the cephalic ends, and (2) near the caudal ends, of the posterior cardinals; thereafter, between those two points, the posterior cardinals disappear. Their remaining caudal parts on both sides become the common iliac and internal iliac veins, the transverse part of the left common iliac vein being the remains of a transverse anastomosis between the two posterior cardinals. The cephalic part of the right posterior cardinal vein remains in the adult as the terminal portion of the vena azygos; and the cephalic part of the left posterior cardinal becomes the caudal part of the left superior intercostal vein.

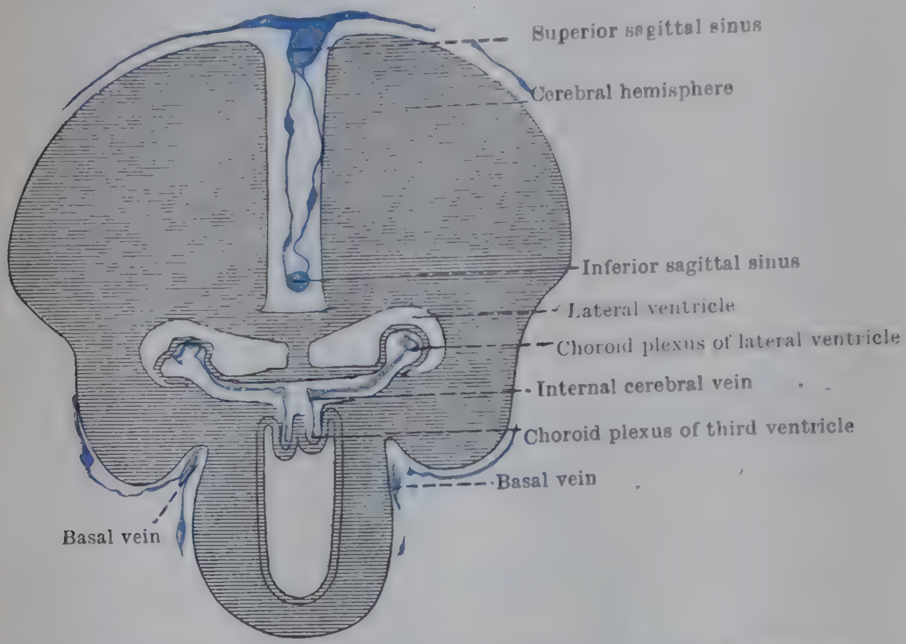

Fig. 1141 a.—Diagram of Transverse Section of Brain showing Sagittal Sinuses still connected by Remains of the Plexuses.

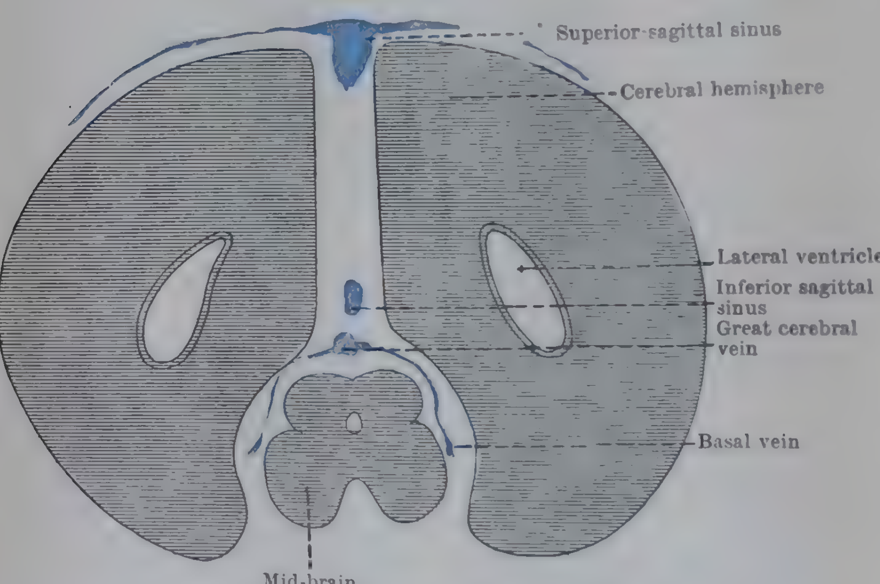

Fig. 1141 b.—Diagram of Transverse Section of Brain after Completion of Sagittal Sinuses.

The **Subcardinal Veins** appear later than the posterior cardinals, and in the dorsal part of the thorax and abdomen, ventro-lateral to the aorta and ventro-medial to the mesonephros. They anastomose freely together dorsal to the superior mesenteric artery, and ventral to the aorta, that is between the two kidneys, which by this time have attained their abdominal position. At each end they anastomose also with the posterior cardinals (see above). After the appearance of the subcardinals the posterior cardinals begin to disappear, and the intersegmental and mesonephric veins which previously passed to them are transferred to the subcardinals. The right subcardinal forms a junction also with a downgrowth from the hepatic part of the inferior vena cava, and each receives the vein from the corresponding kidney.

The thoracic parts of the subcardinals disappear. The cephalic abdominal portion of each of them becomes the corresponding suprarenal vein, and part of the caudal portion enters into the formation of the testicular or ovarian vein (M'Clure & Butler, 1925). The anastomosis between the right subcardinal and the downgrowth from the hepatic part of the inferior vena cava and a part of the right subcardinal itself become part of the pre-renal and inter-renal part of the inferior vena cava. The transverse anastomosis between the two subcardinal veins dorsal to the superior mesenteric artery, becomes part of the left renal vein. The remaining parts of both subcardinals disappear.

Supracardinal Veins.—These veins have been defined by Huntington & M'Clure (1920) as bilateral and originally symmetrical venous channels which develop " dorso-medial to the

PLATE LXXXV

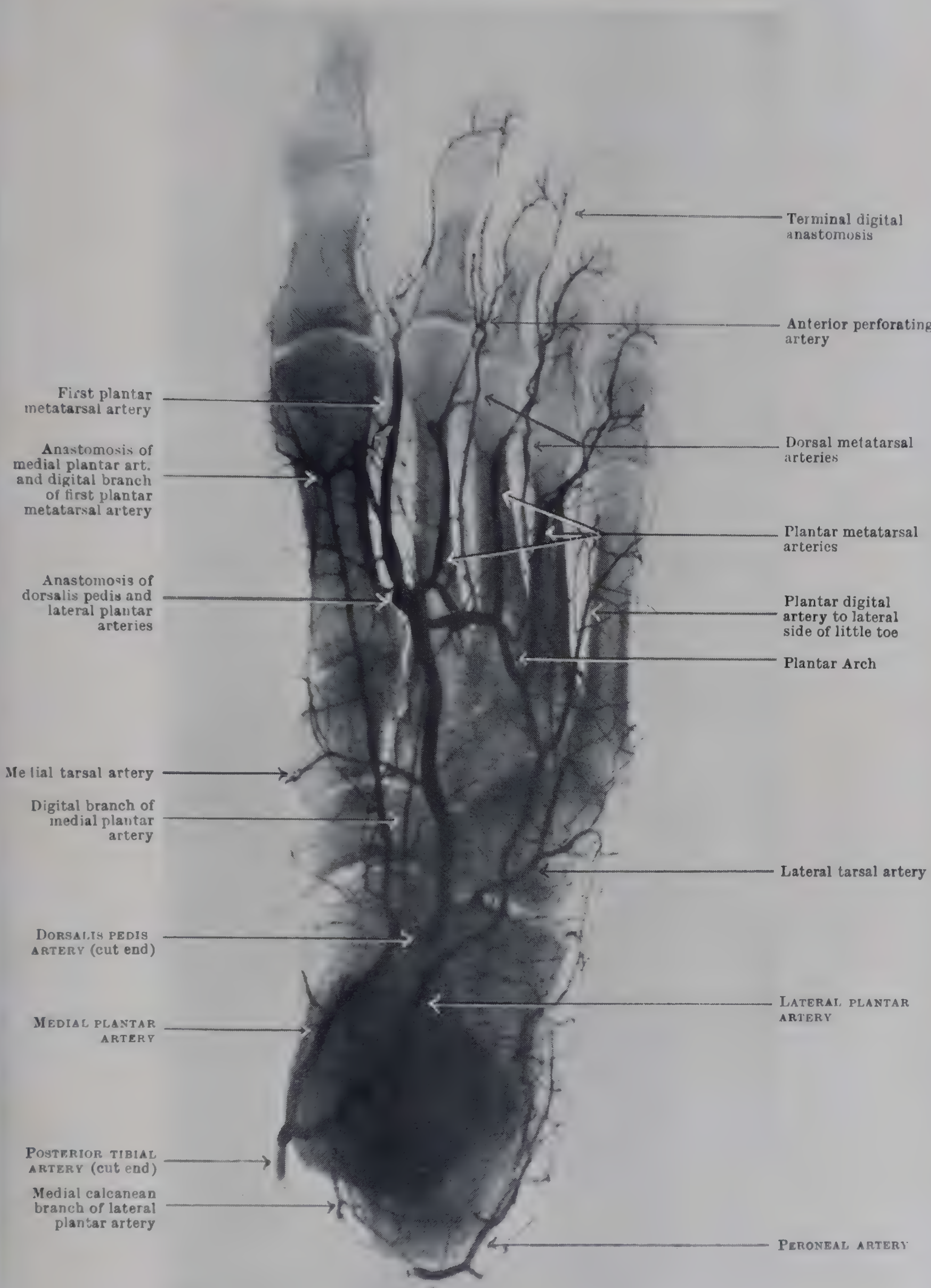

PLATE LXXXV.—PLANTAR RADIOGRAPH OF FOOT, SEPARATED AT ANKLE AFTER RADIO-OPAQUE INJECTION OF THE ARTERIES (from positive print).

Cf. Plate LXXXVI and Figs. 1105, p. 1324 and 1107, p. 1327.

PLATE LXXXVI

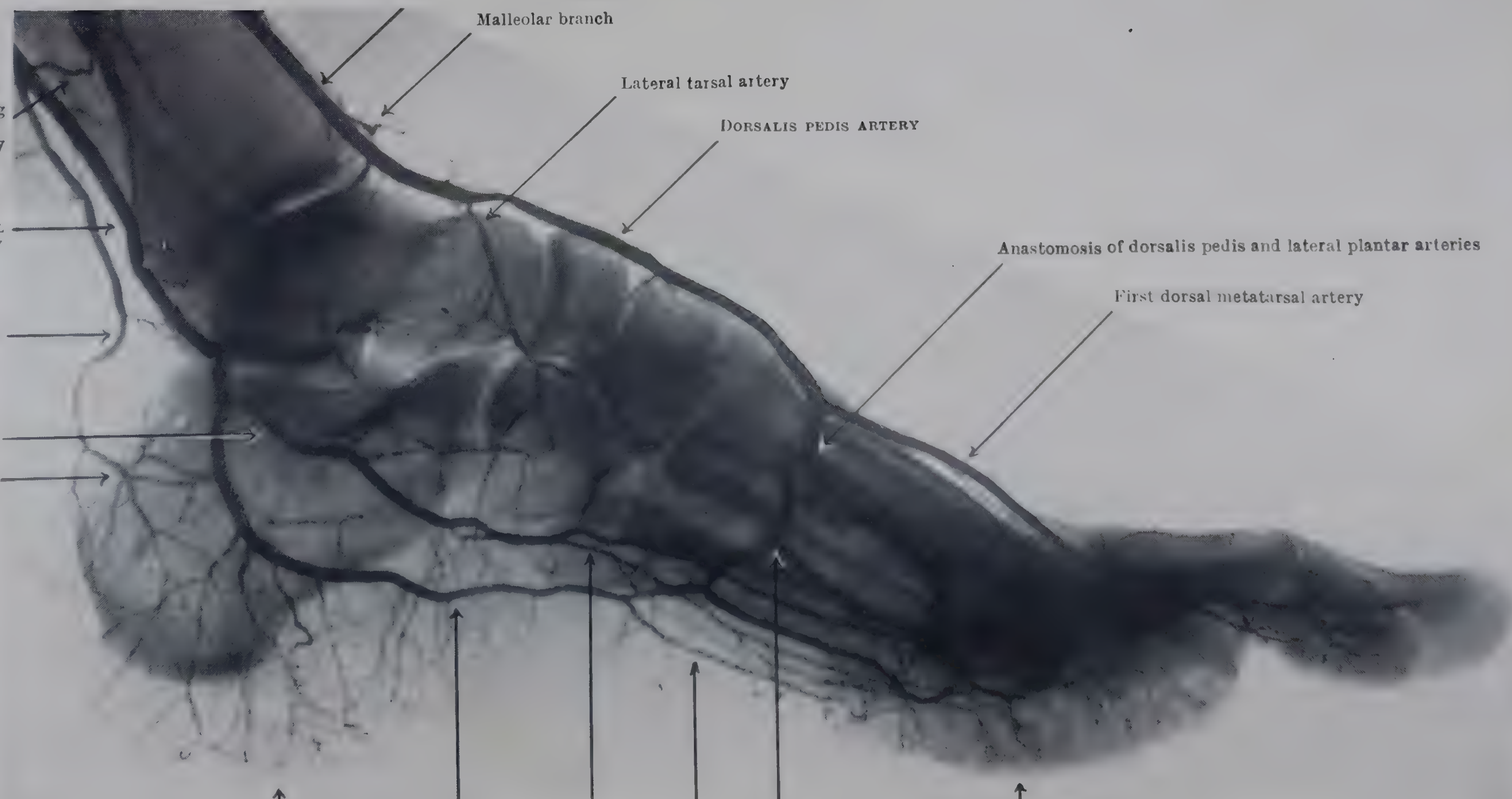

PLATE LXXXVI.—LATERAL RADIOGRAPH OF FOOT AFTER RADIO-OPAQUE INJECTION OF THE ARTERIES (from positive print).

Cf. Plate LXXXV and Figs. 1105, p. 1324 and 1107, p. 1327.

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primitive postcardinal veins by longitudinal anastomosis between somatic postcardinal tributaries ". They describe an anastomosis between the supracardinal and subcardinal veins at the level of the intersubcardinal anastomosis between the kidneys; and this "circum-aortic venous ring" or "renal collar" plays a part in the formation of the inferior vena cava. In the opinion of these observers, the right supracardinal vein takes part in the formation of the post-renal portion of the inferior vena cava, and both, in their thoracic sections, become converted into parts of the azygos system of veins. Unfortunately, the relationship of the supracardinal veins to the sympathetic trunks and their ventral branches (splanchnic and aortic) was not stated, and, as Reagan (1927) has pointed out, the inferior vena cava lies lateral to the nervous structures mentioned and the azygos vein lies medial; therefore the inferior vena cava is not in the azygos venous line, and if the right supracardinal is in the inferior caval line, it cannot be a forerunner of the azygos vein.

It may, however, be stated that each supracardinal vein, when fully formed, anastomoses: (1) with the corresponding posterior cardinal vein in the upper thoracic and lower abdominal regions; (2) with the corresponding subcardinal vein at the caudal border of the intersubcardinal anastomosis; (3) with its fellow of the opposite side; and (4) with the prevertebral plexus. Further, in the abdominal part of its extent it receives the intersegmental veins. As

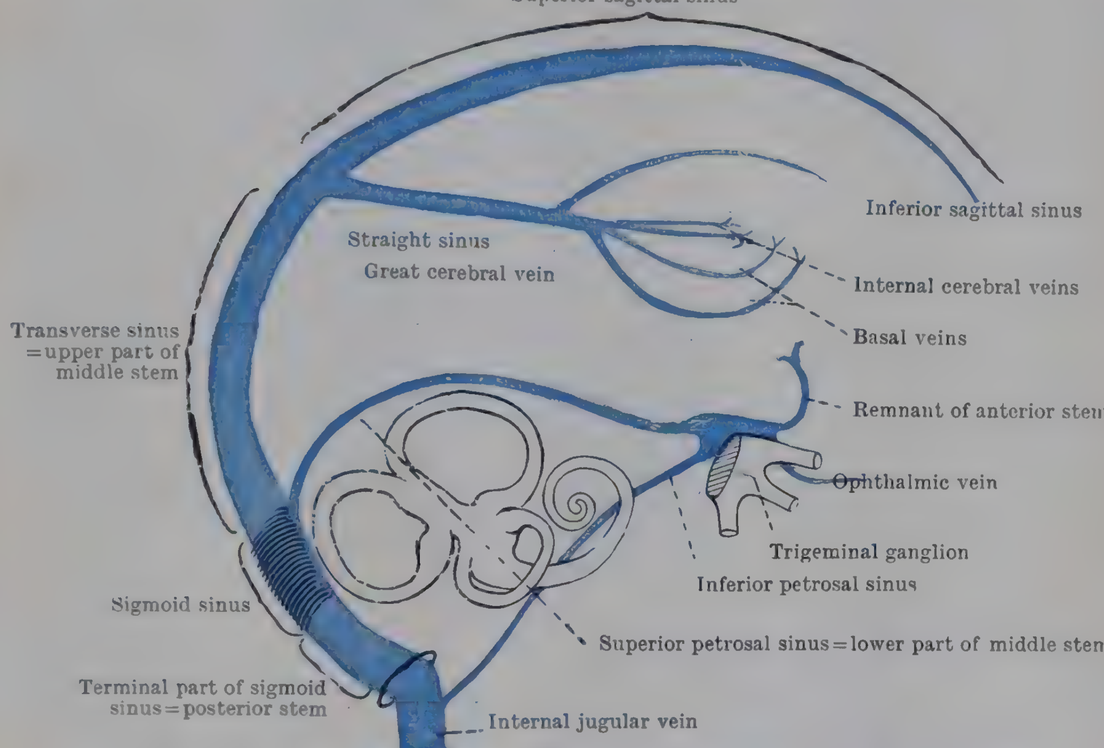

FIG. 1142.—DIAGRAM OF COMPLETION OF DEVELOPMENT OF VENOUS SINUSES.

a rule the left supracardinal disappears almost entirely, but a considerable part of the right supracardinal and the anastomosis between it and the subcardinal persists and becomes the post-renal part of the inferior vena cava.

The **Thoraco-Lumbar Veins** are described, by Reagan (1927), as bilateral longitudinal venous channels which lie lateral to the sympathetic trunks and parallel with the azygos venous line. They are transitory structures which serve as transmitters of blood from the intersegmental veins, "caudally into the inferior vena cava pending the establishment of an azygos line". When their function terminates they disappear, leaving no adult derivative.

Prevertebral Plexus and Azygos Veins.—The prevertebral plexus lies ventral to the bodies of the vertebræ and dorsal to the aorta, in the thoracic and lumbar regions, and to a less extent at the sides of and ventral to the aorta. Its lateral components have been termed *prevertebral* and *circumganglionic* and its median part *subcentral*. It communicates with the subcardinals, precardinal, and thoraco-lumbar venous channels and, as the major parts or the whole of those vessels disappear, their intersegmental tributaries open into it. Simultaneously its lateral parts become transformed into the rudiments of the azygos and hemiazygos veins, and its median part, not uncommonly and especially in the lumbar region, becomes a pre- or sub-central vein. The azygos venous line, on each side, lies lateral to the intersegmental arteries and medial to the sympathetic trunk and its ventral branches, and the precentral vein lies between the intersegmental arteries of opposite sides.

The thoracic part of the right azygos venous line forms the vena azygos, except its terminal part which is a remnant of the right posterior cardinal vein. In the lumbar region it not uncommonly persists as the right lumbar azygos vein, which extends from the inferior vena cava at the level of the renal veins through the aortic opening in the right crus of the diaphragm to the commencement of the azygos vein, the connexion with the inferior vena cava being formed by the persistence of an anastomosis between the azygos venous line and the right

The remains of the left azygos venous line are the superior and inferior hemiazygos veins, and the caudal part of the left superior intercostal vein. The transverse parts of the hemiazygos veins are remnants of the intermediate part of the subvertebral plexus; they are occasionally connected together by a median anastomosis which represents part of a precentral vein.

The lumbar part of the left azygos venous line forms the left lumbar azygos vein which is frequently found, in the adult, passing from the left renal vein, through the left crus of the diaphragm to the inferior hemiazygos vein.

The **inferior vena cava** is a compound structure. Its terminal part is the end of the right vitelline vein; the hepatic part is developed from the liver sinusoids; between the liver and the renal veins it is formed from: (1) an outgrowth from the hepatic part; (2) an anastomosis between the outgrowth and the right subcardinal vein; (3) part of the right subcardinal vein; the post-renal part is a persistent portion of the right supracardinal vein (Fig. 1143).

The intersegmental veins of the thoracic and abdominal regions drain the wall of the trunk and, in the earliest stages, they terminate in the posterior cardinal veins; at successively later periods they are transferred to the subcardinal, the supracardinal, the thoraco-lumbar veins, and finally to a greater or less extent to the azygos lines of veins. Eventually those which lie in the thoracic region enter one or other of the azygos veins or the superior intercostal veins.

The lumbar intersegmental veins have various terminations. The lower lumbar veins on the right side frequently end in the inferior vena cava, the connexion with the right supracardinal vein being retained; the upper right lumbar veins end, not uncommonly, in the right lumbar azygos vein; but cases occur in which all the right lumbar veins end in a vessel, called the right ascending lumbar vein, which connects the right ilio-lumbar vein with the azygos vein; it is a precostal anastomosis between the lumbar intersegmental veins. In such cases the connexions with the right supracardinal and the right lumbar azygos have been obliterated.

The left lumbar intersegmental veins may end: (1) in a left ascending lumbar vein which connects the left ilio-lumbar vein with the inferior hemiazygos vein; (2) in a precentral vein which ends in the azygos vein, or the hemiazygos vein or both; (3) the lower lumbar veins may end in the inferior vena cava, reaching it by transverse anastomoses developed from the prevertebral plexus, and the upper left lumbar veins may end in the left lumbar azygos vein.

The above account of the development of the thoracic and abdominal parts of the venous system is, as already stated, mainly a personal and tentative summary of knowledge by Robinson (1931). The reader who wants to form his own opinion on disputed points should consult Huntington & M'Clure (1920); M'Clure & Butler (1925); Butler (1927); M'Clure & Huntington (1929); Gladstone (1929); Reagan (1927); Seib (1934); Franklin (1948); and, from the historical point of view, Reagan (1929). These communications contain references to all the literature to date dealing with the development of the posterior thoracic and abdominal veins.

FŒTAL CIRCULATION

During fœtal life, food and oxygen are transmitted from the maternal blood to the fœtal blood in the placenta, where the maternal blood flows in near relation to the walls of the fœtal blood-vessels; and the effete products produced by the cells of the fœtal tissues, including carbon dioxide, are passed from the fœtal blood to the maternal blood in the same place. The umbilical arteries and the umbilical vein persist therefore till birth in order to carry the blood from the fœtus to the placenta and back again.

Lungs are present in the fœtus, but they do not function as respiratory organs until birth; and, although the blood-vessels necessary for pulmonary respiration are present, the only blood that flows through them is that which is necessary for their nutrition and growth, the bronchial vessels being apparently, as yet, insufficient for the purpose. The foramen ovale and the ductus arteriosus, therefore, remain patent till birth, so that most of the blood may be transmitted to the aorta without passing through the lungs.

As a consequence, the course of the circulation is different before and after birth (Pl. LXXXVIII, p. 1387). After birth, blood passes from the body as a whole into the right atrium, which passes it on into the right ventricle, whence it is forced, through the lungs, to the left atrium, and thence to the left ventricle, by which it is propelled through the systemic vessels back to the right atrium.

In the fœtus, on the other hand, blood laden with food and oxygen is carried from the placenta by the umbilical vein, and transmitted to the inferior vena cava, partly directly through the ductus venosus, and partly indirectly through the liver by branches which are ultimately taken over by the left branch of the portal vein (Fig. 1137 and Pl. LXXXVII, Fig. 3). In the inferior vena cava it mixes with venous blood returning from the lower limbs, the lower parts of the trunk, the renal organs, and the genital glands; and so it becomes mixed blood. The mixed stream is then delivered by the inferior vena cava into the right atrium and the greater part of it is directed by the valve of the inferior vena cava through the foramen ovale into the left atrium, whence it passes to the left ventricle, which ejects it into the aorta (Fig. 1143 and Pl. LXXXVII, Fig. 1 A).

Some of the blood that enters the right atrium from the inferior vena cava takes another route. The whole stream is not directed by the valve of the inferior vena cava straight through the foramen ovale, but it impinges on the edge of the annulus ovalis so that a small part of it (probably about one-fourth—see references on p. 1386) passes forwards and is carried into the right ventricle with the stream of blood from the superior vena cava (Pl. LXXXVII, Fig. 1 B).

On the other hand, the blood from the head and neck, the upper limbs, and the upper parts

of the trunk, returning by the superior vena cava to the right atrium, passes wholly into the right ventricle, which ejects it into the pulmonary trunk. Only a small quantity of this stream enters the pulmonary arteries for the supply of the lungs; the greater part of it passes through the ductus arteriosus—which is in direct line with the pulmonary trunk (Fig. 1144)—into the

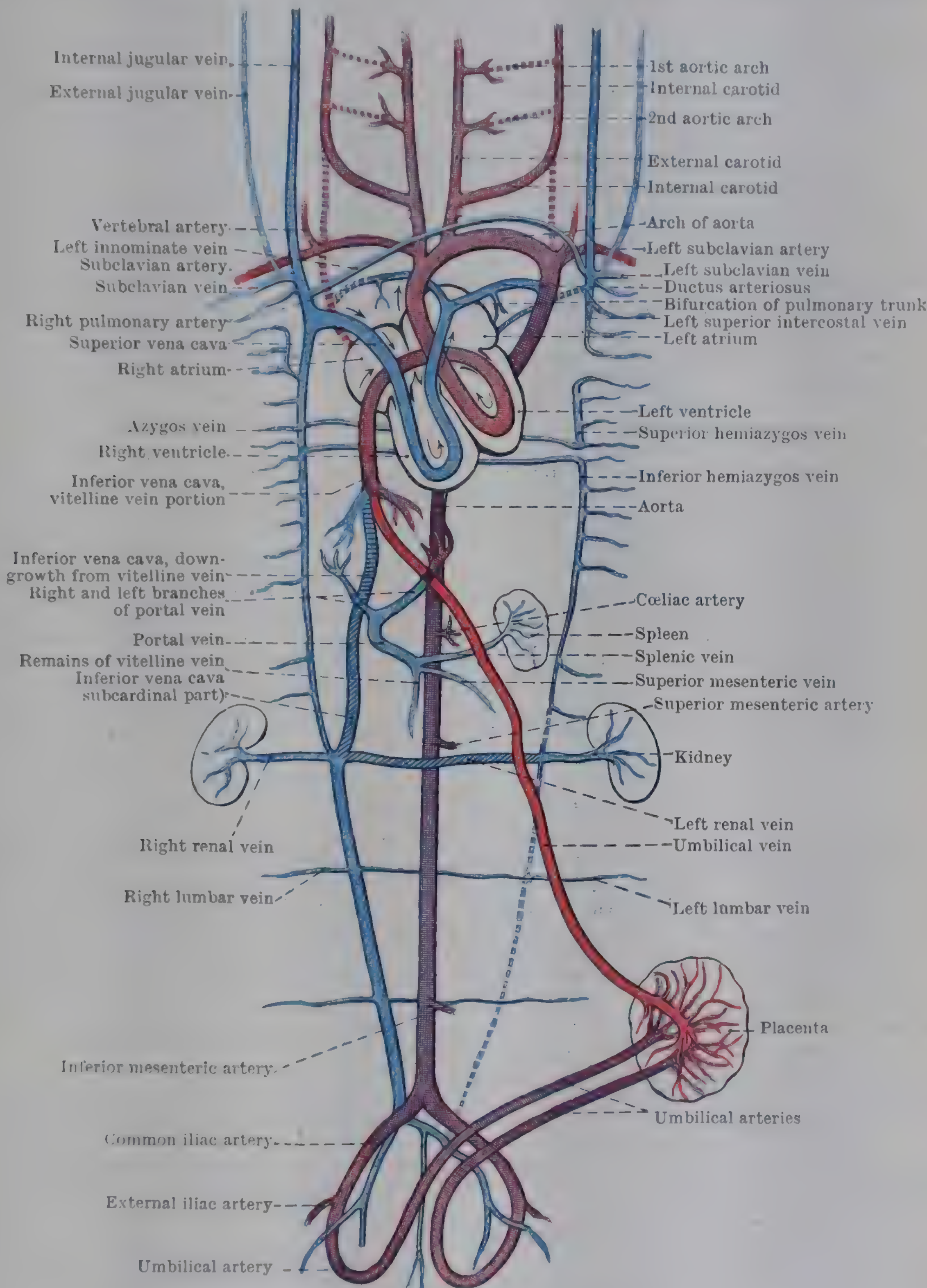

FIG. 1143.—DIAGRAM OF FŒTAL CIRCULATION.

The inferior vena caval blood is represented as passing wholly through the foramen ovale into the left atrium, but recent work (see p. 1384) has confirmed the older view that part of it is directed by the annulus ovalis through the right atrio-ventricular orifice into the right ventricle.

aorta, beyond the origin of the left subclavian artery, where it mixes with the blood from the **left ventricle** (Pl. LXXXVII, Fig. 2 A).

There has been much discussion on the part played by the "intervenous tubercle" (p. 1230) in directing the stream from the superior vena cava through the right atrio-ventricular orifice, and there is no doubt that many statements, based on Lower's original description in 1669, have exaggerated its anatomical and functional importance in the human heart. The factors that

through the two venæ cavæ are the different directions of the two streams and the relation of the valve of the inferior vena cava to the foramen ovale and the annulus ovalis. Doubts about the separation of the two streams of blood seem finally to have been set at rest by the researches of Barcroft and Barclay and their colleagues on the fœtal circulation as demonstrated by X-ray cinematography (Pls. LXXXVII, LXXXVIII). Their observations were directed primarily to the problem of the closure of the ductus arteriosus (see below), but the method of injecting radio-opaque media into the blood-stream of fœtal sheep has given a clear picture of the routes taken by the blood through the living heart. For the original account of these researches, see Barclay, Barcroft, Barron and Franklin (1939), and for further details and references to the full series of papers and the literature in general, Barclay, Franklin and Prichard (1944).

In the fœtus, therefore, pure oxygenated blood is found only in the left umbilical vein and the ductus venosus and that is mixed with venous blood in the inferior vena cava. The mixed stream from the inferior vena cava is delivered into the aorta via the left atrium and ventricle, and most of it passes into the head and neck and the upper limbs; the remainder passes into the descending aorta and is joined, beyond the origin of the left subclavian artery, by the venous stream from the head and neck and the upper limbs, which has passed from the superior vena cava through the right atrium (where it receives a small contribution from the inferior vena cava), the right ventricle, the pulmonary trunk, and the ductus arteriosus.

From the descending aorta part of the blood passes to the walls of the thorax, to the abdomen and its contents, and to the lower limbs; the remainder passes through the internal iliac arteries and their umbilical branches to the placenta.

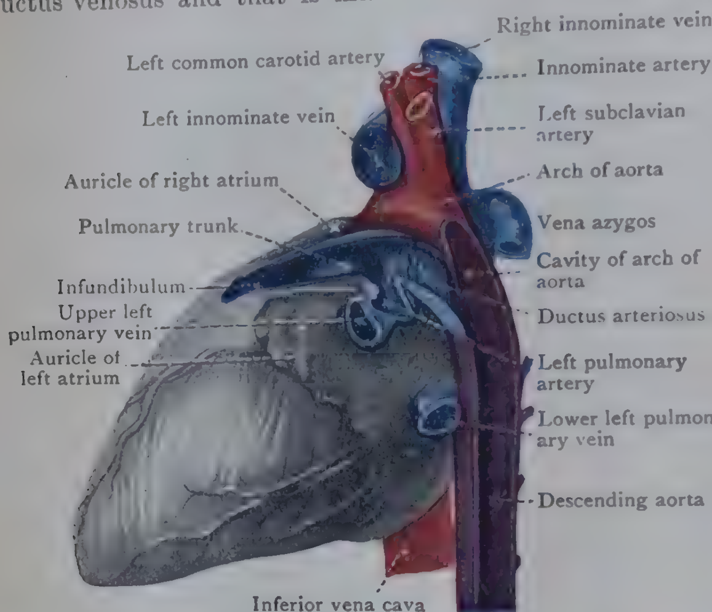

Fig. 1144.—Dissection of Heart and Great Vessels of Fœtus, showing the Angular Junction of Ductus Arteriosus with Aorta.

It is obvious, from what has been stated, that the blood in the descending aorta, which is supplied to the lower part of the trunk and the lower limbs, contains relatively less oxygen and food-material and more effete matter than the blood in the ascending aorta and the arch of the aorta, which is transmitted to the head and neck and the upper limbs.

TRANSITION FROM FŒTAL TO ADULT CIRCULATION

The changes that occur in the vascular system at birth depend on the expansion of the lungs with the onset of breathing and on the cessation of the circulation through the placenta. The flow of blood is altered in several ways, and these functional changes are followed sooner or later by anatomical alterations which affect the pulmonary arteries, the foramen ovale, the ductus arteriosus, the umbilical arteries, the umbilical vein, and the ductus venosus.

As the lungs expand, a greater amount of blood is drawn from the pulmonary trunk into the pulmonary arteries and correspondingly less passes through the ductus arteriosus into the aorta. The **pulmonary arteries** dilate and the ductus contracts; and the increased flow of blood through the lungs raises the pressure in the left atrium so that it at least equalizes the pressure in the right. The **foramen ovale** thus ceases to function as a passage for the blood from the inferior vena cava, and the opposing surfaces of that valve-like aperture come together and begin to unite; and in time the surfaces are usually completely fused so that the foramen is structurally as well as functionally closed. Even if an aperture persists, as it may do throughout life (pp. 1229, 1369), it is of little importance unless it is part of some gross malformation of the heart.

The functional closure of the **ductus arteriosus** appears to occur almost at once by sphincter-like action of its muscular wall (Pl. LXXXVII, Fig. 2 B), possibly assisted by a change in its direction due to rotation of the heart which occurs as the lungs expand. Thereafter, the lumen of the ductus is gradually obliterated and it is transformed into the *ligamentum arteriosum*.

The cessation of the placental circulation, completed by the actual ligature of the umbilical cord, leads to the obliteration of the **umbilical arteries** and **vein**. The arteries, beyond the points at which the superior vesical branches arise, are transformed into the ***lateral umbilical ligaments*** (p. 1311), and the vein becomes the *round ligament of the liver*. The closure of the **ductus venosus**, like the closure of the ductus arteriosus, seems in the first instance to be due to active sphincteric contraction (Pl. LXXXVII, Fig. 3 B), and, like the other fœtal vessels no longer required, it is gradually reduced to a fibrous cord—the *ligamentum venosum*.

In general it may be noted that the sudden change at birth from placental to pulmonary

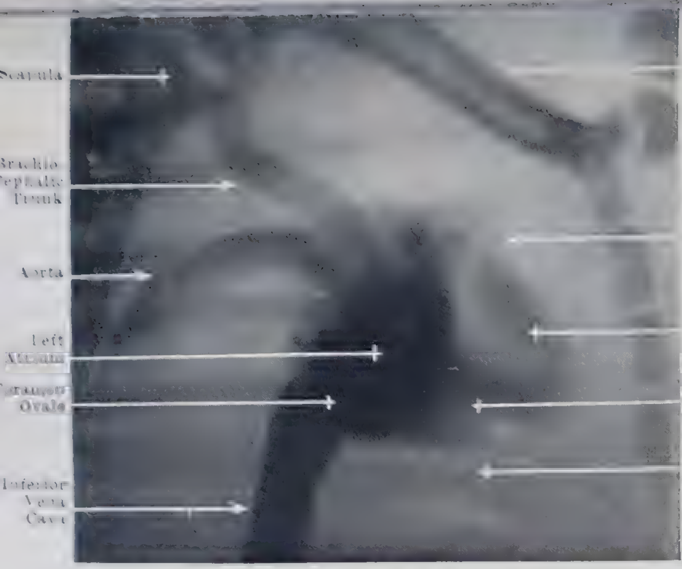

FIG. 1A.—Inf. Vena Cava to Right Atrium and mainly through Foramen Ovale to Left Side of Heart and Aorta; small quantity to Right Ventricle and Pulmonary Trunk. (Fœtal Sheep.)

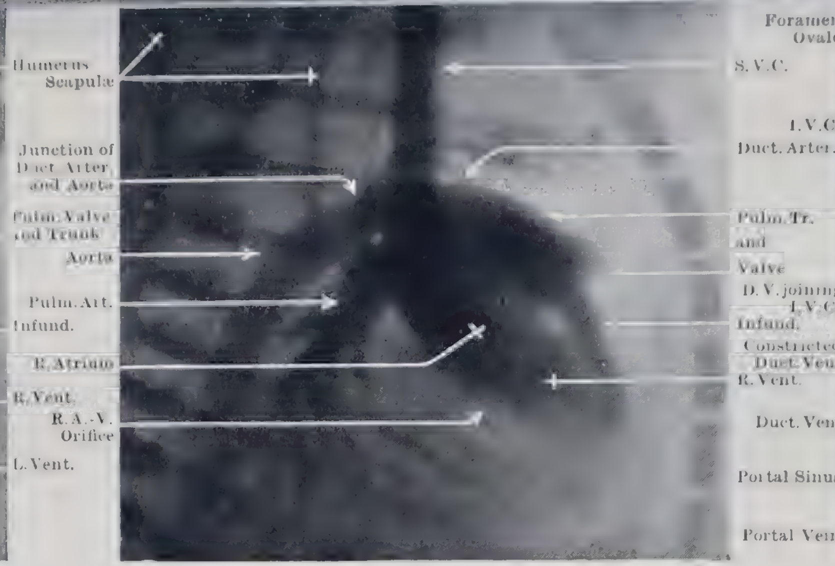

FIG. 2A.—Sup. Vena Cava to Right Atrium, Right Ventricle Pulmonary Trunk and Arteries, and *via* Ductus Arteriosus to Aorta beyond origin of Brachio-Cephalic Trunk. (Fœtal Sheep.)

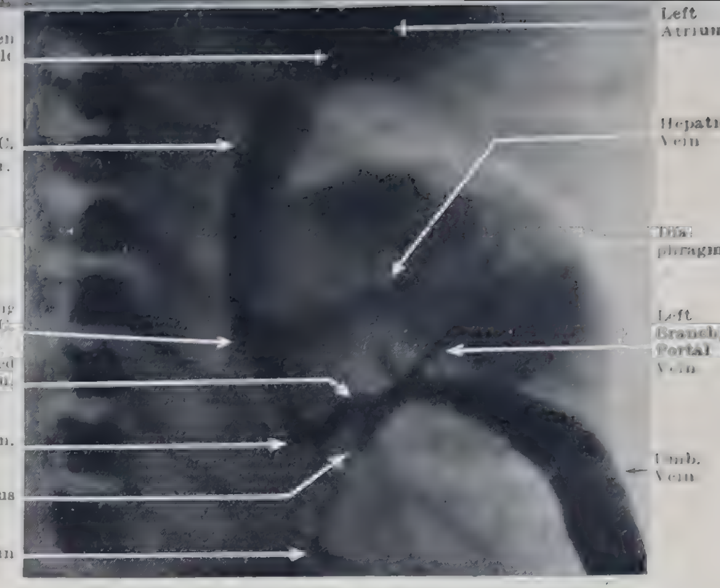

FIG. 3A.—Ductus Venosus in Full-Time Fœtal Sheep after injection into Umbilical Vein in functioning Umbilical Cord.

FIG. 1B.—One second later, the main flow to Aorta and the smaller flow to Pulmonary Trunk, Ductus Arteriosus and Pulmonary Arteries are both seen more clearly.

FIG. 2B.—Functional Closure of Ductus Arteriosus in New-Born Lamb. Note the stub of the Ductus at its origin from the Pulmonary Trunk.

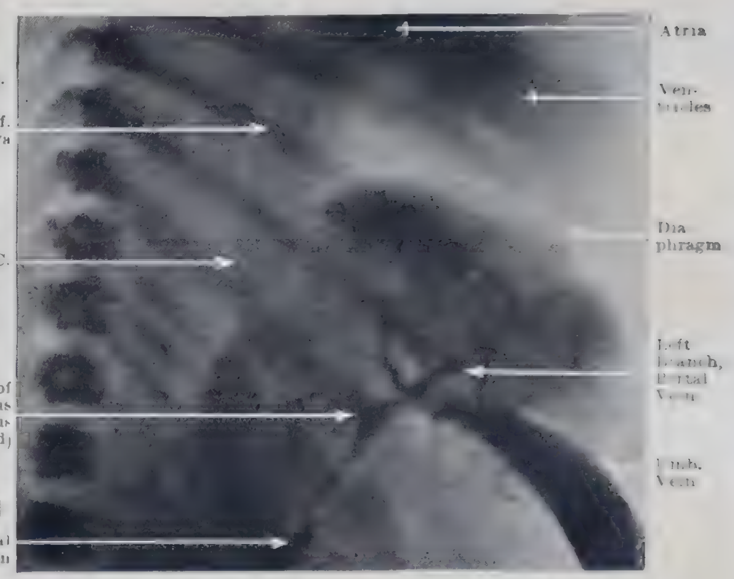

FIG. 3B.—Functional Closure of Ductus Venosus 1 second after Fig. 3A. Note the stub of the Ductus opposite the end of the Umbilical Vein where it joins the left branch of the Portal Vein.

PLATE LXXXVII.—SERIES OF RADIOGRAPHS, AFTER INJECTION OF OPAQUE MEDIA INTO VESSELS, ILLUSTRATING THE FŒTAL CIRCULATION AND CLOSURE OF DUCTUS ARTERIOSUS AND DUCTUS VENOSUS. (The late Dr. A. E. Barclay, Nuffield Institute, Oxford.)

PLATE LXXXVIII

FŒTAL CIRCULATION

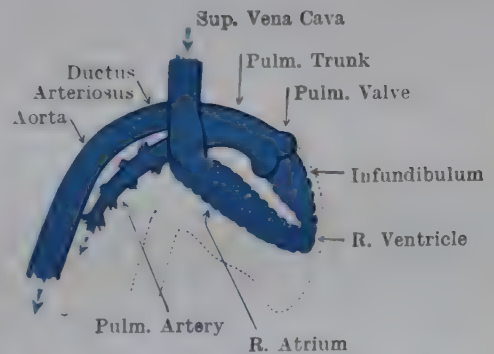

Fig. 1.—From Superior Vena Cava through Right Heart to Pulmonary Trunk, *via* Ductus Arteriosus to Descending Aorta, and *via* Pulmonary Arteries to Lungs.

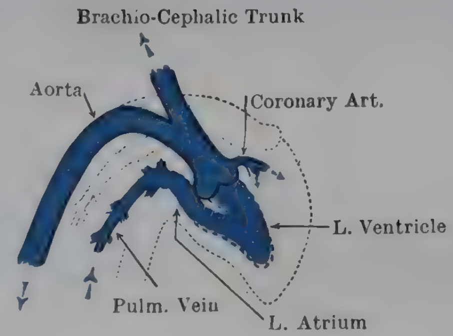

Fig. 2.—From Lungs through Left Heart to Aorta and Brachio-Cephalic Trunk.

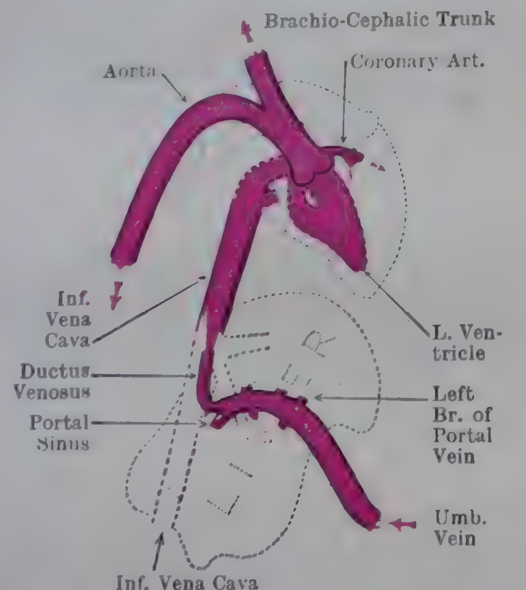

Fig. 3.—From Placenta by Umbilical Vein, Ductus Venosus, Inferior Vena Cava and Foramen Ovale through Left Heart to Aorta and Brachio-Cephalic Trunk.

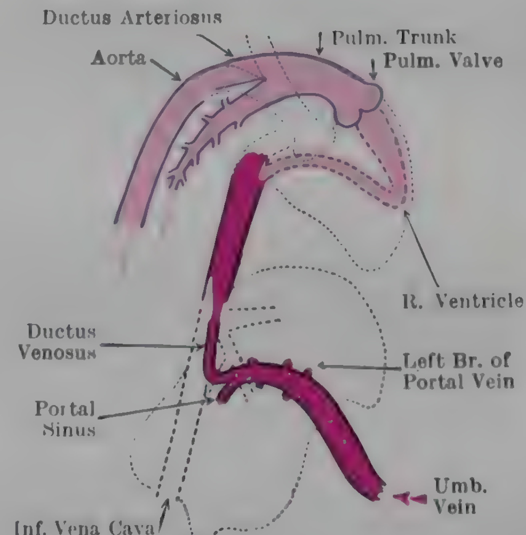

Fig. 4.—From Placenta by Umbilical Vein, Ductus Venosus, and Inferior Vena Cava through Right Heart to Pulmonary Trunk, *via* Ductus Arteriosus to Descending Aorta, and *via* Pulmonary Arteries to Lungs.

POST-NATAL CIRCULATION

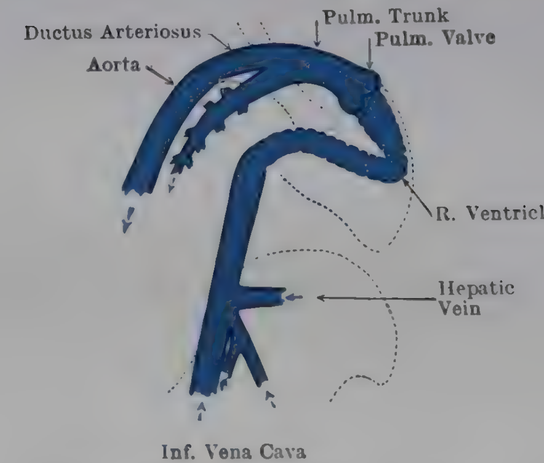

Fig. 5.—After ligature of Umbilical Vein and closure of Ductus Venosus and Foramen Ovale, from Inferior Vena Cava through Right Heart to Pulmonary Trunk, *via* Ductus Arteriosus (so long as patent) to Descending Aorta, and *via* Pulmonary Arteries to Lungs.

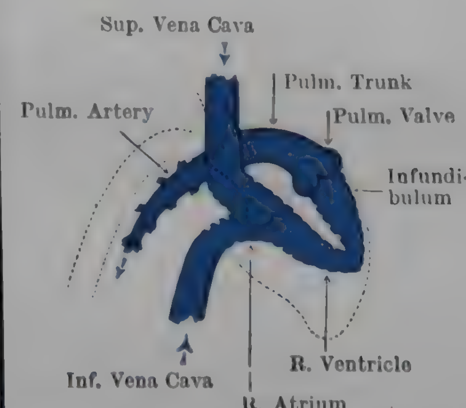

Fig. 6.—From Superior and Inferior Venæ Cavæ through Right Heart, Pulmonary Trunk and Arteries to Lungs.

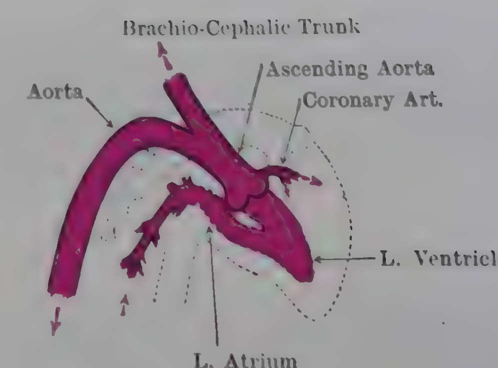

Fig. 7.—From Lungs by Pulmonary Veins through Left Heart to Aorta and Brachio-Cephalic Trunk.

Plate LXXXVIII.—Series of Diagrams illustrating the Fœtal and Post-Natal Circulations in the Sheep. (Nuffield Institute for Medical Research, Oxford.)

[Facing p.

respiration is accompanied by equally sudden functional adaptation of the circulatory system, and that the permanent structural changes follow gradually.

MORPHOLOGY OF BLOOD-VESSELS

In conformity with the general plan of the vertebrate body, the vascular system is essentially segmental and intersegmental in character. The intersegmental character of the intercostal and lumbar vessels is obvious; that of the vessels of the head, neck, and pelvis is less obvious but is still distinguishable in the vessels of the head.

The intersegmental arteries and veins form a series of bilaterally symmetrical vessels. Each of those intersegmental vessels is connected with its cephalic and caudal neighbours by a portion of a longitudinal vessel which lies in the region of a segment and, therefore, may be called a segmental channel. Consequently, in a sense in the adult, the segmental channels anastomose with one another, through the intersegmental vessels which they connect together. The longitudinal trunks of the body are mainly, though not exclusively, segmental. From them the main stem-vessels of the adult are formed, and the intersegmental vessels appear to proceed from or to them as branches or tributaries.

In the course of development the longitudinal trunks become the most important trunks in the body, and they are formed before the branches and tributaries make their appearance.

SEGMENTAL ARTERIES AND THEIR ANASTOMOSES

The main longitudinal trunks are the primitive aortæ. The descending aorta is formed, in the greater part of its extent, by the fusion of the dorsal parts of the primitive aortæ, and from it the intersegmental, lateral, and ventral arteries arise in pairs.

In a typical portion of the body of the embryo there are three arteries on each side. One arises from the dorsal surface of the primitive dorsal aorta, *i.e.*, from the dorsal longitudinal trunk, and runs laterally and ventrally in the tissues developed from the somatic mesoderm; it is distributed to the body-wall, including the vertebral column and its contents, and is termed a **somatic intersegmental artery.** A second vessel arises from the side of the primitive dorsal aorta; it is distributed to the structures developed from or in the region of the intermediate cell-mass—the suprarenal gland, the kidney, and the ovary or the testis—and it is accordingly termed **a lateral or intermediate visceral artery.** The third artery, which is known as the **splanchnic artery,** springs from the ventral surface of the aorta. It runs in the tissues developed from the splanchnic mesoderm, and supplies the wall of the alimentary canal.

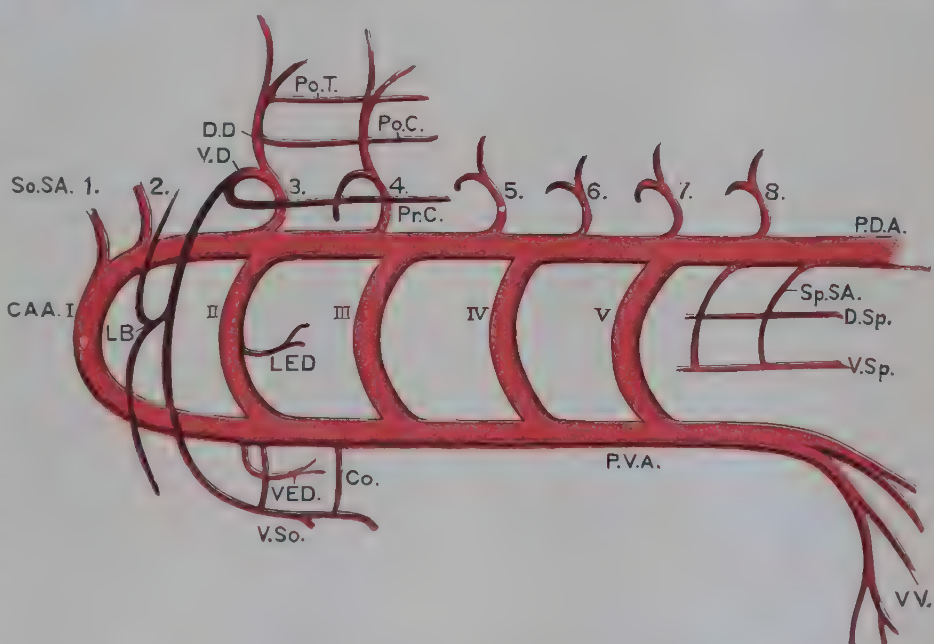

Fig. 1145.—Diagram of Aortic Arches, and of Segmental and Intersegmental Arteries Cephalic to Umbilicus.

C.A.A. I, II, III, IV, V. The cephalic aortic arches.
Co. Anastomosing vessel between the primitive ventral aorta and the ventral somatic anastomosis.
D.D. Dorsal division of a somatic intersegmental artery.
D.Sp. Dorsal splanchnic anastomosis.
L.B. Lateral branch of ventral division of somatic intersegmental artery.
L.E.D. Branch to lateral enteric diverticulum.
P.D.A. Primitive dorsal aorta.
Po.C. Post-costal anastomosis.
Po.T. Post-transverse anastomosis.
Pr.C. Pre-costal anastomosis.
P.V.A. Primitive ventral aorta.
So.S.A. 1, 2, 3, 4, 5, 6, 7, 8. Somatic intersegmental arteries.
Sp.S.A. Splanchnic arteries.
V.D. Ventral division of a somatic intersegmental artery.
V.E.D. Branch to ventral enteric diverticulum.
V.V. Vitelline vessels.
V.So. Ventral somatic anastomosis.
V.Sp. Ventral splanchnic anastomosis.

The **somatic intersegmental arteries** form, in the early embryo, a regular series of paired vessels throughout the cervical, thoracic, lumbar, and sacral regions. It is, however, only in the thoracic and lumbar regions that their original characters are retained. The paired vessels pass dorsally, by the sides of the vertebræ, and divide into dorsal and ventral branches which accompany the posterior and anterior primary rami of the spinal nerves.

The **ventral branches** run ventro-laterally, between the ribs, in the thoracic region, and in

corresponding positions in the lumbar region, and together with the stems they form the main parts or trunks of the vessels in the thoracic and lumbar regions. They are connected together, near their commencements, by a series of pre-costal anastomoses which pass in front of the necks of the ribs; and they are also connected together, near their terminations, by ventral anastomosing channels which run, in the thoracic region behind the costal cartilages, and in the lumbar region behind or in the substance of the rectus abdominis muscle. Each ventral branch gives off a lateral offset which is distributed like the lateral cutaneous branch of a spinal nerve. The ventral branch together with the stem of the intersegmental artery forms the trunk of an intercostal or lumbar artery in the adult.

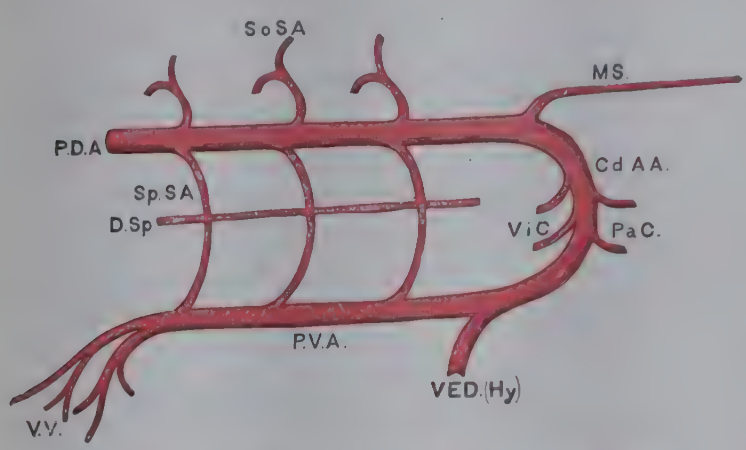

Fig. 1146.—Diagram of Arteries in Region caudal to Umbilicus.

Cd.A.A.	Caudal aortic arch.	So.S.A.	Somatic intersegmental arteries.
D.Sp.	Dorsal splanchnic anastomosis.	Sp.S.A.	Splanchnic arteries.
M.S.	Median sacral artery.	V.E.D. (Hy).	Branch to a ventral enteric diverticulum.
Pa.C.	Parietal branch from caudal arch.	Vi.C.	Visceral branch from the caudal arch.
P.D.A.	Primitive dorsal aorta.		
P.V.A.	Primitive ventral aorta.	V.V.	Vitelline vessels.

The **dorsal branches**, which are present before the ventral branches, run backwards between the transverse processes of the vertebræ, and form the posterior branches of the intercostal and lumbar arteries of the adult; they are connected, behind the necks of the ribs, by post-costal anastomoses, and again, behind the transverse processes of the vertebræ, by post-transverse anastomosing channels. Moreover, each dorsal branch, as it passes by the corresponding intervertebral foramen, gives off a spinal offset which enters the vertebral canal, along the corresponding nerve-root, and

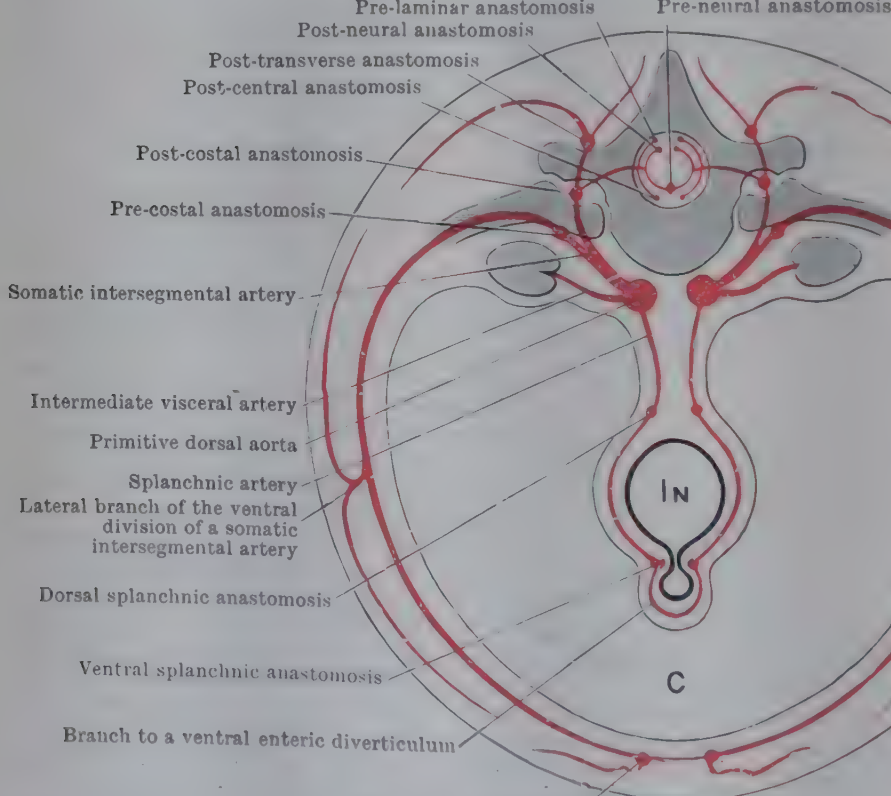

Fig. 1147.—Diagram of Arrangement and Communications of Segmental and Intersegmental Arteries at Early Stage of Development.

C, Cœlom; In, Intestine.

divides into a dorsal, a ventral, and a neural branch. The dorsal branches of those spinal arteries are connected together along the ventral surfaces of the laminæ by pre-laminar anastomoses, and the ventral branches are united on the dorsal surfaces of the vertebral bodies (or centra) with their fellows above and below by post-central anastomoses; they are also

united with their fellows of the opposite side by transverse communicating channels. The neural branches of the spinal arteries divide similarly into dorsal and ventral branches; the dorsal branches of each side are connected together by post-neural anastomoses, which form the posterior spinal arteries; and the ventral branches unite, in the median line, both with their neighbours above and below and with their fellows of the opposite side, forming a single longitudinal pre-neural trunk—the anterior spinal artery.

In the thoracic and lumbar regions of the body the somatic intersegmental arteries persist, and form the posterior intercostal and lumbar arteries. Those vessels spring from the dorsal aspect of the descending aorta, usually in pairs. The corresponding vessels of opposite sides occasionally fuse together at their origins, simultaneously with the fusion of the dorsal longitudinal trunks to form the descending aorta, and then the arteries of opposite sides arise by common stems.

The pre-costal anastomoses between the ventral branches of the somatic intersegmental arteries persist only in the thoracic region, where they are represented by the superior intercostal arteries; in the lumbar region they disappear entirely. The anastomoses between the terminal portions of the ventral branches of the somatic intersegmental arteries persist as the internal mammary and superior and inferior epigastric arteries.

The lateral offsets of the ventral branches are represented by the cutaneous arteries which accompany the lateral cutaneous branches of the spinal nerves; the lateral branch of the seventh somatic intersegmental artery forms the greater part of the arterial stem of the upper limb.

The post-costal and post-transverse anastomoses usually disappear in the thoracic and lumbar regions, but the post-costal anastomoses occasionally persist in the upper thoracic region, and take part in the formation of the vertebral artery, which in such cases arises from the first or second aortic intercostal artery. In some carnivora the post-costal longitudinal vessels persist in the headward part of the thoracic region, and form, on each side, a trunk which is connected with the first aortic intercostal, and supplies the first five intercostal spaces.

The pre-laminar, the post-central, and the pre- and post-neural anastomoses persist, the latter two aiding in the formation of the thoracic and lumbar portions of the anterior and posterior spinal arteries respectively.

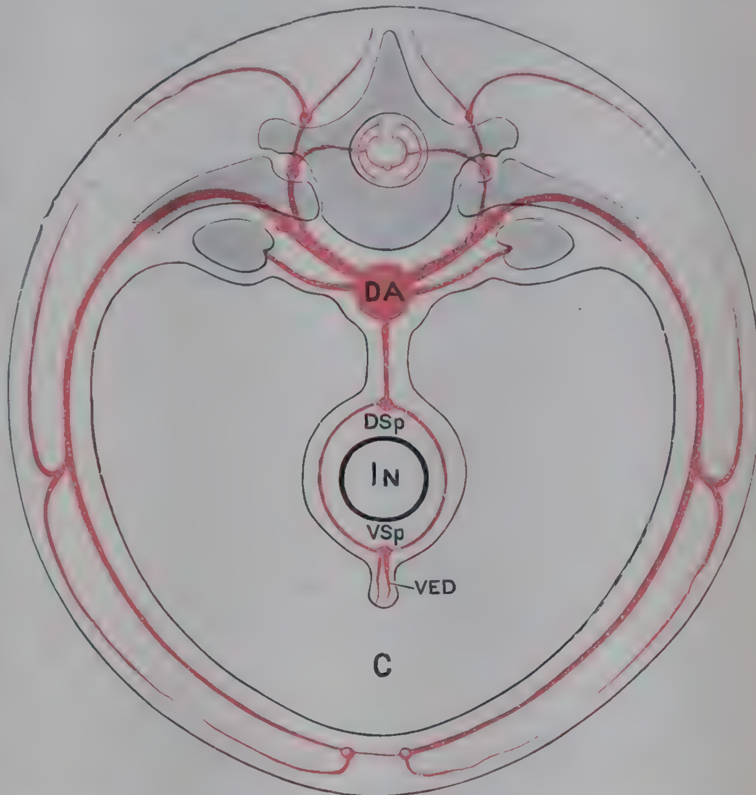

Fig. 1148.—Diagram of Segmental and Intersegmental Arteries at later Period of Development than in Fig. 1147.

C, Cœlom; DA, Dorsal aorta; DSp, Dorsal splanchnic anastomosis; In, Intestine; VED, Branch to ventral enteric diverticulum; VSp, Ventral splanchnic anastomosis.

It is in the cervical region, however, that the most interesting changes occur. The first six pairs of somatic intersegmental arteries lose their connexions with the dorsal roots of the aortic arches, *i.e.*, in other words, with the longitudinal anastomosing channels in that region. The seventh pair, however, persist in their entirety; and from them are formed, on the right side, a portion of the subclavian trunk, and, on the left side, the whole of the subclavian stem from its commencement up to the origin of the vertebral artery. On each side the ventral branch of the seventh intersegmental artery forms that portion of the subclavian artery which lies between the origins of the vertebral and internal mammary arteries, and also the trunk of the internal mammary artery as far as the upper border of the first costal cartilage. The remainder of the internal mammary artery represents the ventral longitudinal anastomoses between the ventral branches of the seventh and the following somatic intersegmental arteries. The continuation of the subclavian artery, beyond the inner margin of the first rib, is the persistent and enlarged lateral offset of the ventral branch of the seventh somatic intersegmental artery, which is continued into the upper limb, caudal or postaxial to the shoulder girdle. The thyro-cervical trunk and the superior intercostal artery, both derived from the subclavian artery, are persistent pre-costal anastomoses, and the ascending cervical artery belongs to the same series of vessels. The vertebral artery, which appears as a branch of the subclavian in the adult, is, morphologically, somewhat complex. The first part represents the dorsal branch of the seventh somatic intersegmental artery; the second part—that passing through the cervical transverse processes—consists of the persistent post-costal anastomoses bewteen the dorsal branches of the first seven intersegmental arteries; a third part, that lying on the arch of the atlas, is the

spinal branch of the first somatic intersegmental artery and its neural continuation; whilst, finally, the upper part of the vertebral artery—the part in the cranial cavity—appears to represent a prolongation of the pre-neural anastomoses, which still farther upwards are probably represented by the basilar artery. As already stated, the post-costal anastomoses below the seventh intersegmental artery occasionally persist, and in such cases the vertebral may lose its connexion with the subclavian, and spring from one or other of the posterior branches of the upper intercostal arteries.

The deep cervical artery is to be regarded as a remnant of the post-transverse longitudinal anastomoses.

The origin of the seventh somatic intersegmental artery from the dorsal longitudinal trunk is, at first, some distance caudal to the sixth aortic arch, but, simultaneously with the elongation of the neck and the retraction of the heart into the thoracic region, it is shifted headwards until it is opposite the dorsal end of the fourth aortic arch.

The median sacral artery is formed by the fusion of two vessels, each of which springs from the dorsal surface of the aorta. It is regarded as the direct continuation of the descending aorta.

The **lateral** or **intermediate visceral arteries** supply the organs developed in the region of the intermediate cell-mass. They form an irregular series of vessels in the adult, but presumably in the primitive condition there was a pair in each segment of the body; many of these disappear, however, and the series is represented in the adult only by the suprarenals, the renals, and the testicular or ovarian arteries—possibly, also, by some of the branches of the internal iliac arteries.

The **splanchnic arteries** arise in the embryo from the ventral aspects of the primitive dorsal aortæ, and are not strictly either segmental or intersegmental in arrangement. They are distributed to the walls of the alimentary canal. Each anastomoses with its immediate neighbours on both the dorsal and the ventral walls of the gut.

After the fusion of the dorsal longitudinal trunks to form the descending aorta, the roots of each pair of the splanchnic arteries fuse into a common stem, or one of the pair—right or left—disappears altogether. At a later period the majority of the splanchnic arteries lose their direct connexion with the descending aorta; those which retain their connexion are the cœliac artery and the superior and inferior mesenteric arteries.

The bronchial and œsophageal arteries are later formations. They appear to correspond morphologically with the more primitive splanchnic arteries, but the developmental history is not known.

The left gastric branch of the cœliac artery, as it passes from its origin to the lesser curvature of the stomach, represents a right splanchnic artery; the remainder of the left gastric artery and the right gastric branch of the hepatic are remnants of the ventral anastomoses between the splanchnic arteries headwards of the umbilicus.

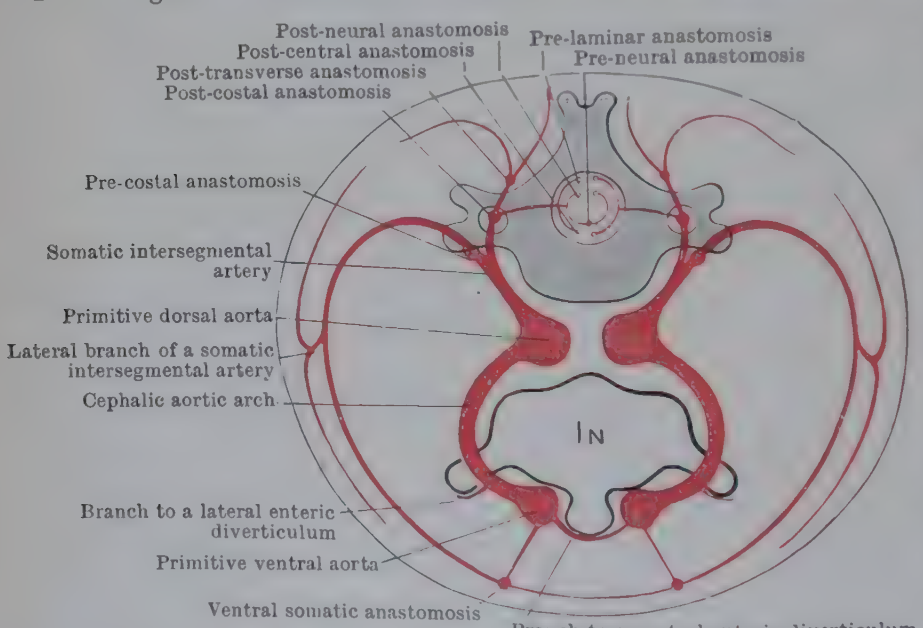

Fig. 1149.—Diagram of Arrangement and Communications of Segmental and Intersegmental Arteries in Region of Cephalic Aortic Arches.

In, Intestine.

The splenic artery is a branch given off from a splanchnic artery to an organ developed in the mesogastrium; and the hepatic is a branch from the ventral splanchnic anastomoses to the hepatic diverticulum of the duodenal portion of the fore-gut.

The superior and inferior mesenteric arteries represent at their origins splanchnic branches, and in the remainder of their extent they represent the dorsal anastomoses on the gut-wall.

Aorta, Pulmonary Trunk, and other Chief Stem-Vessels

The heart and the majority of the great arterial trunks of the body, including the aorta, the innominate, part of the right subclavian, the common, external, and greater parts of the internal carotid arteries, and the pulmonary trunk, are all modified portions either of the primitive aortæ or of the aortic arches. The developmental changes, which result in the formation of the vessels named, are described in the preceding chapter, and the morphology of these vessels is obviously the same as that of the trunks from which they are derived.

It will be sufficient, therefore, to point out that the primitive aortæ may be regarded as the greatly enlarged pre-central or pre-vertebral longitudinal anastomoses between the successive intersegmental arteries of each side; obviously, therefore, each primitive aorta, like the rest of the longitudinal anastomoses, consists chiefly of segmental elements. The origins of the intersegmental vessels enter into its formation only in so far as they connect the segmental vessels together, and so complete the longitudinal anastomoses.

The first cephalic aortic arches are simply portions of the primitive aortæ. The other aortic arches have possibly a different morphological significance, but their exact nature is not definitely settled.

The second, third, fourth, fifth, and sixth cephalic aortic arches of each side are developed in the undivided mesoderm of the head region, caudal to the first arch. They spring from the part of the primitive aorta which, after the head-fold is formed, lies on the ventral aspect of the fore-gut, and they extend, at the side of the pharyngeal part of the fore-gut, to the dorsal aorta. Thus in some respects they may be looked upon as segmental vessels. In addition to the vessels already mentioned, there are given off from the ventral aortæ and the aortic arches a series of branches which supply ventral and lateral diverticula from the alimentary canal; these are represented in the adult by the superior thyroid and the thyroidea ima arteries.

Iliac Arteries and their Branches.—The common iliac arteries are formed from the secondary roots of the umbilical arteries, and their exact morphological position is uncertain. The true morphological position of the internal iliac arteries is not yet defined. They also are parts of the secondary roots of the umbilical arteries, and they give off both somatic and splanchnic branches; therefore they do not correspond either with somatic intersegmental or with splanchnic arteries. The branches of the internal iliac artery are arranged in two groups: (1) a visceral set which supplies the walls of the hind-gut and the genital organs, and (2) a parietal set which is distributed to the body-wall and to the hind-limbs. The branches distributed to the gut probably represent the splanchnic vessels, more or less homologous with ordinary splanchnic branches of the primitive aortæ, and the parietal branches are possibly the homologues of intersegmental arteries.

Arteries of Limbs

In all probability the vessels of both the upper and the lower limbs are derived originally from several somatic intersegmental arteries, the majority of which, however, have atrophied. The upper limb is supplied in man by the lateral offset from the ventral branch of the seventh somatic intersegmental artery. It passes into the limb caudal to the shoulder girdle, courses through the upper arm, enters the cubital fossa, and is continued through the forearm, in the early stages, as the anterior interosseous artery, which ends in the deep palmar arch. At a later period, ontogenetically, a median artery appears as a branch of the parent stem, and it ends in a superficial palmar arch; still later the radial and ulnar branches are formed. The latter grow rapidly, soon exceeding in size the parent stem, and they terminate in the superficial and deep palmar arches. The interosseous and median arteries decrease, and generally lose their direct connexions with the palmar arches. The posterior interosseous artery also is a secondary branch from the parent stem, and the digital arteries are offsets from the palmar arterial arches (Fig. 1135, p. 1375).

The chief arteries of the lower limbs spring directly from the secondary roots of the umbilical arteries, and may be looked upon as being essentially intersegmental; whether they represent the whole or only parts of typical somatic intersegmental arteries, however, is not clear.

The arteries of the lower limbs certainly show no very obvious indications of division into dorsal and ventral branches, though such indications are not entirely wanting. In their comparative absence it is supposed that the dorsal branches have been either suppressed or incorporated with the common stems; that similarly the ventral branches and their lateral offsets are indistinguishably fused, and that probably both are represented in a limb-artery.

The original stem-vessel of the lower limb is the inferior gluteal artery, which is continued distally, posterior to the pelvic girdle, into the popliteal and peroneal arteries, and so to the sole of the foot, where it ends in a vascular plexus. Subsequently the external iliac artery is given off from the secondary root of the umbilical artery, dorsal to the origin of the inferior gluteal, and, passing into the limb anterior to the pelvic girdle, it becomes the greater part of the femoral artery. That vessel ultimately unites with the proximal part of the popliteal artery, and after the communication is established the distal part of the inferior gluteal atrophies and loses its connexion with the popliteal, which henceforth appears to be the direct continuation of the femoral trunk; therefore, whilst the main artery of the upper limb is formed by the prolongation of the lateral branch of one intersegmental artery, the corresponding vessel of the lower limb is developed from representatives of, probably, two somatic intersegmental arteries, the external iliac and femoral trunks being the representatives of one, whilst the popliteal and its continuation, the peroneal, are parts of another.

The first main artery of the leg, ontogenetically, is the peroneal, which is continued into the plantar arch; after a time, however, the posterior and anterior tibial branches appear. As a rule, they soon preponderate in size, and they terminate in the plantar arch, whilst the original trunk diminishes and loses its direct connexion with the arch (Fig. 1136).

The peroneal artery corresponds in position and development with the common interosseous trunk and the anterior interosseous artery in the forearm. The posterior tibial apparently corresponds with the median artery; it develops in a similar way, and has similar relations to

homologous nerves, the posterior tibial nerve representing the combined median and ulnar nerves of the upper limb.

The anterior tibial artery represents the posterior interosseous, whilst the radial and ulnar arteries of the upper limb are not represented in the lower limb (cf. Figs. 1135 and 1136).

MORPHOLOGY OF VEINS

The formation of the chief adult veins from the various longitudinal trunks which appear in the embryo has been described in the account of the development of the veins (pp. 1377-1384); and the transference of the terminations of the intersegmental veins from one position to another was noted.

In the discussion of the morphology of the arteries it was shown that the ventral branches of the intersegmental arteries are primitively connected by pre-costal and ventral anastomoses; the dorsal branches by post-costal and post-transverse anastomoses; the spinal offsets of the dorsal branches are linked together by post-central and pre-laminar anastomoses, and their neural branches by pre- and post-neural anastomoses.

Similar anastomoses are formed between the corresponding veins, but they tend in many cases to be plexiform, as in the case of the vertebral veins.

Remnants of pre-costal venous anastomoses are found in the adult as the ascending lumbar and lateral sacral veins; and ventral anastomoses are represented by the internal mammary, and the superior and inferior epigastric veins.

Post-costal anastomoses are represented by the vertebral veins, and post-transverse anastomoses by the deep cervical veins.

Pre-laminar and post-central anastomoses form the adult posterior and anterior longitudinal vertebral sinuses; and pre- and post-neural anastomoses give rise to the antero-lateral and postero-lateral veins of the spinal cord.

The morphology of the splanchnic veins corresponds closely with that of the splanchnic arteries, and does not require separate consideration.

Veins of Limbs.—The veins of the limbs, like the arteries, were probably at one time intersegmental in character, but we have no indisputable proof that this was the case. Looked at from an embryological standpoint, the most primitive limb-veins are a superficial distal arch and a post-axial trunk-vein in each limb; at a later period digital veins are connected with the distal arch, and a pre-axial trunk is formed. In the upper limb the distal arch and its tributaries remain as the dorsal venous arch and the digital veins, and the post-axial vein becomes the basilic, axillary, and subclavian veins. The pre-axial vein of the upper limb is represented in the adult by the cephalic vein; the latter vessel originally terminated in the external jugular vein, above the clavicle, the union with the axillary portion of the post-axial vessel being a secondary condition; the primary condition is, however, frequently retained in Man, and is constant in many monkeys. The anastomosis between the pre-axial and post-axial veins in the region of the elbow, and the connexion of the anastomosing channels, are brought about by newly formed vessels of secondary character.

The distal arch in the lower limb and the tributaries connected with it remain in the adult as the dorsal venous arch of the foot and the digital veins. The post-axial vein becomes the short saphenous vein, which was originally continued proximally as the popliteal and inferior gluteal veins to the internal iliac portion of the posterior cardinal vein.

The pre-axial vein of the lower limb becomes the long saphenous vein, which is continued proximally to the posterior cardinal portion of the left common iliac vein as the proximal part of the femoral and the external iliac veins.

The venæ comitantes of the arteries in both the upper and lower limbs are secondarily developed vessels which become connected with the upper portions of the pre-axial venous trunks.

VARIATIONS AND ABNORMALITIES OF VASCULAR SYSTEM

Variations are of special interest to the anatomist because of their morphological significance, and the vascular system is, perhaps more than any other, rich in such variations, many of which are of great practical importance.

With the exception of those irregularities which are directly due to the effect of morbid conditions and external influences, all variations are the result of modifications of normal developmental processes. The exceptions referred to are, however, very numerous; thus, disease and external influences may lead to the obliteration of vessels, a condition which is invariably associated with the enlargement of collateral vessels; and it is obvious that abnormalities so produced may occur in almost any situation.

Variations which are determined by, or are dependent upon, modifications of the usual developmental processes are of greater interest. In the human subject they are generally due either to the retention of conditions which, normally, are only transitory in ontogenetic development, or to the acquirement of conditions which, though not as a rule present at any time in Man, occur normally in some animals.

There are, in addition, other variations from the normal, such as the division of the axillary artery into radial and ulnar branches; the higher or lower division of the brachial artery; the

formation of "vasa aberrantia", *e.g.*, of long slender vessels that connect the axillary or brachial to the radial, ulnar, or interosseous arteries; the altered position of certain vessels, *e.g.*, the transference of the subclavian artery to the front of the scalenus anterior, or of the ulnar artery to the front of the superficial flexor muscles; all of which, though undoubtedly due to alterations of ordinary developmental processes, still do not represent any known conditions met with, either temporarily or permanently, in Man or in other animals. Their occurrence cannot at present be adequately explained, and their retention in the adult is dependent entirely upon their utility.

To the first and the last of these different groups of abnormalities it is not necessary to refer further, whilst, with regard to the rest, they have been already sufficiently indicated after the accounts of the heart and individual vessels. They cannot, however, be fully understood and explained except on the basis of a comprehensive knowledge of the development and morphology of the vascular system, to the paragraphs on which the reader is referred.

Abnormalities or variations of veins are more frequently met with than those of arteries, and they are due to similar causes. Those who require more detailed information should consult special monographs (Quain, 1844 ; Dubrueil, 1847 ; Adachi, 1928, 1933).

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LYMPHATIC SYSTEM

While the arterial system is the sole distributing agent, the veins are assisted by another set of absorbent vessels—the lymph-vascular system. The fluid absorbed by it—called **lymph**—contains numerous white corpuscles and is colourless except that from the intestinal canal, which appears milky during digestion because of its fatty content.

In structure the **lymph-vessels** resemble veins, but differ in the following ways. (*a*) the capillaries are wider and more irregular in calibre; (*b*) beyond the stage corresponding with venules the vessels are smaller than veins and have their valves

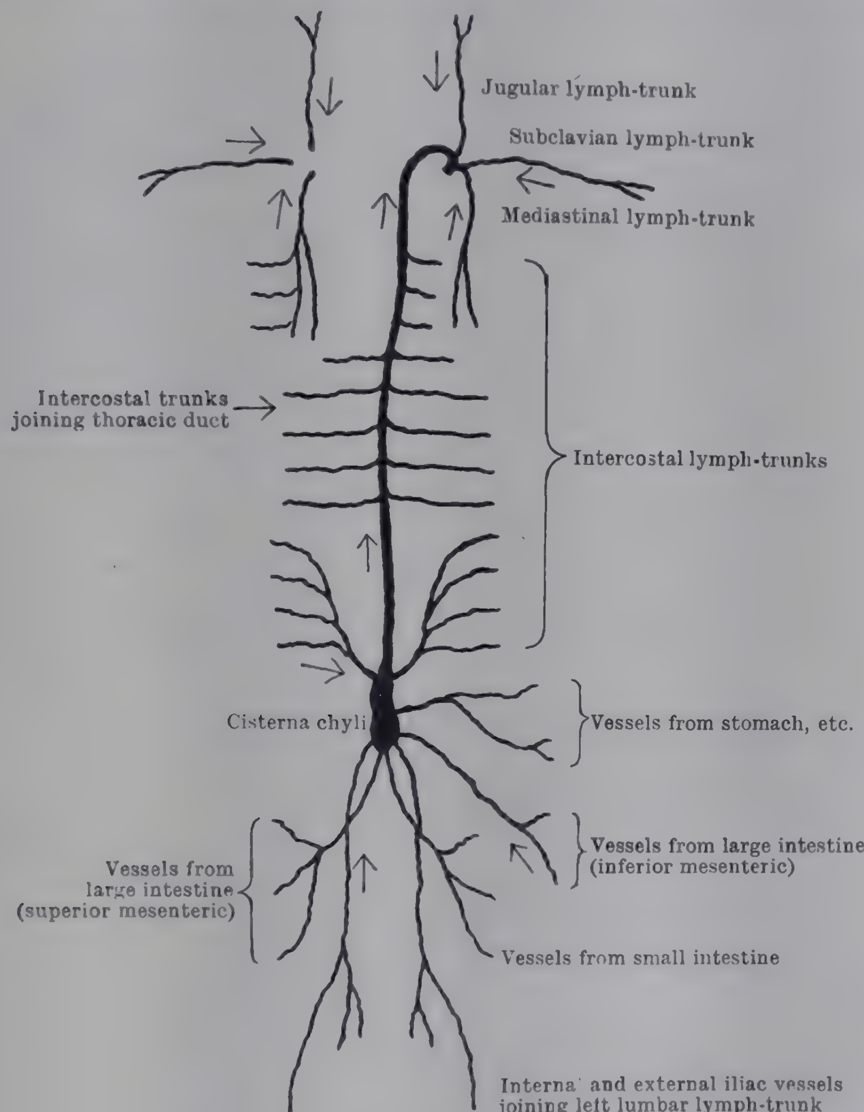

FIG. 1150.—DIAGRAM OF MAIN LYMPH-VESSELS.

so closely and regularly set that in distension they have a uniform beaded appearance—a distinguishing characteristic; (*c*) they run in streams with little tendency to form large trunks; (*d*) they are interrupted by nodular aggregations of lymphoid tissue called **lymph-glands**; (*e*) their distribution is limited, for they are absent not only from avascular tissues but also from the entire central nervous system, and possibly from muscle and bone.

The lymph-vessels merely collect and convey lymph; the lymph-glands serve in part as "filters"—arresting solid particles or bacteria which may be taken up by the lymph-vessels—and in part as the sources of origin of those lymph-corpuscles which are called **lymphocytes** and become white blood-corpuscles when they enter the blood-stream. In its course from the tissues to the blood-vessels most of the lymph passes through at least one lymph-gland, and generally more than one; direct delivery of lymph into the veins is very exceptional (see p. 1439).

The capillaries from which **lymph-vessels** arise are essentially sub-epithelial in position and are found abundantly in the skin, mucous membranes, all glands (including ductless glands), all serous membranes and synovial membranes.

The *superficial lymph-vessels* lie in the skin and subcutaneous tissues; they frequently accompany the superficial veins and, in the limbs, they join the deep vessels in definitely localized situations.

On each side of the body the cutaneous lymph-vessels converge from three large areas upon three groups of lymph-glands (Figs. 1151, 1152, 1178): (*a*) from the skin of the lower limb, perineum, external genital organs and the trunk below the level of the umbilicus—to empty into the lymph-glands in the groin; (*b*) from the skin of the upper limb and the trunk above the umbilicus to the level of the clavicle in front and halfway up the back of the neck behind—to the lymph-glands in the axilla; (*c*) from the scalp, face, and the rest of the neck—to the cervical glands.

The *deep lymph-vessels* drain the lymph from parts of the body which lie deep to the deep fascia. They tend to accompany the blood-vessels of the various parts and organs; those of the viscera, however, frequently take unexpected courses to reach the nearest lymph-glands.

The deep vessels of the limbs and trunk are relatively scanty and arise primarily in the synovial membranes of the joints. As cutaneous lymph-vessels may penetrate the deep fascia with the veins and run between muscles to join the deep stream, and as the lymph-vessels of mucous membranes have to burrow through the muscular structure of the organs from the tongue downwards, it may appear that lymph-vessels take origin in muscular tissue; but in relation to muscle they are probably mainly passengers. Lymph-capillary networks have, however, been described on tendons; and some observers believe that they occur also in the fibro-areolar tissues of muscle. Indeed, it has been stated that a capillary plexus exists around the fibres of striated muscle (Aagaard, 1913).

The **lymph-glands** also are divided into superficial and deep groups. The former lie in the superficial fascia and are comparatively few in number; they are associated more particularly with the superficial lymph-vessels of the limbs and the trunk. The deep glands of the limbs also are comparatively few in number, but those of the head, neck, and trunk are very numerous.

General Plan of Lymphatic System.—This may be set out as follows:—(1) The capillaries of origin form plexuses which underlie surface epithelia and surround the acini and ducts of glands. (2) From these networks larger vessels of the venule type pass more deeply and penetrate the subjacent tissue—whether superficial fascia, submucous and muscular coats, or stroma of a gland—in which they communicate freely in networks. (3) From these deeper networks arise the valved collecting vessels which run towards the lymph-glands. On reaching a lymph-gland the vessels, conveniently called **afferent vessels**, penetrate the capsule at numerous points. (4) The lymph-glands are stations in which the vessels are broken up into a labyrinth of active reticular tissue (p. 12) by which the fluid is treated in such a manner that a large part of it is absorbed by the venous network in the gland and only a residue is passed out by one or two lymph-vessels. (5) These are called **efferent vessels**, and they may run with afferent vessels into another gland of the same group or pass on to another group. (6) From the most central group of each chain of glands the efferent vessels unite to form **lymph-trunks** which are named: (*a*) *Lumbar*; (*b*) *Intestinal*; (*c*) *Intercostal*; (*d*) *Mediastinal*; (*e*) *Subclavian*; (*f*) *Jugular*. (7) Each trunk drains a definite territory of the body, and they all empty into great terminal vessels—the **thoracic duct** and **right lymphatic duct** (p. 1403)—which open into the great veins in the root of the neck (Fig. 1150).

By constant reduction of the stream of lymph as it passes through the chains of lymph-glands, the *lymph-trunks*, though draining large areas, are actually small vessels which easily escape notice in a dissection; and as most of the lymph absorbed from the body is thus restored to the circulation gradually, the residue, mainly derived from the intestines (*chyle*), is accommodated in the thoracic duct—no larger than a crow-quill.

Order of Description.—After the following general paragraphs on lymph-vessels and lymph-glands, the main lymph-vessels are described first, and then the position of the groups of glands and the arrangement of the vessels in each of the territories drained by the lymph-trunks, in the order given above. The student should note that these territories do *not* correspond precisely with the ordinary divisions of the body. Readers who desire a more detailed description

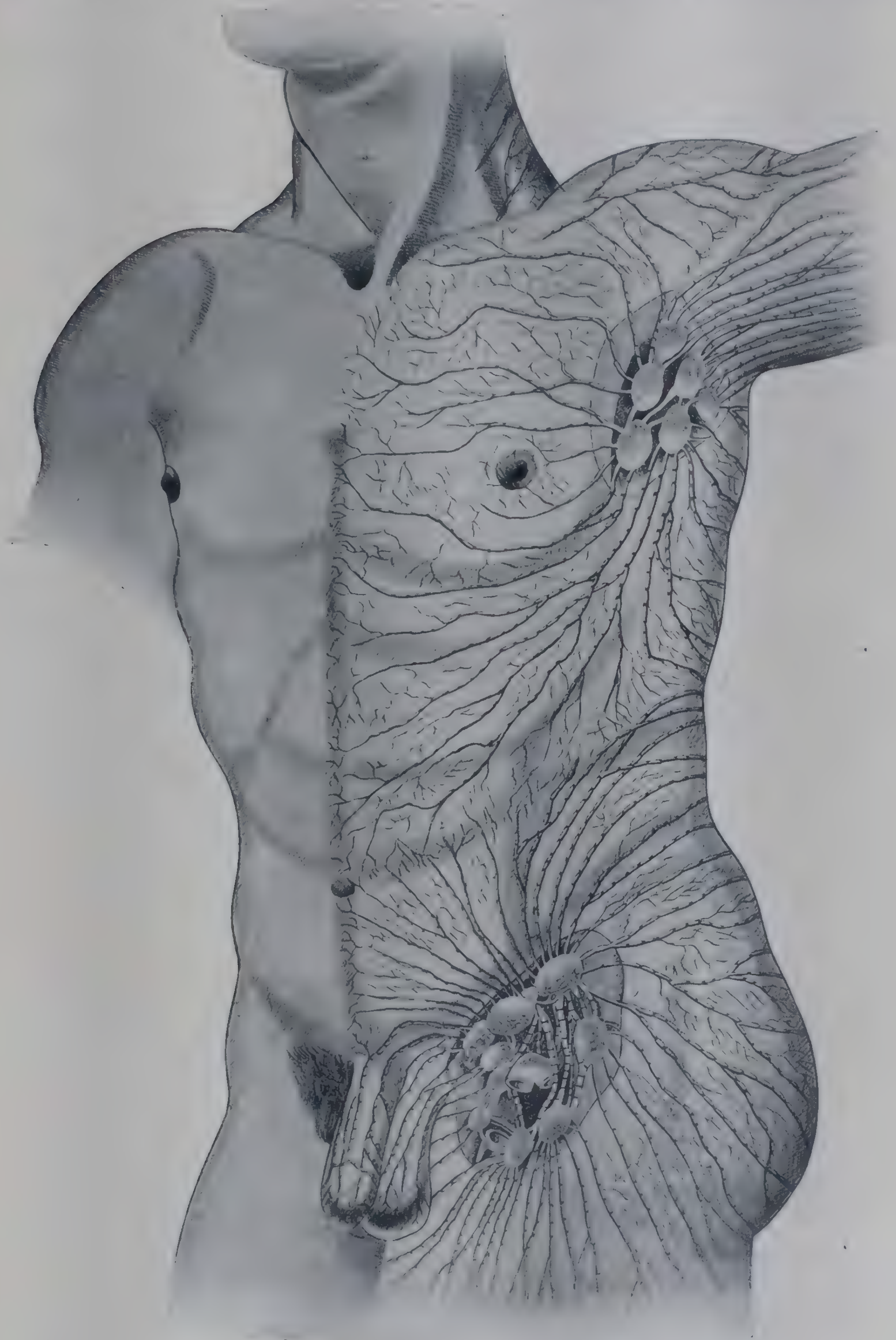

Fig. 1151.—Cutaneous Lymph-Vessels of Anterior Surface of Trunk. (After Sappey, 1874.) Note the "lymph-shed" between the vessels that pass to the axillary and to the inguinal lymph-glands.

of the topography and variations of the lymph-glands and lymph-vessels are referred to the standard works on the subject—Poirier & Cunéo (1902), or Leaf (1903); Bartels (1909); Rouvière (1932)—and to the papers quoted on special topics. For a critical account of the physiological and clinical significance of the lymphatic system in general, the monograph by Drinker & Yoffey (1941) should be consulted.

Lymph-Vessels.—The *capillaries* of origin are *closed*, having no communication with blood-vessels or with tissue-spaces. The stomata, by which they have been said

to communicate with serous cavities, are probably only patches of intercellular substance, and though fluid readily passes through serous membranes into the tissue-spaces, from which it is absorbed by the lymph-capillaries, there is no proof of a direct connexion. Lymph-capillaries are wider than blood-capillaries and more irregular in calibre ; but they have the same structure a single layer of endothelial cells through

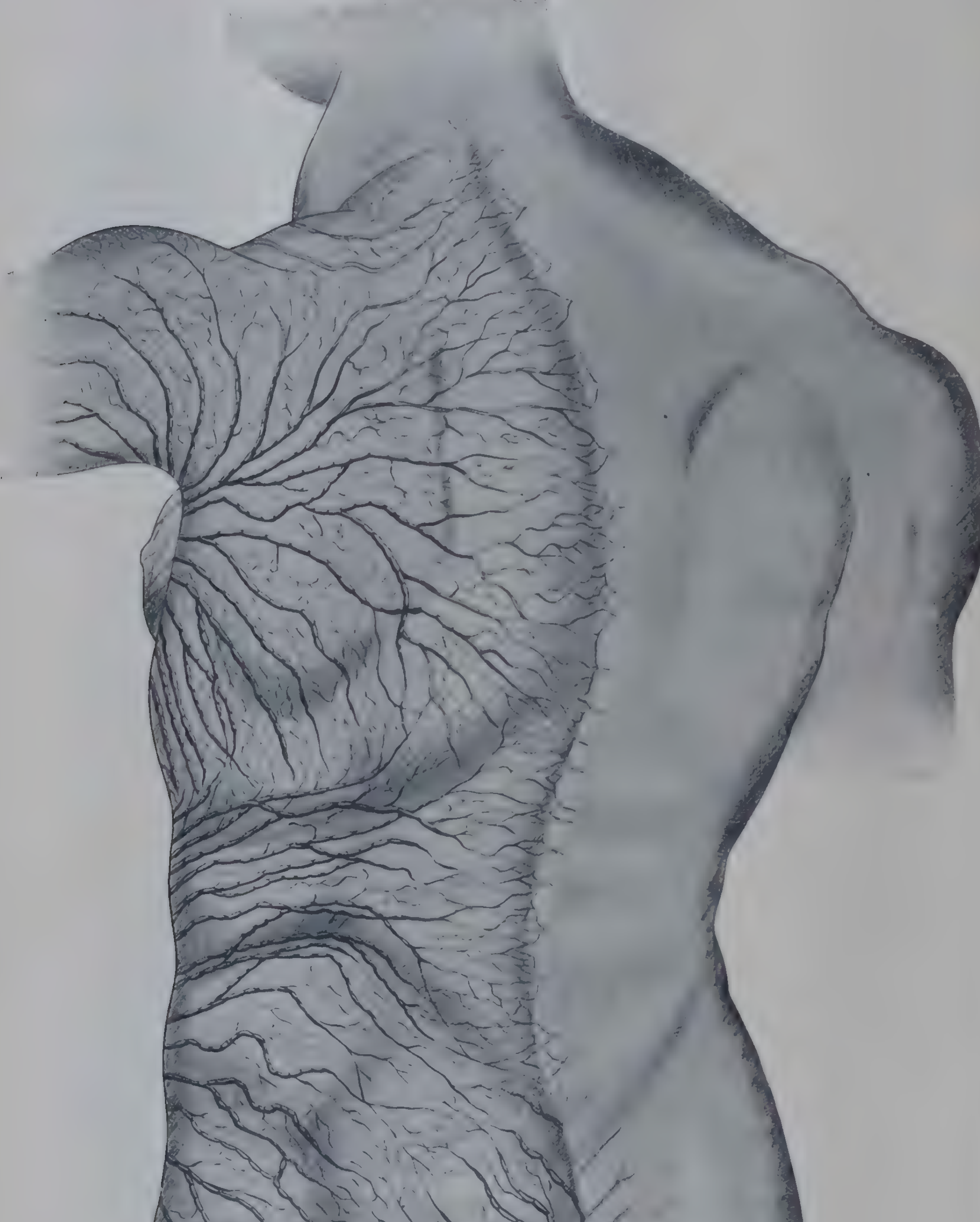

FIG. 1152.—CUTANEOUS LYMPH-VESSELS OF POSTERIOR SURFACE OF TRUNK. (After Sappey, 1874.) Note the "lymph-sheds" between the vessels that pass to the axillary and to the inguinal lymph-glands, and on the buttock between vessels that pass to the inguinal glands by lateral and by medial routes.

which lymph is absorbed from the tissue-fluid. Wandering phagocytic cells carry in solid particles (*e.g.*, carbon-dust and germs) which have entered the body through the skin or the mucous membranes.

From their subepithelial position lymph-capillaries are well placed to absorb the elements which form chalky, keratinous, and chitinous deposits and thus prevent their deposition in the

skin and in mucous, synovial, and serous membranes. There seems to be a relation between the evolution of the lymph-vascular system and the disappearance of the exoskeleton of lower forms; and nails and horns are found only in the positions which are the last to be reached by the lymph-vessels in the development of individuals.

Although the lymph-capillaries form an extensive network, it is probable that this is not continuous over large areas but arranged in more or less discrete patches from which there is selective absorption by larger vessels of the venule type. These vessels form wider-meshed networks in the skin, mucous membranes, etc., and from them vessels coalesce to form the collecting vessels.

The *collecting vessels*, as they run towards the lymph-glands, receive tributaries from a narrow area. They are small vessels, white in colour, and are distinguished by their characteristic beaded appearance due to valves of the venous type placed at close and regular intervals. They are joined by smaller, tributary vessels and frequently communicate with neighbouring collecting vessels, but, unlike the veins, they always run in streams of individual vessels rather than by confluence into larger trunks (see Fig. 1172). On reaching a gland each afferent vessel usually breaks up into smaller branches which penetrate the capsule. The issuing, efferent vessels are only slightly larger than the afferent vessels and have the same structure. Owing to the valves, the collecting lymph-vessels can be injected only by thrusting a hollow needle into the plexus of origin and pumping in metallic mercury (used by early investigators) or a colouring fluid that flows freely (Gerota, 1896; Jamieson & Dobson, 1910 *b*). Small patches only are injected from each puncture, and thus a large number of injections is required for a picture such as is given by a single injection into an artery.

As the lymph-vessels attain a larger size, their walls are strengthened by a layer of elastic fibres on the outer surface of the endothelial coat. The fibres run longitudinally, and in some cases fuse together to form a fenestrated elastic membrane.

The walls of all the largest lymph-vessels resemble those of veins and have three coats. The **inner coat** is a layer of endothelium covered externally by elastic fibres or a fenestrated elastic membrane. The **middle coat** is formed of transverse and oblique plain muscle-fibres, intermingled with elastic fibres. The **outer coat** consists of longitudinal fibrous tissue elements with which oblique and longitudinal plain muscle-fibres are intermingled; the latter feature is not met with in the blood-vascular system, except in the walls of some of the larger veins (p. 1224).

The bicuspid valves of lymph-vessels are semilunar folds of the inner coat similar to those of veins. They are extremely numerous in the collecting vessels and are present also near the entrances of the great lymph-channels into the venous system.

Lymph-Glands.—These are nodules varying in size from a pin's head to an almond; they are usually ovoid but may be globular, flattened, or irregular in shape. The larger glands show a depressed area, known as the *hilum*, through which the blood-vessels enter and the efferent lymph-vessel emerges. The consistence is firm and the colour is usually greyish pink, but the tint varies with the position, vascularity, and state of activity of the gland. The lymph-glands of the lungs are commonly blackened by deposit of carbon particles and those of the liver and spleen are often brownish; those of the mesentery are creamy or white while the chyle is passing through in quantity.

The lymph-glands lie in loose areolar tissue, generally in groups but occasionally single. As they develop, the great majority are found in association with the primitive digestive canal in the pelvis, abdomen, thorax, and neck, and in the roots of the limb-buds (axilla and groin). With the exception of the superficial inguinal glands, very few lie in the plane of the superficial fascia. A few small glands stray along the blood-vessels into the limbs, into the intercostal spaces and the intervals between the lumbar transverse processes, along the internal mammary artery behind the costal cartilages, and along the occipital, posterior auricular, and facial arteries; but all these are outposts of the main groups which lie deeply in the neck and trunk, for the most part by the sides of the great blood-vessels.

The structure of lymph-glands is such that they tend to arrest for a while the central spread of malignant, cancerous tumours, cells from which may be passing or growing along the lymph-vessels. This is the most important reason why exact knowledge of the situation of the lymph-glands to which the lymph-vessels of any region or organ may run is essential for surgical practice.

Structure of Lymph-Glands.—Lymph-glands consist essentially of: (1) masses of lymphoid tissue, supported by (2) a fibrous framework including an external capsule and internal trabeculæ separated from the lymphoid tissue by (3) spaces called lymph-sinuses. Each gland is separable also into cortex and medulla. The *cortex* lies immediately internal to the capsule, except at

the hilum, where it is absent. The *medulla* forms the internal part of the gland and reaches the surface at the hilum.

The **capsule** is formed of white fibrous tissue interspersed with elastic fibres; it contains some plain muscle-fibres which extend into the trabeculæ.

The **trabeculæ** spring from the deep surface of the capsule and radiate through the cortex into the medulla, where they are broken up to form a coarse, supporting network.

The **lymph-sinuses** lie internal to the capsule and around the trabeculæ; and they separate both from the lymphoid tissue. The afferent lymph-vessels of the gland pierce the capsule and enter the subcapsular sinus, from which branches pass inwards along the sides of the trabeculæ. The sinuses are traversed by fine fibrous tissue strands, and their channels are thus converted into a kind of sponge-work through which the lymph percolates into and through the lymphoid tissue. The lymph is ultimately collected by one or two efferent vessels which emerge from the medulla at the hilum.

The **lymphoid tissue** is continuous throughout the gland; but in the cortex it appears as rounded masses—*lymphoid nodules*—and in the medulla as branching and uniting strands known as *lymphoid cords.* Capillary-like lymph-spaces pass from the lymph-sinuses into the lymphoid tissue; and the endothelial lining becomes gradually converted into a *reticulum* of active phagocytic cells. It is through the meshes of this reticulo-endothelial tissue (p. 12) that the lymph has to pass on its way from afferent to efferent vessels, taking up *lymphocytes* from the masses of these cells with which the meshes of the reticulum are crowded.

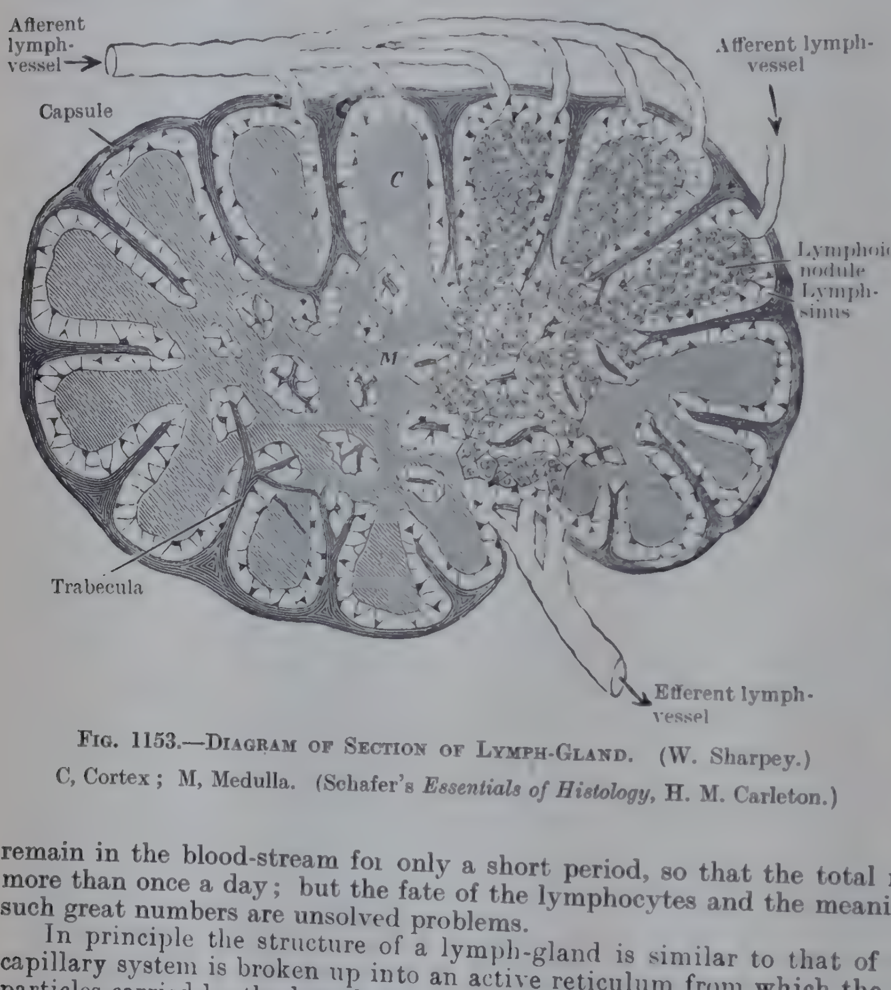

Fig. 1153.—Diagram of Section of Lymph-Gland. (W. Sharpey.)
C, Cortex; M, Medulla. (Schafer's *Essentials of Histology*, H. M. Carleton.)

One of the principal functions of the lymph-glands is the production of lymphocytes which enter the blood through the thoracic duct in prodigious numbers, to be reckoned in thousands of millions per day (Yoffey, 1933, 1936). The lymphocytes remain in the blood-stream for only a short period, so that the total number may be replaced more than once a day; but the fate of the lymphocytes and the meaning of their production in such great numbers are unsolved problems.

In principle the structure of a lymph-gland is similar to that of the spleen, in which the capillary system is broken up into an active reticulum from which the veins reform. Insoluble particles carried by the lymph to a gland are taken up by the phagocytic reticular cells, and may be permanently encapsuled in the gland.

Blood-Vessels of Lymph-Glands.—Small arteries are distributed to the capsule and through the capsule to the trabeculæ of the glands; but the main artery enters the hilum and breaks up into branches which follow the trabecular network of the medulla and enter the lymphoid nodules and cords, where they end in capillaries. The veins emerge at the hilum (Fig. 1049).

Hæmal Lymph-Glands.—In various parts of the body, but more particularly in the retro-peritoneal region, and especially along the line of the abdominal aorta, a number of glands may be found which differ from ordinary lymph-glands in that some of their sinuses contain blood (p. 1440). They are called hæmal lymph-glands; the sinuses which contain lymph are in continuity with lymph-vessels, whilst the blood-filled sinuses open into blood-vessels.

Solitary Lymphatic Nodules.—Pin-head collections of lymphoid tissue, consisting of a reticulum enmeshing lymphocytes, are found in the mucous coat of the alimentary canal. They appear to be set in the path of lymph-vessels proceeding from the capillary plexus of origin and may be deemed to be lymph-glands in miniature. These *solitary lymphatic nodules* resemble the lymphoid nodules in the cortex of lymph-glands. In the pharynx there are great aggregations of units which form tonsils; in the ileum many of the nodules

coalesce to form elongated raised patches (*aggregated lymphatic nodules*); and in the vermiform appendix they form masses which constitute the most striking feature of its structure.

Rudimentary Lymph-Glands.—In the path of lymph-vessels before they reach the regional glands there are frequently minute nodules which interrupt one or two vessels

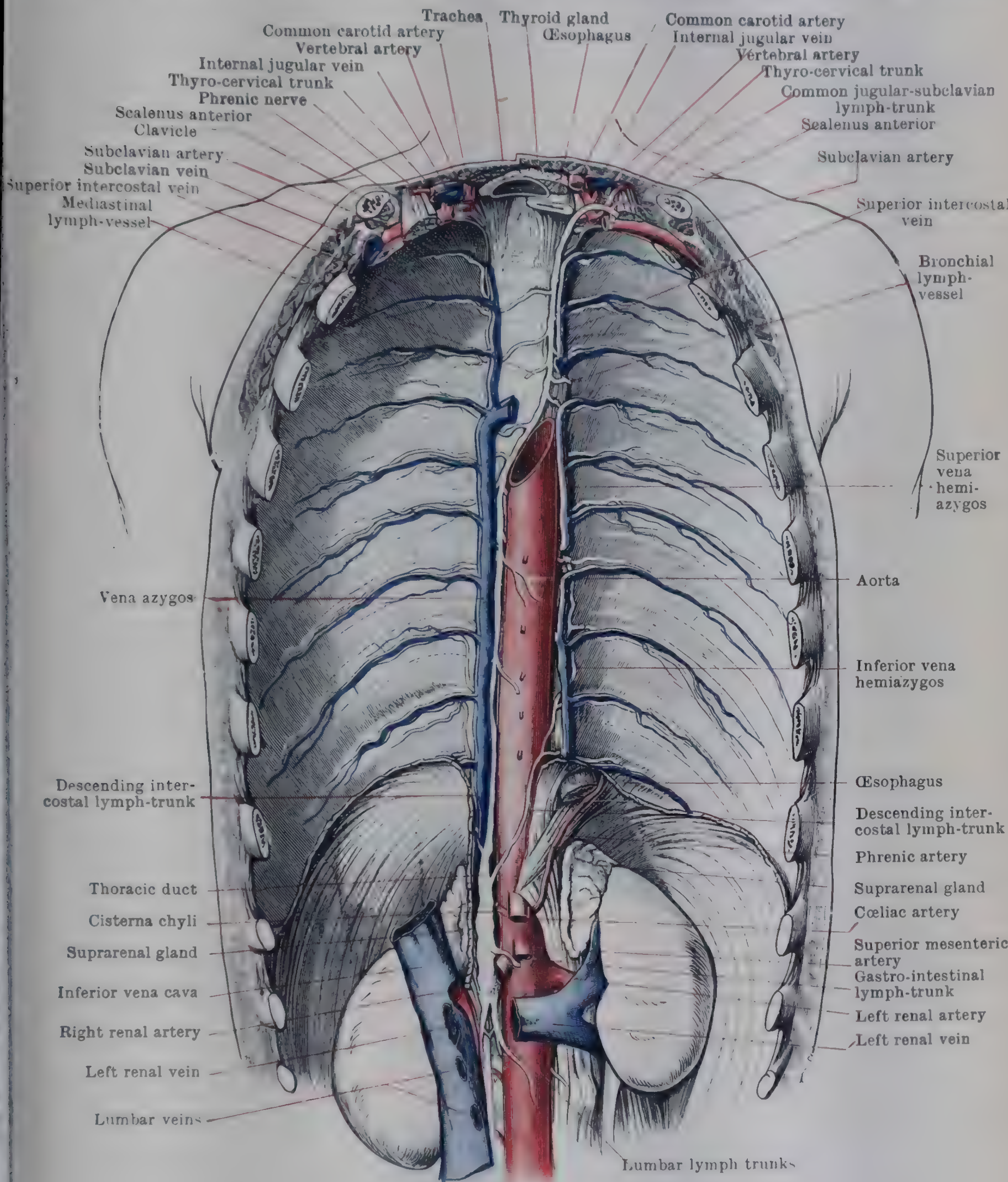

FIG. 1154.—THORACIC DUCT AND ITS TRIBUTARIES.

only. They are tiny lymph-glands in which only a few lymphoid units are involved: examples are the glands on the tibial vessels, deep vessels of forearm, tongue, etc. In some situations these minute glands become recognizable only during functional activity, *e.g.*, in the axilla during lactation.

TERMINAL LYMPH-VESSELS

The terminal lymph-vessels are the **thoracic duct** and the **right lymphatic duct** (or the vessels that represent it).

The **thoracic duct** is by far the wider and the longer of the two. It begins in the abdomen as an elongated, ovoid dilatation—the **cisterna chyli**—which measures $\frac{1}{4}$ to $\frac{1}{3}$ of an inch (6 to 8 mm.) in its broadest diameter, and from 2 to 3 inches (50 to 75 mm.) in length. The cisterna chyli lies between the aorta and the right crus of the diaphragm, and opposite the first and second lumbar vertebræ. Passing upwards from the cisterna, through the aortic opening of the diaphragm, the thoracic duct enters the posterior mediastinum, and ascends, on the front of the vertebral column, to the right of the median plane, to the level of the fifth thoracic vertebra; it then crosses from the right to the left of the median plane, and ascends through the superior mediastinum to the root of the neck, where it turns laterally behind the carotid sheath and

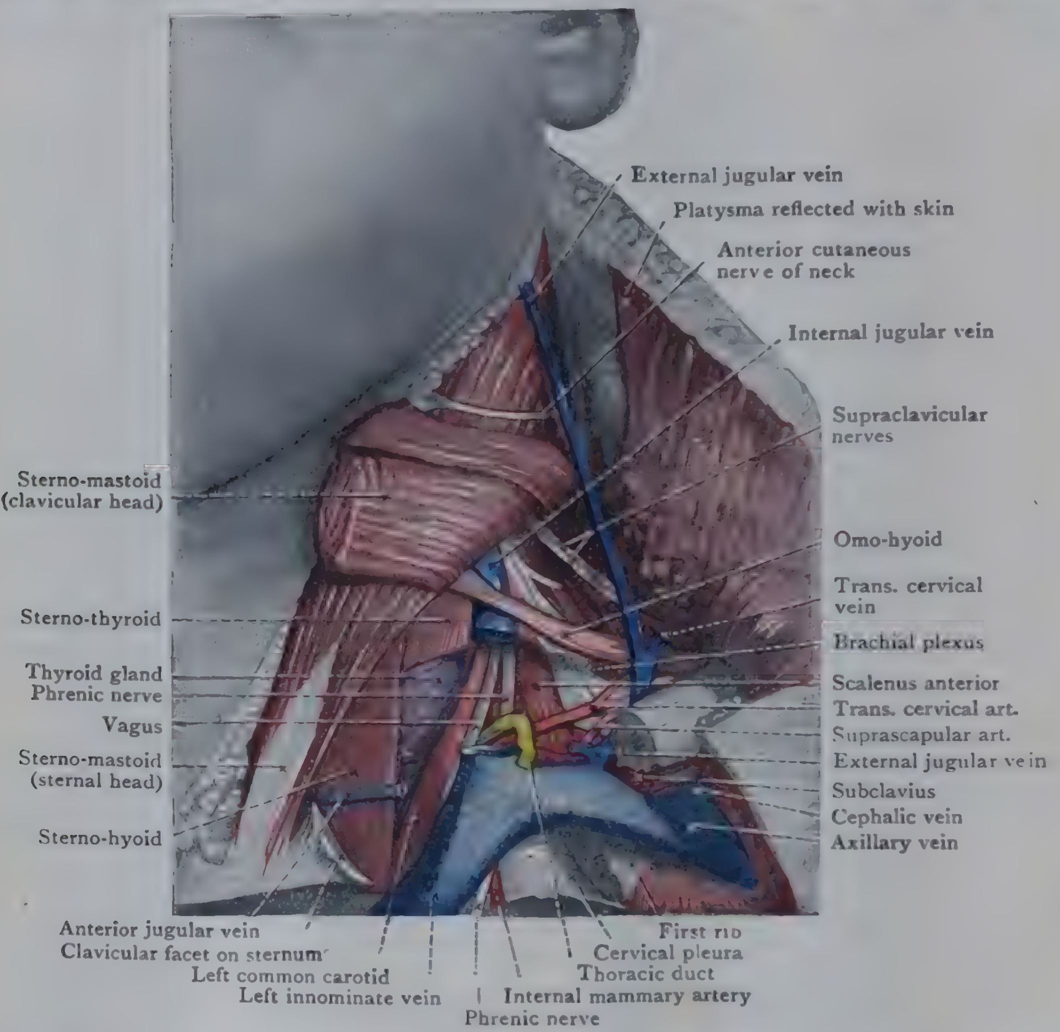

Fig. 1155.—Deep Dissection of Root of Neck on Left Side to show Cervical Pleura and Relations of Thoracic Duct.

Parts of the sterno-mastoid and the sterno-thyroid have been removed.

then descends across the subclavian artery to end at the medial border of the left scalenus anterior by joining the left innominate vein in the angle of junction of the internal jugular and the left subclavian veins.

The thoracic duct is about 18 inches (45 cm.) long, and about a line (2 mm.) in diameter, but it is rather wider at its origin from the cisterna. It may divide and reunite in its course through the thorax, and its terminal part is often broken up into a number of branches which end separately in the great veins. It is provided with numerous valves arranged in pairs, the most perfect of which is near its termination.

Relations.—*In the abdomen*, the cisterna chyli lies anterior to the upper two lumbar vertebræ and the corresponding right lumbar arteries, between the aorta on the left and the vena azygos and the right crus of the diaphragm on the right. *In the posterior mediastinum*, the thoracic duct is separated from the vertebral column and the anterior longitudinal ligament by the right posterior intercostal arteries and the transverse parts of the hemiazygos veins; it is covered, in front, in the lower part of its extent by the diaphragm and the

right pleura, and in the upper part by the œsophagus; to its right is the vena azygos, and to its left the descending aorta. *In the superior mediastinum* it passes forwards from the vertebral column and it is separated from the left longus cervicis muscle by a mass of fatty tissue; the œsophagus lies in front of it in that region, but the left margin of the duct projects beyond the œsophagus, and is in relation anteriorly, and from below upwards, with the arch of the aorta, the left subclavian artery and the pleura. As the duct enters the root of the neck it passes behind the left common carotid artery, whilst to its right and a little in front is the œsophagus, and the left pleura is still in association with its left border.

At the root of the neck it arches laterally in front of the apex of the pleura and then downwards across the first part of the left subclavian artery. It passes in front of the vertebral artery and vein, the roots of the inferior thyroid, transverse cervical, and suprascapular arteries, the medial border of the scalenus anterior and the left phrenic nerve, and behind the left carotid sheath and its contents (Fig. 1155).

Tributaries.—The cisterna chyli commonly receives five tributaries:—(1) The **intestinal trunk**, which is formed by the efferents of the superior mesenteric and cœliac groups of lymph-glands, and conveys lymph from the lower and anterior part of the liver, the spleen, the pancreas, the stomach, the small intestine and the greater part of the large intestine. (2) A pair of **lumbar trunks**, formed by the efferents of the aortic glands, carry lymph from the whole of the skin below the level of the umbilicus, from the deep portions of the lower limbs, the lower abdominal and the pelvic walls, from the rest of the large intestine and the pelvic viscera, and from the kidneys, suprarenal glands and genital glands. (3) A pair of **descending intercostal lymph-trunks**, formed by the efferent vessels from the lower intercostal glands (see p. 1423), descend to the cisterna through the aortic opening of the diaphragm. Occasionally they unite to form a single trunk, and sometimes they, or some of the tributaries from which they are usually formed, open directly into the thoracic duct (Fig. 1154).

In its course through the posterior mediastinum the thoracic duct receives efferents from the posterior mediastinal glands and such of the intercostal glands as do not send their efferents into the descending trunk; through the posterior mediastinal glands it receives lymph from the œsophagus and the back of the pericardium, and also some from the upper and posterior part of the liver.

In the superior mediastinum the efferents of the upper intercostal glands of both sides open into it; it may receive also communications from the mediastinal lymph-trunks of both sides.

At the root of the neck, immediately before its termination, it may receive: (1) the efferents from the glands of the left upper limb, which frequently unite to form a **subclavian trunk**; and (2) the **left jugular trunk**, which conveys the lymph from the left side of the head and neck; but either of those vessels or both of them may end separately in the innominate or the subclavian vein. The **left mediastinal trunk** is rarely a tributary of the thoracic duct in the neck; almost invariably it has an independent entrance into the left innominate vein. It collects lymph from the deeper parts of the anterior thoracic wall and of the upper part of the anterior abdominal wall and from the anterior part of the diaphragm on the left side, from the left half of the mediastinum, the left side of the heart and the left lung.

The **right lymphatic duct** (Fig. 1156) is not always present. Indeed, it rarely exists as such, since the three vessels which occasionally unite to form it usually open separately into the right internal jugular, subclavian, and innominate veins. These vessels are (1) the **right jugular trunk**, (2) the **right subclavian trunk**, and (3) the **right mediastinal trunk**. It is not uncommon for the jugular and subclavian trunks (conveying lymph from the right side of the head and neck and from the right upper limb respectively) to unite, as on the left side, before entering the veins at the point corresponding to that at which the thoracic duct enters on the left side; and this is the commonest form of "right lymphatic duct". The right mediastinal trunk, which collects lymph from an area corresponding to that drained by the left vessel, but including also the upper part of the right lobe of the liver, almost invariably enters the right innominate vein separately: but even in the rare event of its union with the other two trunks the resulting *right*

lymphatic duct does not correspond to the thoracic duct but only to the united tributaries which the thoracic duct also receives.

Variations.—The **cisterna chyli** may be very irregular or may be replaced by a plexus of vessels, formed by the intestinal and lumbar lymph-trunks, from which the thoracic duct takes origin by several roots.

The **thoracic duct** in its course through the thorax frequently divides into two unequal branches which may run side by side for some distance before reuniting; or it may even be broken up into a plexiform arrangement of lymph-vessels. It may end in a number of branches which enter the great veins separately; and it sometimes divides in the upper part of the thorax into two stems, of which the right joins the right jugular trunk to form one variety of the right lymphatic duct (Fig. 1156). The thoracic duct may end in either the internal jugular or the subclavian vein, or even in the vertebral vein; whilst very rarely it may open into the vena azygos.

The arrangement and mode of termination of the **three lymph-trunks—subclavian, jugular, mediastinal**—found in the root of the neck on each side are very variable indeed. They may all open separately into one or other of the great veins; or they may unite together in a variety of ways. Their number may be increased by division of one of them, or by some of their tributaries ending independently—for example, the main efferent of the internal mammary lymph-glands may fail to join the mediastinal trunk. On the left side, the mode of ending is influenced, in addition, by the presence of the thoracic duct, which, as noted, may itself break up into several divisions. The following statement may thus be taken as indicating only what are probably the commonest arrangements of the trunks.

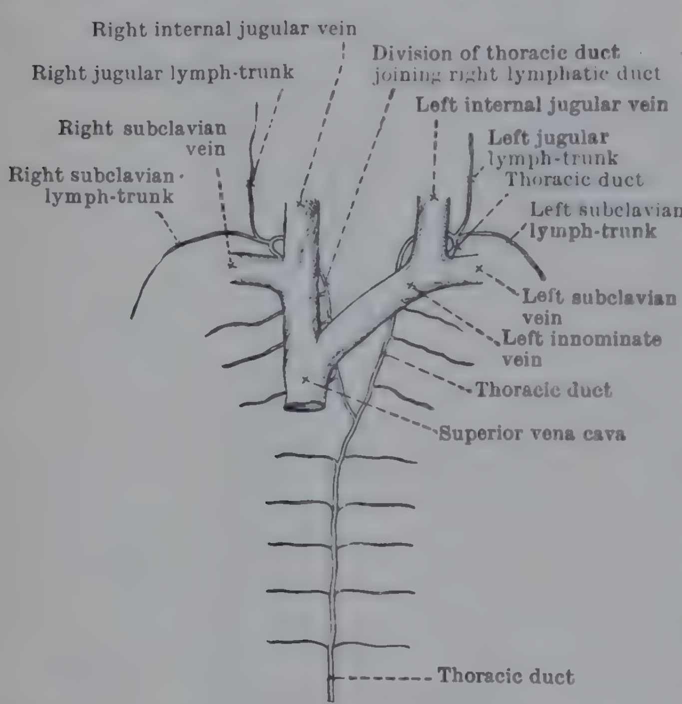

Fig. 1156.—Diagram showing Variation in Ending of Thoracic Duct.
The mediastinal lymph-trunks are not represented.

On the left side the jugular trunk ends in the thoracic duct, and the other two trunks may do so also; but the subclavian trunk often ends in the subclavian vein, and the mediastinal trunk usually ends in the innominate vein.

On the right side the subclavian, jugular, and mediastinal trunks usually have separate entrances into the subclavian, internal jugular, and innominate veins respectively. But it is not uncommon for the subclavian and jugular trunks to unite at the medial margin of the scalenus anterior above the subclavian artery. The resulting vessel is called the *right lymphatic duct*. In rare cases the mediastinal trunk also joins the duct; and its internal mammary tributary may have independent entrance into the innominate vein.

LUMBAR LYMPH-TRUNKS

The **lumbar lymph-trunks** receive the lymph from the lower limbs, the perineum and external genital organs, the abdominal wall below the level of the umbilicus, the urogenital system in the pelvis and abdomen, and the part of the digestive tract supplied by the inferior mesenteric artery. In maintaining the idea of the continuity of this great lymph-stream it is necessary to trespass over the boundaries of the usual divisions of the body, since, for example, a true picture of the drainage of the skin of the area cannot be obtained by a description of the lymph-vessels of the lower limb alone.

Superficial Lymph-Glands of Lower Limb

The **superficial inguinal lymph-glands** (Figs. 1151 1157) lie in the subcutaneous fat below the inguinal ligament, and extend downwards on each side of the long

saphenous vein for a few inches. They are arranged in a *proximal* set (5-6) below and parallel with the ligament and a *distal* set (4-5) associated with the vein. Each set may be divided into medial and lateral parts, but, as all these glands are freely interconnected, they are best considered as one T-shaped group. Their *afferents* are derived from the skin of the whole body below the level of the umbilicus and from the lining membranes of the anal canal and of the penile portion of the spongy part of the urethra, or, in the female, of the vulva and lower end of the vagina. In the female they receive also one or two vessels from the uterus which run along the round ligament through the inguinal canal. The

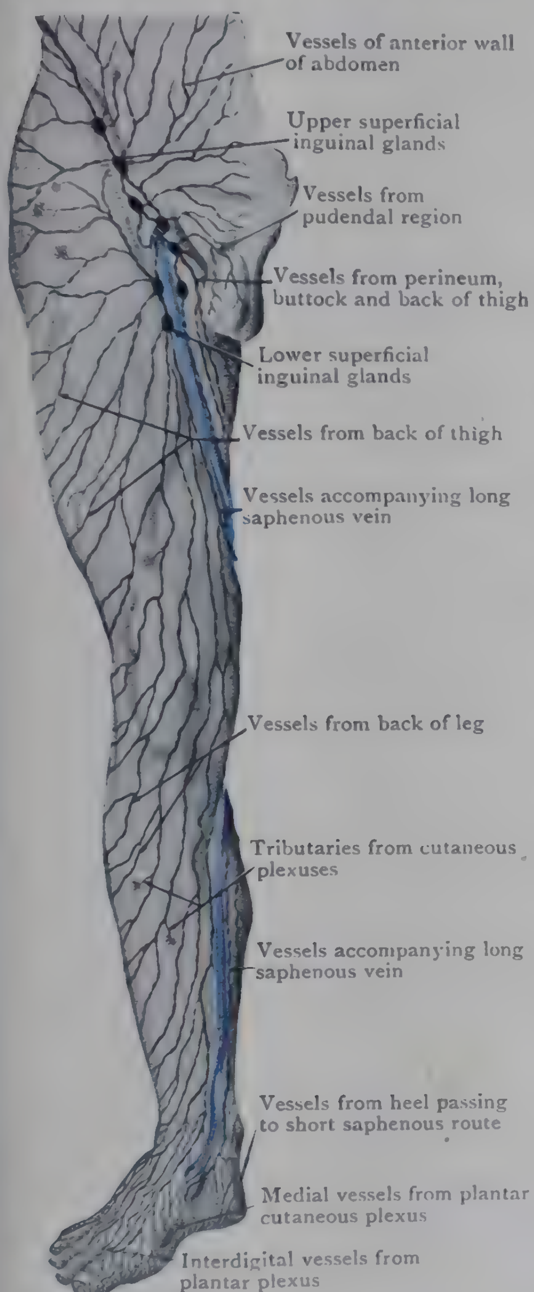

Fig. 1157.—Superficial Lymph-Vessels of Front of Lower Limb.

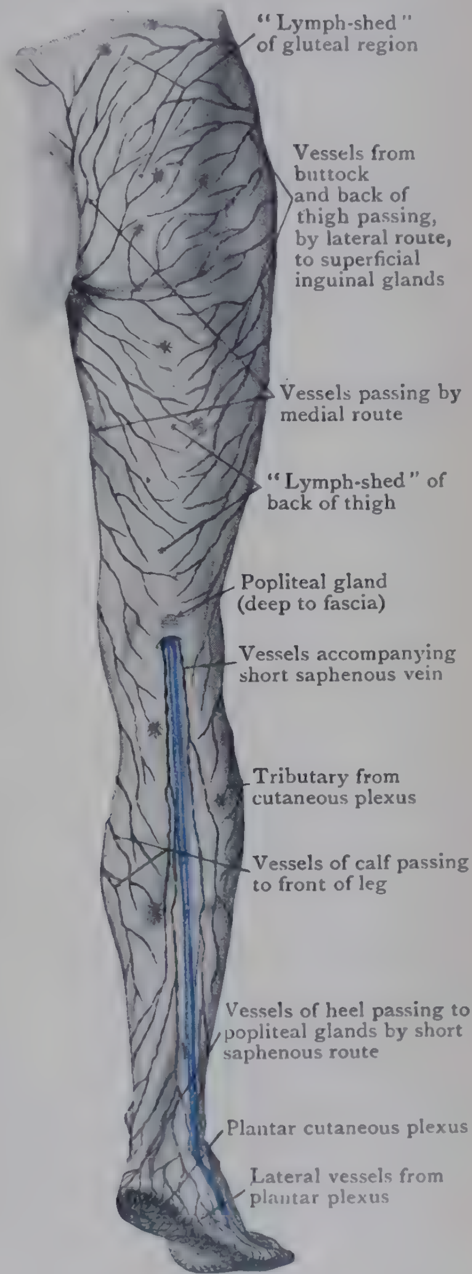

Fig. 1158.—Superficial Lymph-Vessels of Back of Lower Limb.

efferents pass deeply through the cribriform fascia and, though some enter the deep inguinal lymph-glands, most of them pass upwards through the compartments of the femoral sheath, mainly the femoral canal, to end in the glands on the external iliac artery.

Superficial Lymph-Vessels of Lower Limb and Trunk

The **superficial lymph-vessels of the territory of the lumbar trunk** arise in the capillary network of the skin, from which the collecting vessels stream from a wide area toward the groin. The main stream begins in the foot, follows the direction of the long

the lateral and medial borders of the leg and thigh from the back and sides of the limb. Towards the root of the limb the vessels run almost horizontally; the lateral vessels of the buttock sweep round below the iliac crest and are succeeded by a descending stream from the back, sides, and front of the abdominal wall below the level of the umbilicus: on the medial side a stream descends from the back of the sacrum and the natal cleft, is joined by some vessels from the medial third of the buttock, by the perineal, anal, and scrotal or vulvar lymph-vessels, and turns laterally in the superficial fascia that overlies the adductor longus: and, lastly, the lymph-vessels of the penis, including those of the penile urethra, complete the great whorl (Figs. 1151, 1152, 1157, 1158).

Certain exceptions and peculiarities must be noted: (*a*) a few lymph-vessels from the skin over the area of the short saphenous vein accompany that vessel into the popliteal glands; (*b*) at several points lymph-vessels leave the superficial stream and are conducted along the blood-vessels through the deep fascia to join the deep stream; (*c*) the lymph-vessels of the skin of the penis accompany those of the scrotum but those of the glans follow the deep dorsal vein till in contact with the pubis; there, the majority turn laterally to reach the superficial inguinal glands, but a few accompany the vein under the pubic arch into the pelvis. As the lymph-vessels of the glans run towards the pubis they receive numerous tributaries which emerge from the urethra along the ventral median line and encircle the organ. The student should note that these vessels were formed when the urethra was a groove on the surface and have been turned in by the closure of the groove; (*d*) the testis does *not* send lymph-vessels to the superficial inguinal glands.

The arrangement of the superficial lymph-vessels of the toes and the foot is very similar to that met with in the fingers and the hand (p. 1429). From plexuses on the plantar surface vessels pass to the dorsum of the foot and toes, where they unite into a number of vessels, the majority of which accompany the long saphenous vein and end in the distal group of superficial inguinal glands. Some of the lymph from the lateral part of the plantar surface and from the lateral border of the foot, and the lymph from the heel, enter vessels which accompany the short saphenous vein; these end in the popliteal glands (Fig. 1158).

Deep Lymph-Glands and Lymph-Vessels of Lower Limb

The deep lymph-glands and lymph-vessels of the lower limb are associated with the blood-vessels. The deep glands of the lower limb are few and small. The **anterior tibial lymph-gland** is a small nodule on the upper part of the interosseous membrane; usually minute or immature, it is occasionally large enough to be detected in a dissection. It interrupts the course of one of the deep lymph-vessels.

The **popliteal lymph-glands** (6 or 7) are small nodules, of the size of wheat grains, most of which lie in the popliteal fat alongside the great blood-vessels. A more superficial gland lies under the deep fascia on the upper end of the short saphenous vein and receives the cutaneous lymph-vessels which accompany it (Fig. 1158). Those alongside the popliteal blood-vessels receive the anterior and posterior tibial lymph-vessels and others which issue from the knee joint with the lateral and medial genicular blood-vessels: one gland lies on the surface of the posterior ligament of the knee joint and receives the lymph-vessels which issue along the middle genicular blood-vessels. The *efferents* of the popliteal glands pass upwards to form the deep femoral lymph-vessels which end in the deep inguinal glands.

The **deep inguinal lymph-glands** (Figs. 1160, 1162, 1163) are situated on the medial side of the femoral vein. They are small glands, one to three in number, and are difficult to demonstrate. Of these, one below the femoral canal is the most constant, one in the canal is occasional, and one in the femoral ring is frequently found. They receive all the deep vessels in the region of distribution of the femoral artery, including vessels from the front of the hip joint and a few from the glans penis and urethra which have followed the track of the deep external pudendal artery. Their *efferents* pass to the external iliac glands.

The **deep lymph-vessels** of the lower limb arise from capillary networks in the synovial membranes of joints and tendon-sheaths, and follow the main blood-vessels. They are joined by some cutaneous lymph-vessels from the limb and penis which have passed deeply along the cutaneous blood-vessels. Many of the vessels from the leg and foot end in the popliteal glands, but some pass directly to the deep inguinal glands in which also deep vessels of the more proximal parts end. The deep lymph-vessels of the gluteal region and perineum accompany branches of the internal iliac artery into the pelvis and will be noted in the next section.

Lymph-Vessels of Anterior Wall of Abdomen

The **lymph-vessels of the anterior wall of the abdomen** may be briefly reviewed at this point. Since they pass in different directions and ultimately discharge not only into the *lumbar lymph-trunk* but also into the *subclavian* and *mediastinal* lymph-trunks, their description is to be found in the sections dealing with these respective trunks.

The *superficial lymph-vessels* of the upper part of the anterior wall of the abdomen go mainly to the anterior or pectoral group of axillary glands; but some pierce the wall of the lower part of the thorax and end in the internal mammary glands. Those of the lower part of the abdominal wall end in the proximal group of superficial inguinal glands (Fig. 1151).

The *deep lymph-vessels* of the upper part of the anterior abdominal wall accompany the superior epigastric blood-vessels and end in the internal mammary glands. Those of the lower part accompany the inferior epigastric and deep circumflex iliac vessels, and end in the inferior external iliac glands (see below). Small lymph-glands are often found interrupting these deep lymph-vessels.

Lymph-Vessels of External Genital Organs

The **lymph-vessels of the scrotum** or of the **vulva** pass to the proximal superficial inguinal glands, and mostly to the medial group.

The **superficial lymph-vessels of the penis** go to the medial glands of the proximal superficial inguinal group. The **deep lymph-vessels of the penis**, including those of the penile portion of the urethra, end either in the medial glands of the proximal superficial inguinal group or in the deep inguinal glands. A few vessels follow the deep dorsal vein, and join the rich outflow of the prostate to the internal iliac glands. The **lymph-vessels of the clitoris** end like those of the penis.

Lymph-Glands of Pelvis

The lymph-glands of the pelvis may be grouped according to their position in association with blood-vessels: (1) *external iliac* in succession to the inguinal lymph-glands; (2) *internal iliac* with sub-groups associated with the branches of the artery; and (3) *common iliac*. (Figs. 1159, 1160, 1162.)

The **external iliac lymph-glands** (8-10) form three incomplete chains—lateral, intermediate, and medial—which lie along the external iliac vessels. The largest members are found on the lower end of the blood-vessels—usually one in front, one on the medial side, and one on the lateral side; each of these may be single or may be accompanied by smaller glands. A few are scattered along the blood-vessels at higher levels. They receive the efferents of the inguinal glands, superficial and deep, the deep lymph-vessels of the lower part of the anterior abdominal wall—interrupted by small outlying members of the group, *inferior epigastric glands* and *circumflex iliac glands*—and a number of afferents *direct* from the pelvic viscera. Their *efferents* pass to the common iliac glands.

The **internal iliac lymph-glands** lie along the trunk and branches of the internal iliac vessels on the pelvic wall and in the fatty tissue around the organs. They receive *afferents* from all the pelvic viscera, and also from the perineum and the gluteal region. Their *efferents* pass to the common iliac glands. On the pelvic wall some of the glands around the stem of the internal iliac artery merge into the medial external iliac chain above; others may be found on the stems of the parietal branches of the artery—*gluteal, pudendal, obturator*—and they may be so named; but only one group need be specially designated—the **sacral lymph-glands**, which lie in the hollow of the sacrum.

In the fatty tissue near the viscera there are usually a number of small outlying glands:—

(*a*) **Ano-rectal lymph-glands** (2-8) in relation with the ampulla of the rectum and the back of the bladder or the vagina; (*b*) a **middle rectal lymph-gland** on each side of the rectum about its middle; (*c*) **vesical lymph-glands**—*anterior* (occasional) in the retropubic fat, and *lateral* along the side of the bladder in relation with the obliterated umbilical artery; (*d*) in the female the **para-uterine lymph-glands** in the root of the broad ligament close to the cervix.

The **common iliac lymph-glands** (4-6) continue the internal and external iliac groups upwards; those on the lateral side and behind each common iliac artery may

two common iliac groups come together in the angle between the common iliac arteries they form a *median* group of glands.

The nominal groups of pelvic glands are in reality quite artificial. The important facts are that a number of lymph-glands are situated in the fat round the internal iliac blood-vessels and their branches—**lymph-glands of the cavity**; and that a number on the external and common iliac vessels form a collar on the brim—**lymph-glands of the brim**.

The glands of the brim (external iliac and common iliac) receive the efferent

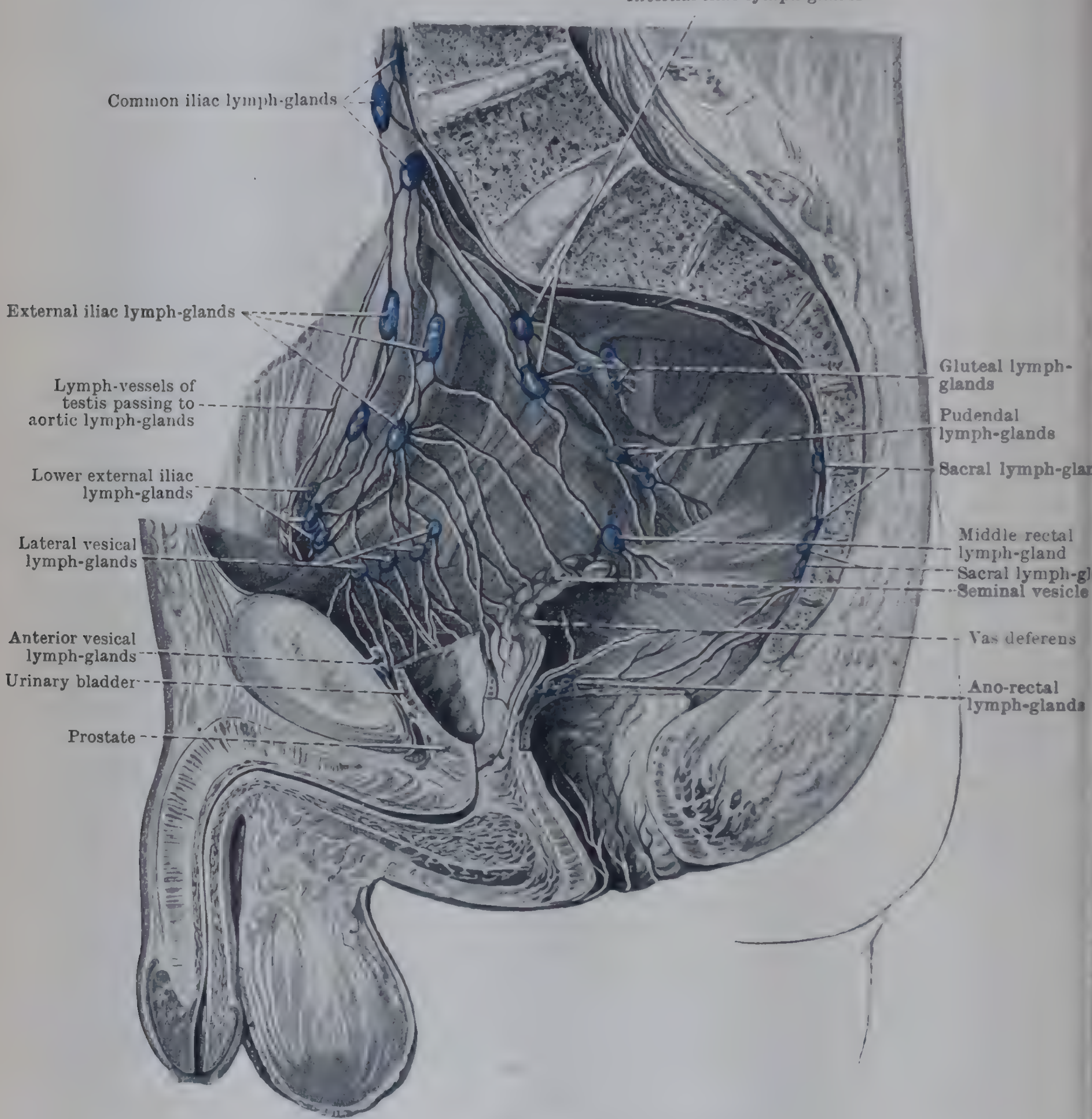

FIG. 1159.—LYMPH-GLANDS OF THE PELVIS.

vessels from the glands of the cavity (internal iliac and all sub-groups) and also numerous direct afferent vessels from *all the pelvic organs* and from the peritoneum of the lower abdominal wall. Moreover, vessels from the upper part of the rectum, from the upper part of the uterus and from the uterine tube and the ovary, escape even the glands of the brim and pass into the abdomen to end in the aortic glands.

PARIETAL AFFERENT LYMPH-VESSELS OF PELVIC GLANDS

The deep lymph-vessels from the anterior and lateral abdominal wall below the umbilicus and from the iliac fossa arise from a subperitoneal capillary network, and

follow the inferior epigastric and deep circumflex iliac arteries to the lowest external iliac glands.

Lymph-vessels that arise from the medial side of the hip joint follow the obturator artery, and from the back of the joint others pass along the gluteal vessels, with deep lymph-vessels of the gluteal region, to reach internal iliac glands situated on these branches of the main artery. Deep lymph-vessels from the perineum, arising in the bulbar and membranous parts of the urethra, from the bulbo-urethral glands (from the greater

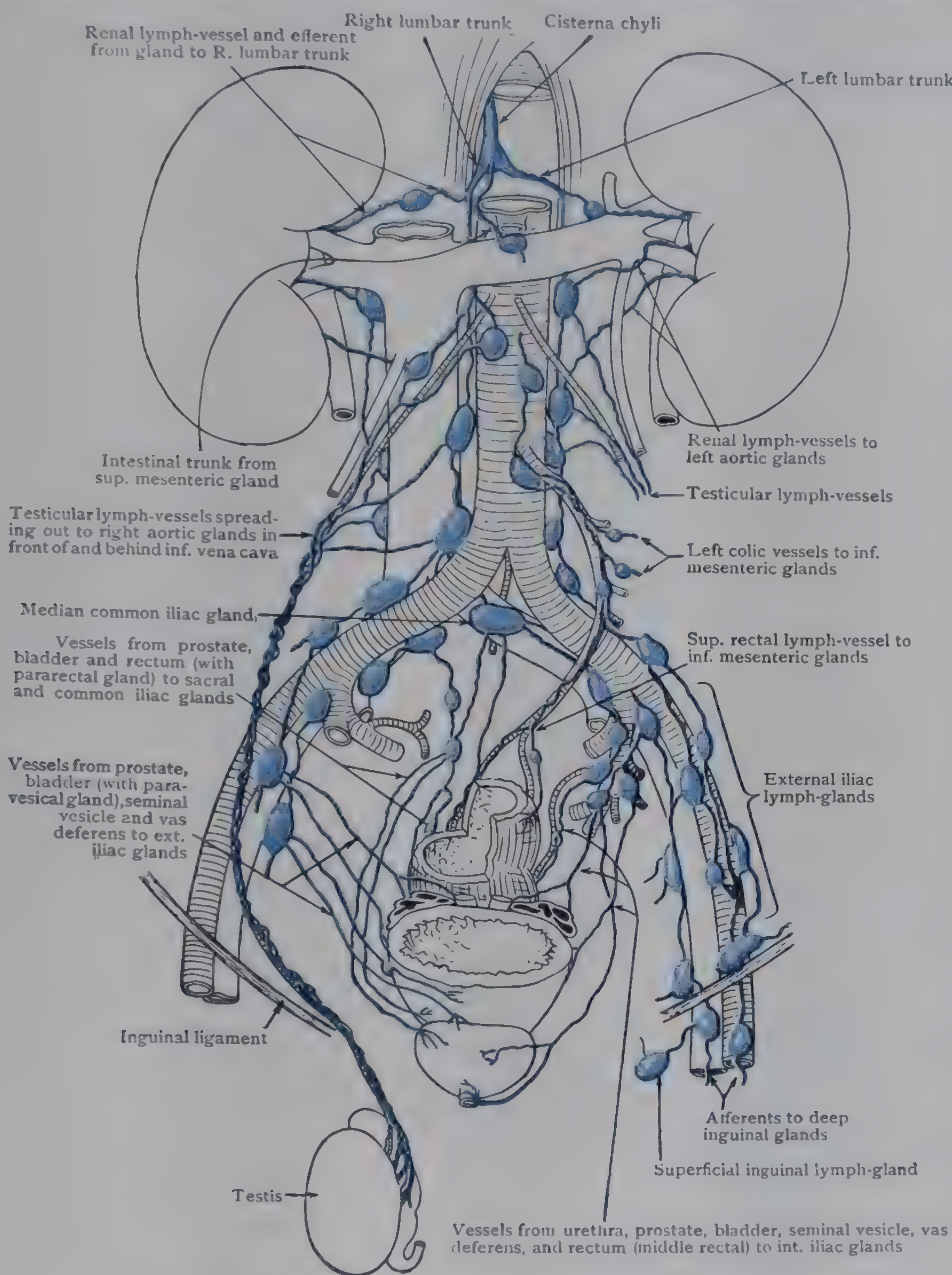

FIG. 1160.—DIAGRAM OF LYMPH-VESSELS AND LYMPH-GLANDS OF MALE PELVIS AND ABDOMEN.

vestibular glands in the female), and some from the anal canal, follow the internal pudendal artery to the internal iliac glands, and thence to the lymph-glands of the brim.

LYMPH-VESSELS OF PELVIC VISCERA

Although the lymph-glands of the pelvis are for the most part situated along the blood-vessels, it is important to note that the lymph-vessels of pelvic organs do not necessarily follow only the paths of the blood-vessels that supply them. Many of them take other paths (*e.g.*, to the external iliac glands) and the drainage of pelvic organs is therefore to some extent along unexpected lines. On the other hand the lymph-vessels of the ovary and of the upper part of the rectum do follow their blood-vessels out of the pelvis to end in glands in the abdomen.

Lymph-Vessels of Urinary Bladder.—The lymph-vessels of the urinary bladder arise from a submucous plexus, most abundant in the region of the trigone (Albarran, 1892),

and pierce the muscular coat. From the superior and infero-lateral surfaces of the bladder, the vessels, some of which are interrupted in the anterior and lateral vesical glands, pass to the external iliac lymph-glands. From the base of the bladder also vessels pass to the external iliac glands, but some end in internal iliac glands. Lymph-vessels from the neck of the bladder are associated with those from the prostate that run to the sacral and the median common iliac glands.

Lymph-Vessels of Ureter.—The lymph-vessels of the *pelvic part* of the ureter are associated with those of the urinary bladder (see also p. 1416).

Lymph-Vessels of Prostate.—The prostatic lymph-vessels mainly follow the inferior vesical artery and end in the anterior and lateral vesical glands, and in the internal iliac glands; some, however, pass backwards to the sacral glands, and others follow the vas deferens to external iliac glands; one or two may run downwards to join the vessels of the membranous part of the urethra.

Lymph-Vessels of Male Urethra.—It has been pointed out that the lymph-vessels of the greater part of the *spongy part* of the urethra pass to the superficial inguinal glands; others go with lymph-vessels of the glans penis to the deep inguinal glands. The lymph-vessels of the *bulbar* and *membranous parts* of the urethra have been mentioned under the parietal afferents of the pelvic glands, since they mainly follow the internal pudendal artery to the internal iliac glands; other vessels may pass behind the pubic symphysis to the lower medial gland of the external iliac group, and with lymph-vessels from the lower part of the anterior wall of the bladder to higher medial glands of the same group. The lymph-vessels of the *prostatic part* of the urethra unite with the other lymph-vessels of the prostate.

The **lymph-vessels of the female urethra** correspond with those of the membranous and prostatic parts of the male urethra.

Lymph-Vessels of Seminal Vesicle.—The seminal vesicle is associated in lymph-drainage with the base of the bladder, the prostate, and the ampulla of the vas deferens. Collectors pass with prostatic vessels to internal iliac glands and others end in a posterior gland of the medial external iliac group.

Lymph-Vessels of Vas Deferens.—The lymph-vessels of the pelvic part of the vas deferens are associated with those of the seminal vesicle, the prostate, and bladder, and they pass, according to their site of origin, to the external and internal iliac glands (see also p. 1416).

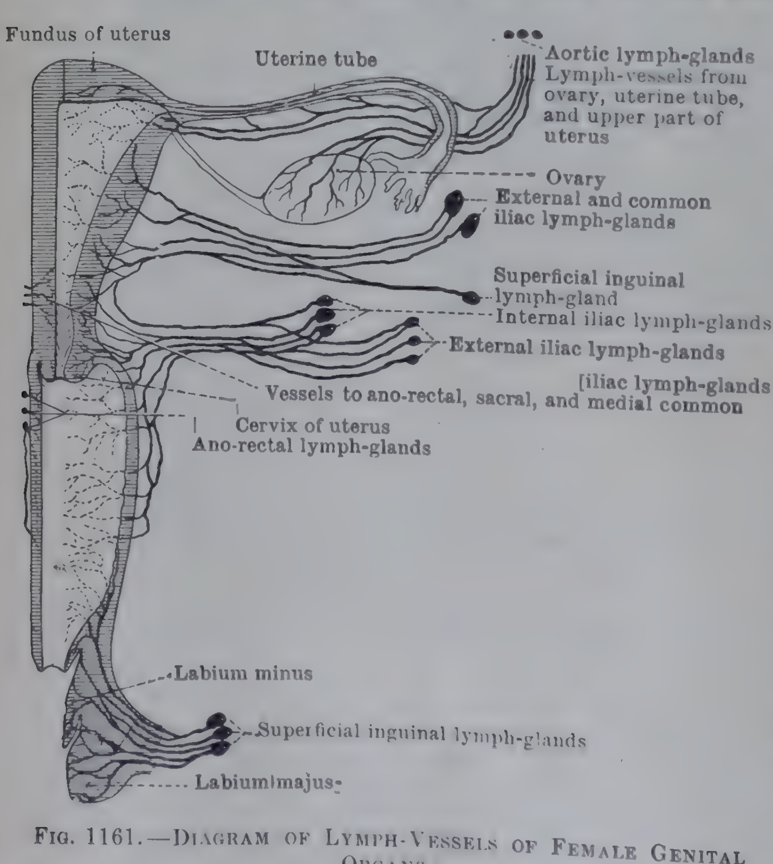

Fig. 1161.—Diagram of Lymph-Vessels of Female Genital Organs.

Lymph-Vessels of Vagina.—The lymph-vessels of the vagina scatter widely. From the lower part some go to sacral and common iliac glands, and others from the region of the hymen pass with vessels from the vulva to the superficial inguinal glands; from the middle part they accompany the vaginal blood-vessels to internal iliac glands; from the upper part they accompany lymph-vessels from the cervix of the uterus to external and internal iliac glands (Figs. 1161, 1162). Some of the vessels from the lower part of the posterior wall of the vagina may be interrupted in the small ano-rectal glands.

Lymph-Vessels of Uterus.—The capillary plexus in the mucous coat of the uterus communicates with a voluminous subserous plexus from which the collecting vessels arise. They run to widely separated groups of lymph-glands—superficial inguinal, external and internal iliac, sacral and common iliac, and aortic (Figs. 1161, 1162).

From the *cervix*, vessels pass to both external and internal iliac glands, and also to the sacral and median common iliac glands. From the *lower part of the body* some may pass with vessels from the cervix to internal iliac glands, but most of them go to external iliac glands. From the *upper part of the body* and the *fundus* the most important outflow is with the vessels of the uterine tube and ovary upwards over the pelvic brim to aortic lymph-glands (see p. 1416). The aortic glands that receive lymph-vessels from the uterus are situated near the origin of the inferior vena cava on the right side and of the inferior mesenteric artery on the left. In addition, one or two vessels from the fundus and the body run along the round ligament of the uterus to the superficial inguinal lymph-glands. Some of the uterine lymph-vessels are interrupted in the para-uterine glands.

Lymph-Vessels of Uterine Tube.—The main lymph-drainage of the uterine tube is with the lymph-vessels of the fundus of the uterus and of the ovary to aortic lymph-glands (see p. 1416); but a vessel may occasionally pass to an external iliac or even to an internal iliac gland.

Lymph-Vessels of Ovary.—The lymph-vessels of the ovary pass entirely out of the pelvis to aortic lymph-glands (see p. 1416).

Lymph-Vessels of Rectum and Anal Canal.—Like those of the uterus and vagina, the lymph-vessels of the anal canal and rectum end in widely separated groups of glands. They arise mainly from a plexus in the mucous coat continuous through the plexus of the anal canal with the cutaneous plexus of the perineum. Most of the collecting vessels end in pelvic glands—sacral, internal iliac, and common iliac—but from the lower end of the anal canal some pass with cutaneous vessels to superficial inguinal glands, and, from the upper part of the rectum, the lymph-drainage is continuous with that of the pelvic colon, and the vessels pass upwards out of the pelvis to the inferior mesenteric glands.

From the lower end of the anal canal vessels run, with those of the skin around the anus, forwards in the perineum and ascend to the superficial inguinal glands. From the greater part of the anal canal the lymph-vessels run either across the ischio-rectal fossa or upwards with those of the lower part of the rectum along the middle rectal blood-vessels to internal iliac glands. Other vessels from the rectum end in the sacral and median common iliac glands; and a very important group ascends along the superior rectal blood-vessels to reach glands about the stem of the inferior mesenteric artery. Vessels from the anal canal and lower part of the rectum may be interrupted in the small ano-rectal lymph-glands; and others from the middle and upper parts of the rectum pass through para-rectal glands.

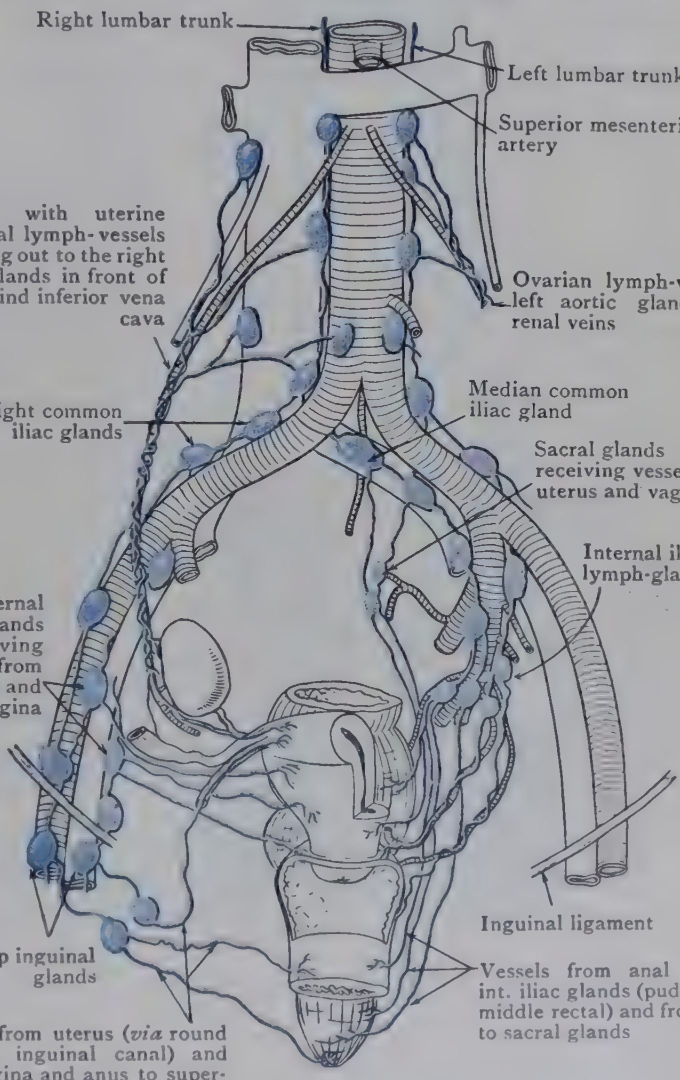

Fig. 1162.—Diagram of Lymph-Vessels and Lymph-Glands of Female Pelvis and Abdomen.

Aortic and Inferior Mesenteric Lymph-Glands

The **aortic lymph-glands** (Figs. 1160, 1163) are arranged in a number of chains which lie in the loose tissue around the aorta and inferior vena cava. Below they are in continuity with the common iliac glands; and from the upper members of the aortic group behind the pancreas the right and left lumbar lymph-trunks emerge. The lymph-glands lie at the sides of the great vessels, between them, in front of and behind them: they have, therefore, been subdivided into *right lateral* (pre-venous, retro-venous), *left lateral*, *pre-aortic*, and *retro-aortic*; but these names, which have

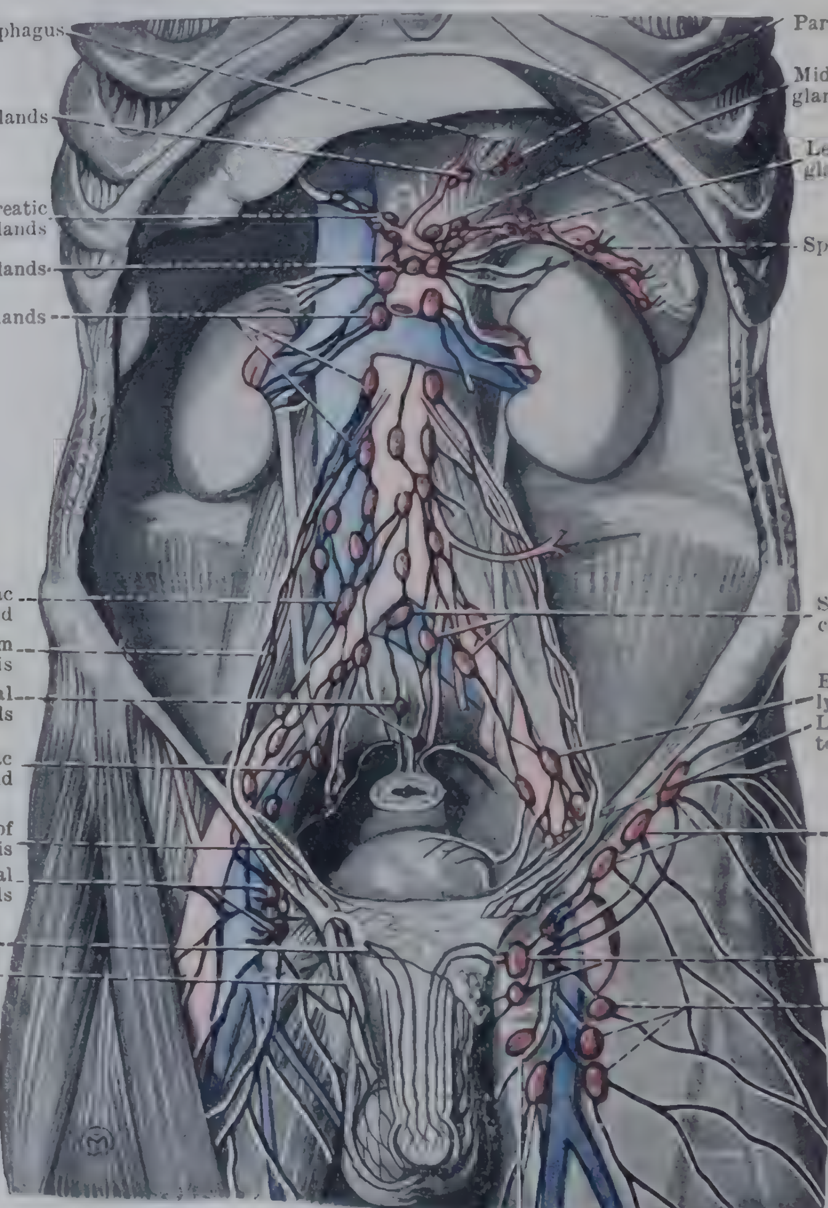

Fig. 1163.—Semi-Diagrammatic view of Lymph-Glands and Lymph-Vessels of Inguinal Region, Pelvis and Posterior Wall of Abdomen.

an occasional value, should not be allowed to obscure the fact that the aortic glands are all freely interconnected. They are most numerous on the left side of the aorta, where they are tightly packed from the common iliac artery up to the renal artery. Their concentration in this situation may be explained, first by the fact that the corresponding members on the right side have to be disposed around the vena cava, and secondly by the fact that the upper end of the inferior mesenteric chain is not separated from the aortic glands. Above the level of the renal vessels the aortic group is represented by a few small glands not easily distinguished from the cœliac and superior mesenteric groups. In the process of development a large number of glands are formed in the primitive mesentery. Those at the root of the mesentery drain the body-wall and the abdominal organs developed in the region of the inter-

mediate cell-mass—suprarenal, kidney, and testis or ovary—and receive the efferents from lower limbs and pelvis. Those in the primitive mesentery are associated with the three great visceral vessels—cœliac, superior mesenteric, and inferior mesenteric arteries—and drain the abdominal part of the fore-gut, the mid-gut, and the hind-gut. Each of these great groups may be regarded as offshoots of the aortic glands, but while the inferior mesenteric group does not dissociate itself from the lumbar trunks, the efferent lymph-vessels of the cœliac and superior mesenteric groups open separately into the cisterna chyli by the intestinal trunk.

Some outlying small members of the aortic group of glands are separated from the main body by the psoas and lie in the intervals between the lumbar transverse processes; they are in series with the sacral glands below and the intercostal glands above; they may be called the *lateral lumbar lymph-glands.*

The *afferent* vessels of these lateral glands are derived from the lumbar synovial joints, the dura mater of the vertebral canal and some cutaneous vessels from the lumbar region which have followed the posterior branches of the lumbar arteries; their *efferents* pass along the lumbar blood-vessels to the aortic glands. The main aortic glands receive: (*a*) the efferents of the common iliac glands (lymph of whole lower limb, abdominal wall below umbilical level, perineum, external genital organs and pelvis); (*b*) efferents of the lateral lumbar glands; (*c*) efferents of the inferior mesenteric chain; (*d*) afferents from the testis and epididymis (ovary, uterine tube, and upper part of uterus in the female); and (*e*) afferents from the abdominal part of the ureter, the kidneys and suprarenal glands, and from the under surface of the diaphragm. The territory of drainage corresponds to the distribution of the paired branches of the aorta, with that of the inferior mesenteric artery added.

The **inferior mesenteric system of lymph-glands** is an extension of the aortic group of glands along the inferior mesenteric artery and its branches. The main **inferior mesenteric lymph-glands** lie along the stem of the artery. They receive lymph from the outlying glands of the system that are scattered along the branches of the artery as far as the wall of the intestine. The outlying glands are known as the lymph-glands of the colon, and are arranged in subsidiary groups. The same arrangement of lymph-glands is found along the branches of the *superior mesenteric artery* that supply part of the large intestine (see p. 1419).

The **lymph-glands of the colon** (Fig. 1166) may be considered as forming four groups—epicolic, paracolic, intermediate and main colic (Jamieson & Dobson, 1909).

(*a*) The **epicolic glands** are small nodules which lie in the appendices epiploicæ and in relation with the wall of the gut. (*b*) The **paracolic glands** lie along the medial borders of the ascending and descending parts of the colon, along the upper border of the transverse colon, and on the mesenteric border of the pelvic colon. (*c*) The **intermediate colic glands** lie along the branches of the colic arteries. (*d*) The **main colic glands** are situated around the stems from which the colic arteries arise.

The lymph gathered by the lymph-plexuses in the walls of the gut passes through one or more of these subsidiary groups of glands before it reaches the lymph-glands situated on the stems of the main blood-vessels. In addition to the drainage of the rectum by lymph-vessels that pass upwards out of the pelvis with the superior rectal artery, *afferents* of the main inferior mesenteric glands convey lymph from the descending and pelvic parts of the colon; their *efferents* pass to the aortic lymph-glands which drain mainly into the left lumbar lymph-trunk.

Afferent Lymph-Vessels of Aortic Glands

Lymph-Vessels of Testis and Epididymis.—A rich capillary network surrounds the tubules in the testis and gives origin to collecting vessels which traverse the mediastinum testis to emerge through the back of the organ; they are joined by the vessels of the epididymis and a superficial set from the serous covering. These vessels (6-8) ascend in the spermatic cord, pass through the deep inguinal ring and then follow

curve medially and spread out like a fountain spray to end in the lower aortic lymph glands, from the bifurcation of the aorta to the level of the renal veins (Fig. 1160). On vessel (probably from the tunica vaginalis) usually diverges into an external iliac glan (Jamieson & Dobson, 1910 *a*). The student should note that the lymph-vessels of th testis were developed while the organ lay on the posterior abdominal wall, and that th scrotum is merely a diverticulum of the lower abdominal wall: hence the difference i the destination of the lymph-vessels of the scrotum (inguinal glands) and of the testi and epididymis (aortic glands).

Lymph-Vessels of Vas Deferens.—As far as the brim of the pelvis, these joi the testicular lymph-vessels: from the pelvic portion (as already noted, p. 1412 they pass upwards to the external iliac glands and backwards to the internal ilia glands.

Lymph-Vessels of Ovary.—Like the lymph-vessels of the testis those of the ovar end in aortic lymph-glands; their destination also depends on the development of th organ in the abdomen. They emerge through the hilum of the ovary, are joined b lymph-vessels from the fundus of the uterus and the uterine tube and ascend over th pelvic brim with the ovarian blood-vessels. On the posterior wall of the abdomen the spread out to end in aortic glands from the bifurcation of the aorta to the level of th renal veins (Fig. 1162).

Lymph-Vessels of Ureter.—The vessels of the ureter are believed to arise from a scanty plexus in the mucous coat. The collecting vessels are not numerous. From th pelvic part of the ureter, vessels pass to the internal, external, and common iliac glands from the middle part to the aortic glands; and from the upper end, including the pelvi and calyces, they run with the renal lymph-vessels.

Lymph-Vessels of Kidney.—These vessels are injected with difficulty and, like those o the bladder and ureter, appear to be scanty.

In addition to the subserous plexus on the parts of the kidney covered wit peritoneum, there is a plexus of lymph-vessels in the renal fat from which collector pass to aortic glands. In the fibrous capsule of the kidney there is another plexu which receives communications from the vessels in the cortex of the organ and give origin to collecting vessels which pass medially to join those emerging from th hilum.

The lymph-vessels of the cortical and medullary parts of the substance of the kidne unite in the region of the bases of the pyramids and traverse the renal columns to appea in the sinus. They emerge from the hilum both in front of and behind the blood-vessel and run medially to end in aortic glands at and below the level of the hilum. On th right side some of the glands in which they end are situated behind the inferior ven cava.

From the back of the upper end of the kidney a few vessels may pass with some from the suprarenal glands through the diaphragm (with the communications between th renal and suprarenal veins and the azygos veins) into the lowest lymph-glands in th posterior mediastinum.

Lymph-Vessels of Suprarenal Gland.—Lymph-vessels emerge from the surface of th suprarenal gland with the arteries and through the hilum with the vein. These vessel drain the cortex and the medulla respectively, but they arise from a continuous capillar plexus. They end mainly in cœliac and upper aortic lymph-glands; but some of then have been noted above as passing through the diaphragm into the posterior mediastina glands.

Lymph-Vessels of Peritoneum.—The lymph-vessels of the serous coats of the viscer are described with the lymph-drainage of each organ. Those from the parietal peri toneum arise from a subserous network—specially rich on the diaphragm—and tend t converge on the blood-vessels which run in the extraperitoneal tissue in the differen regions. In the pelvis they pass to the nearest glands in the cavity or on the brim On the anterior abdominal wall and in the iliac fossa they accompany the superior an inferior epigastric and the deep circumflex iliac blood-vessels. On the posterior wall o the abdomen in the lower part they join the vessels that run from the ascending an descending colon and are thus conveyed to the groups of glands on the superior and inferio mesenteric arteries. Laterally they accompany the lumbar blood-vessels to the latera aortic glands. Higher up they join the vessels from the kidneys. Above, the diaphrag matic lymph-vessels mainly pierce the diaphragm to join the rich subpleural plexus o its upper surface; the stream which accompanies the phrenic blood-vessels to reach th uppermost aortic glands is therefore small.

INTESTINAL LYMPH-TRUNK

The **intestinal lymph-trunk** enters the cisterna chyli and is formed by the union of the efferents of the proximal members of great groups of lymph-glands situated on the cœliac and superior mesenteric arteries and their branches. The efferents of the proximal lymph-glands of the group associated with the inferior mesenteric artery empty into the aortic glands on the left side of the aorta, and so mainly into the left lumbar lymph-trunk. These three sets of glands are developed in the parts of the primitive mesentery associated with the fore-gut, mid-gut, and hind-gut respectively.

The student will note that the term "aortic glands" is applied to those which lie on the great vessels at the root of the primitive mesentery, and the terms "cœliac", "superior mesenteric", and "inferior mesenteric" to those originally *in* that mesentery. Above the level of the renal vessels, where the superior mesenteric and cœliac glands merge and communicate with the upper aortic glands, it is impossible to distinguish clearly between the two sets. The distinctions in that region are rather artificially made to facilitate description.

Cœliac and Superior Mesenteric Lymph-Glands

The **cœliac system of lymph-glands** presents descriptive difficulties. The main group extends along the upper border of the pancreas in association with the cœliac artery and its hepatic and splenic branches. For convenience of appellation and because they found all the glands on the hepatic and splenic arteries to be stations for the lymph-vessels of the stomach and less importantly associated with the liver and spleen, Jamieson & Dobson (1907*a*) subdivided and named them the *right, middle, and left suprapancreatic glands*; to each set certain lymph-streams converge from well-defined territories. The term "gastric" glands for any particular group is apt to be misleading, as *all* the groups in the cœliac system receive lymph-vessels from the stomach. The following table indicates the relation of the different groups of glands in the cœliac system:—

CŒLIAC LYMPH-GLANDS

Right Suprapancreatic	—	Middle Suprapancreatic	—	Left Suprapancreatic
Biliary Glands	Suprapyloric	Subpyloric	Left Gastric	Splenic
Cystic Gland		Right Gastro-epiploic		Left Gastro-epiploic

The **splenic lymph-glands** are a few small glands situated above the tail of the pancreas at the hilum of the spleen. They receive the lymph-vessels of the spleen and also vessels which accompany the left gastro-epiploic artery from the lower border of the stomach; in the course of some of these, one or two small **left gastro-epiploic lymph-glands** may be found in the gastro-splenic ligament near the spleen.

The **left suprapancreatic lymph-glands** lie on the stem of the splenic artery. They receive the efferents of the splenic glands, lymph-vessels from the body of the pancreas, and an abundant stream from the fundus and body of the stomach with the short gastric arteries.

The **left gastric lymph-glands** form a long chain. The most distal members—lower left gastric—lie on the lesser curvature of the stomach to the left of the angular notch. Above this, the cardiac end of the stomach is surrounded by the glands like a string of beads round the neck of the organ (*paracardial lymph-glands*). Beyond that the chain lies around the trunk of the left gastric artery—upper left gastric glands. Finally the chain merges with the middle suprapancreatic group. The left gastric glands receive the lymph-vessels from an area of the stomach, front and back, between the lesser curvature and a line from the summit of the fundus downwards

canal. From any part of this surface some of the vessels skirt past the lower and paracardial glands and reach the upper group. This behaviour is characteristic of the lymph-vessels of the alimentary canal (see Figs. 1166, 1167).

The **middle suprapancreatic lymph-glands** surround the stem of the cœliac artery and receive the efferents of the left gastric glands, of the left and right suprapancreatic glands, and some efferents of the subpyloric glands (see below).

The **right suprapancreatic lymph-glands** lie along the horizontal part of the stem of the hepatic artery and are continuous in various directions with the following subgroups.

The **hepatic** and **biliary lymph-glands** form a continuous chain which runs along the ascending part of the stem of the artery as far as the porta hepatis and downwards behind the duodenum and the head of the pancreas with the bile-duct;

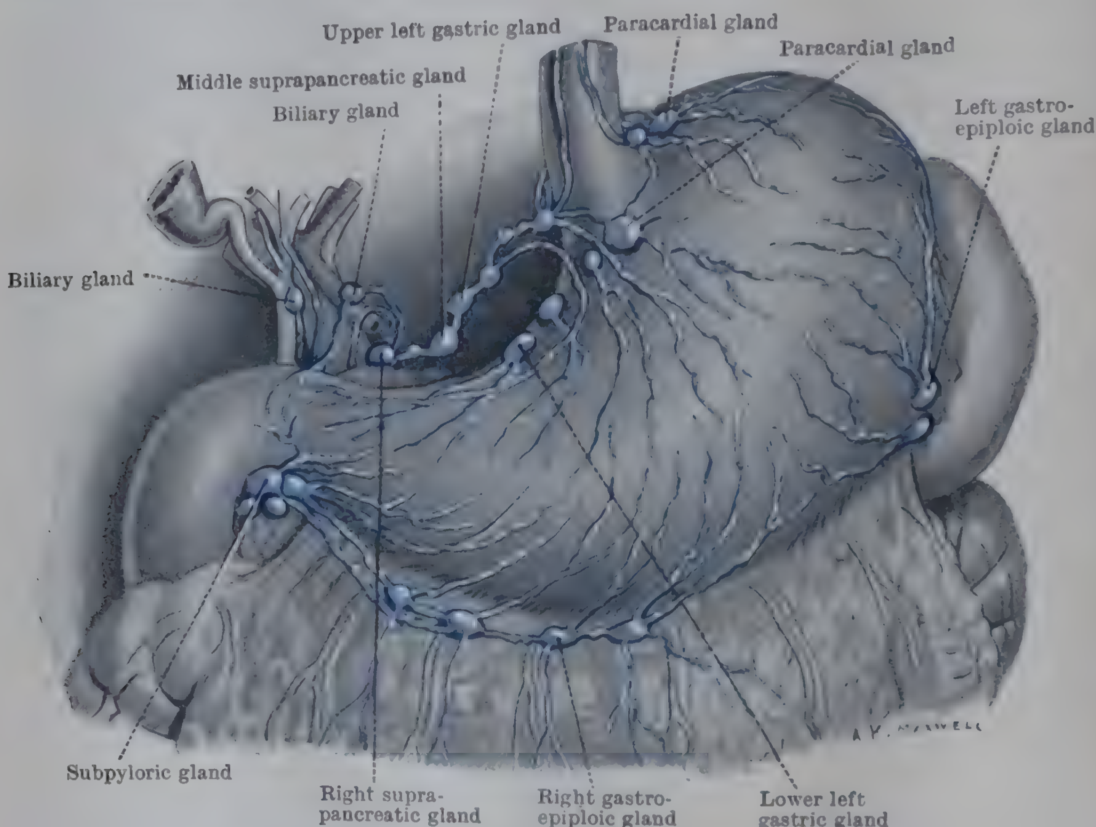

FIG. 1164.—LYMPH-VESSELS AND LYMPH-GLANDS OF STOMACH.
(Jamieson & Dobson, 1907 *a*, redrawn.)

a constant member of this group lies in the curve of the neck of the gall-bladder—the **cystic lymph-gland**. The lower end of this chain receives *afferents* from the head of pancreas, the back of the duodenum, and a few from the pyloric end of the stomach; the upper members of the chain (hepatic glands) receive numerous afferent vessels from the liver (lower margin of the parietal surface and the whole of the visceral surface), and from the gall-bladder and the bile-ducts. The *efferents* end in the right suprapancreatic group.

The **subpyloric lymph-glands** form an important group which lies on the head of the pancreas below the beginning of the duodenum, and after a short interval is continued as a chain of single glands in the course of the right gastro-epiploic artery between the layers of the great omentum—**right gastro-epiploic lymph-glands.** These glands together drain the lower part of the pyloric portion of the stomach, and the subpyloric *efferents* run in various directions, some to the nearest main group—the superior mesenteric root glands, some obliquely over the pancreas to the middle suprapancreatic group, and some to the right suprapancreatic glands (Fig. 1165).

The **suprapyloric lymph-glands** are a small group found in the lesser omentum along the right gastric artery; they interrupt a few vessels from the pyloric canal, and send *efferents* to the right suprapancreatic group.

The *efferent* vessels of the middle and right suprapancreatic glands combine

with the superior mesenteric ultimate efferents to form the single or multiple *intestinal trunk*. Some efferent vessels pass to communicate with glands in the superior mesenteric and aortic groups.

The **superior mesenteric system of lymph-glands** extends into the primitive mesentery of the mid-gut, and the glands that belong to it are scattered along the stem of the artery and all its branches as far as the intestinal wall. They

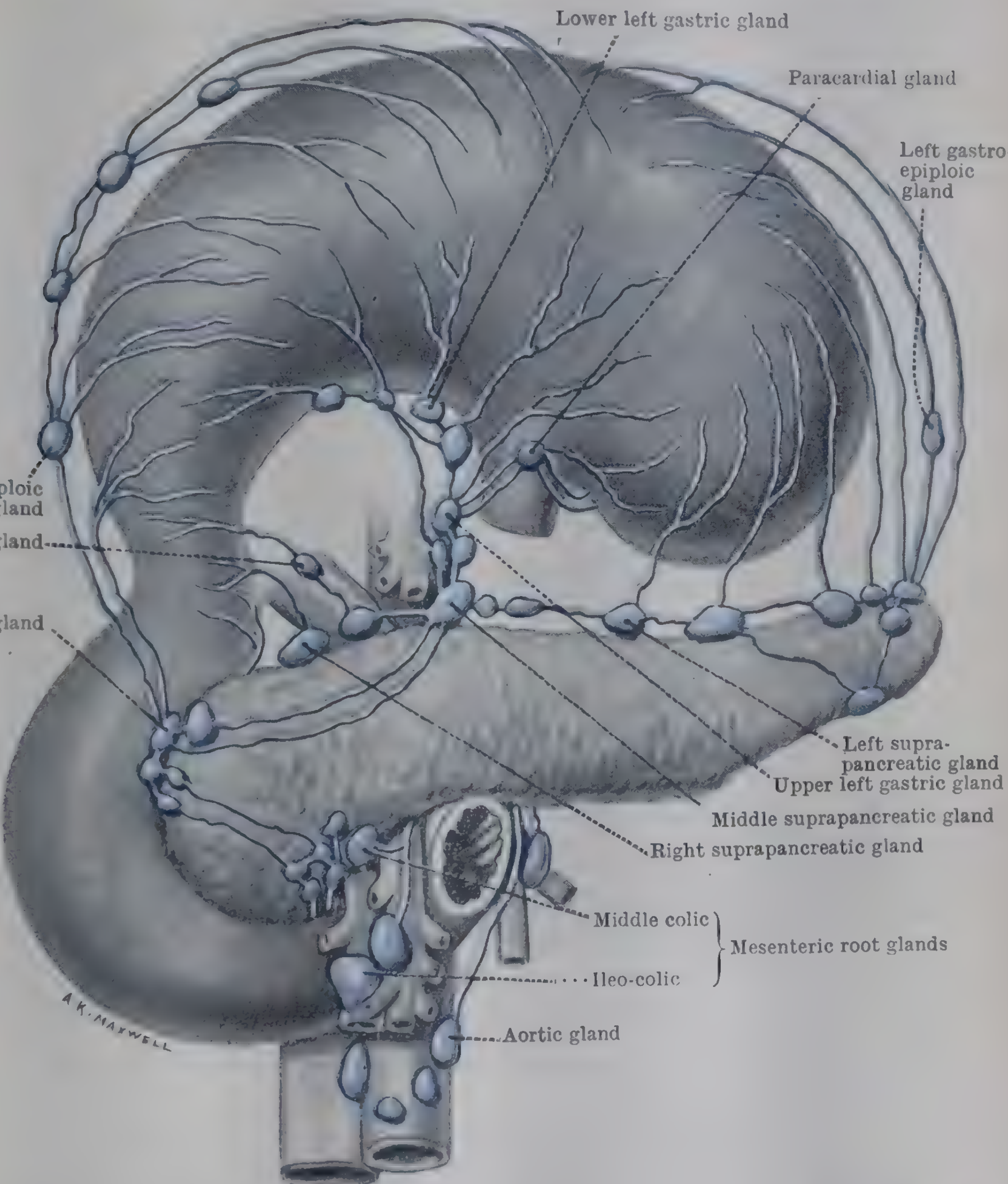

FIG. 1165.—LYMPH-VESSELS AND LYMPH-GLANDS OF POSTERIOR SURFACE OF STOMACH. The stomach has been turned upwards to show the suprapancreatic and other groups of glands.
(Jamieson & Dobson, 1907 *a*, redrawn.)

form one great group, but it is customary, for convenience of topographical reference, to indicate the following subdivisions: (*a*) mesenteric root glands; (*b*) subsidiary chains with the branches of the artery—(1) the glands of the mesentery, (2) ileo-colic, (3) right colic, (4) middle colic.

(*a*) The **mesenteric root glands** are large and numerous, clustered around the stems of the main blood-vessels as they lie in front of the duodenum and the head of the pancreas. They receive the ultimate efferents of all the subsidiary groups as well as some efferents from the subpyloric glands and direct afferents from the head of the pancreas and the duodenum, and also some efferents from the upper left colic group (see p. 1420).

(*b*) In the subsidiary groups related to the drainage of the large intestine the

vessels (*paracolic*) and some form irregular chains along the colic vessels and tend to group themselves into *intermediate* and *main* sets. There is no such regular order in the lymph-glands of the mesentery.

(1) The **lymph-glands of the mesentery** (100-200 in number) are scattered in the fatty tissue of the mesentery without order: they receive the *afferent* vessels from the jejunum and the ileum (excepting the lowest few inches); the *efferents* pass from gland to gland and the ultimate efferents enter the mesenteric root glands.

(2) The epicolic and paracolic members of the group of **ileo-colic lymph-glands** are represented by a cluster in the ileo-colic angle from which a few outlying glands descend with the anterior and posterior cæcal vessels in front of and behind the ileo-colic junction—**cæcal lymph-glands**. One **appendicular gland** may be found in the mesentery of the appendix. The intermediate group is a clump half-way up the stem of the ileo-colic artery, and the main group is situated on the artery at its origin from the superior mesenteric, and may lie on the front of the third part of the duodenum. The vessels of the lower end of the ileum, of the appendix, cæcum, and lower end of the ascending colon form the *afferent* vessels of the group, and all parts of the chain receive direct vessels from the intestine as well as the efferent vessels of the distal glands. The ultimate *efferents* pass into the mesenteric root glands.

(3) The **right colic lymph-glands** form a variable group according with the variations of the artery. When distinct, it may be described in the same manner as the ileo-colic group.

(4) The **middle colic lymph-glands** form a chain consisting of numerous epicolic and paracolic glands disposed along the transverse colon from the right flexure as far as the junction of its middle and left thirds, an intermediate group about the point of bifurcation of the middle colic artery, and a main group on the stem of the artery as it enters the mesocolon. The chain drains the right flexure and the proximal two-thirds of the transverse colon; and the ultimate *efferents* enter the mesenteric root glands.

Inferior Mesenteric Lymph-Glands.—As already noted, the inferior mesenteric chain of glands is blended with the aortic glands, and its vessels contribute to the lumbar lymph-trunks; but as it is convenient to describe together all the lymph-vessels of the digestive system in the abdomen, the description of the course of the inferior mesenteric lymph-vessels has been deferred to the next section.

LYMPH-VESSELS OF DIGESTIVE SYSTEM IN ABDOMEN

The lymph-vessels of the abdominal part of the alimentary canal arise from a capillary plexus in the mucous membrane under the lining epithelium and around the gastric and intestinal glands. In the small intestine they also have a very important origin in the central lacteal vessels of the villi (Fig. 533, p. 626). Many vessels appear to arise from labyrinthic networks in the solitary lymphatic nodules, but it is probable that these vessels have come from the plexus of origin and are broken up in the solitary nodules—which are thus lymph-glands in miniature. The lymph-vessels from the mucous membrane perforate the muscular coats, between which they communicate freely, and on emerging are joined by the tributaries from the subserous network: they then pass away with the blood-vessels. In the small intestine they may run longitudinally on the surface for some inches before turning into the mesentery. The vessels are not all trapped by the glands nearest the wall of the alimentary canal; from all parts of the canal many run directly to glands at any point along the course of the blood-vessels.

Lymph-Vessels of Large Intestine.—In the area of distribution of the inferior mesenteric artery, the lymph-vessels of the large intestine pass to the epicolic, paracolic, and intermediate and main groups of glands associated with the branches of the artery. Those which follow the inferior left colic arteries from the **descending** and **pelvic colon** are joined by the stream which passes upwards from the rectum on the superior rectal artery (p. 1413). The lymph-drainage from the *left third* of the **transverse colon** and the **left flexure** must be specially mentioned because the stream divides at the intermediate glands (Fig. 1166) to follow two paths—one leading along the superior left colic artery to the inferior mesenteric main group on the left side of the aorta, the other along the curve of the inferior mesenteric vein to the superior mesenteric root

glands. Some small peritoneal lymph-vessels from the flexure run up in the greater omentum and thence through the gastro splenic ligament to the glands at the hilum of the spleen. The vessels from the *right two-thirds* of the **transverse colon** and from the *right flexure* run to the middle colic group; from the upper and middle parts of the **ascending colon** to the right colic group; from the lower part of the ascending colon, **cæcum, appendix** and **end of the ileum** to the ileo-colic group. The course of the lymph-vessels from the cæcum and appendix is shown from the front in Fig. 1166, and is specially illustrated from behind in Fig. 1167. Many collecting vessels leave the appendix and enter its mesentery where they unite to form four or five main lymph-vessels. These follow the

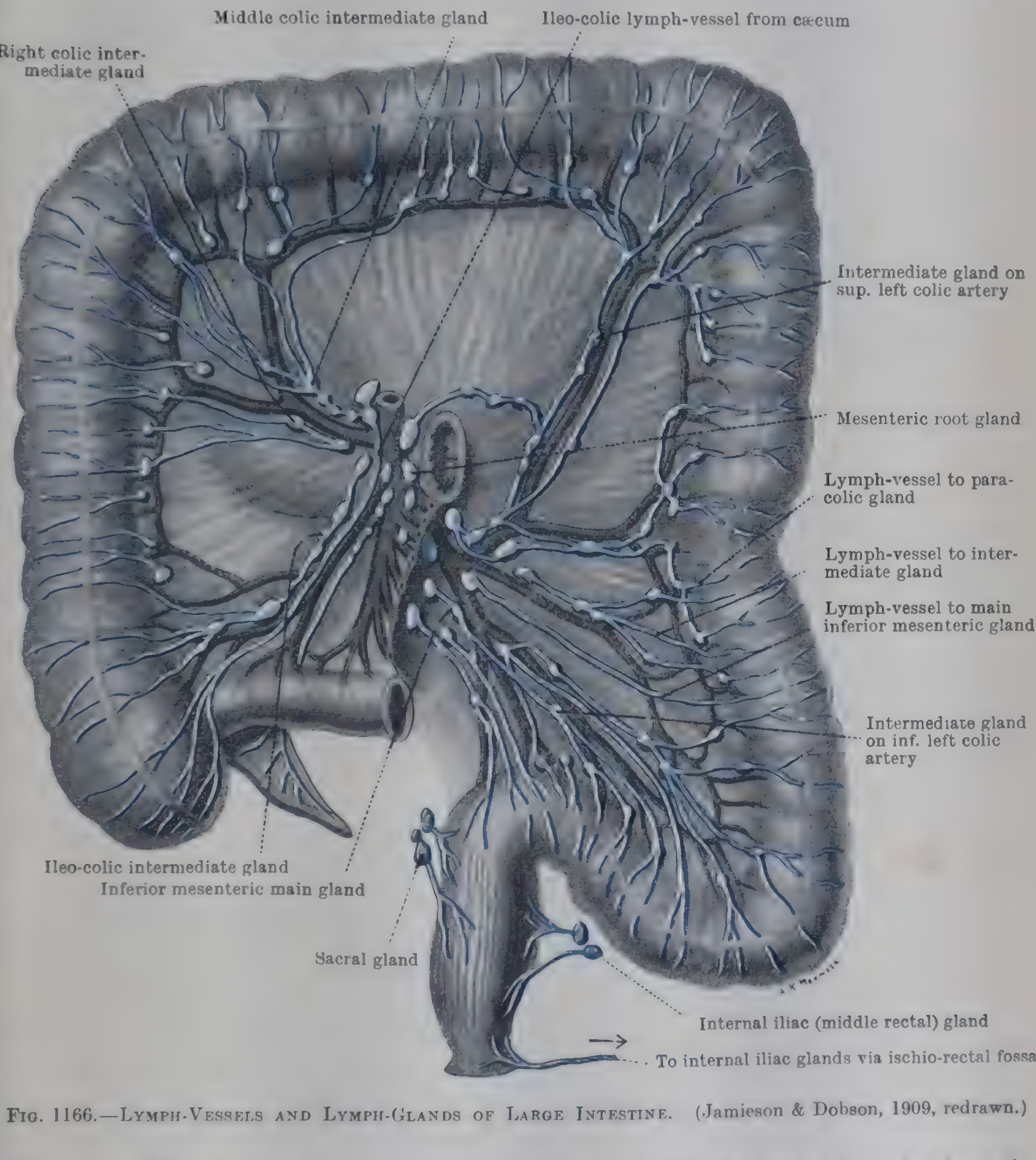

Fig. 1166.—Lymph-Vessels and Lymph-Glands of Large Intestine. (Jamieson & Dobson, 1909, redrawn.)

appendicular blood-vessels behind the lower end of the ileum and end in glands along the whole length of the ileo-colic chain.

Lymph-Vessels of Small Intestine.—From the lower end of the ileum to the duodeno-jejunal flexure—**ileum** and **jejunum**—the lymph-vessels run to the glands of the mesentery. From the lower half of the **duodenum** the vessels run directly to the mesenteric root glands, from the upper half to the subpyloric glands in front and to the biliary glands behind.

Lymph-Vessels of Stomach.—These run in three streams: (*a*) from the front and back of the fundus and body over an area indicated by a line (nearer the greater than the lesser curvature) from the fundus to the pyloric canal, to the left gastric glands;

epiploic and subpyloric glands, and upwards in the right end of the lesser omentum to the suprapyloric glands, lower members of the biliary chain and the right suprapancreatic glands (Figs. 1164, 1165).

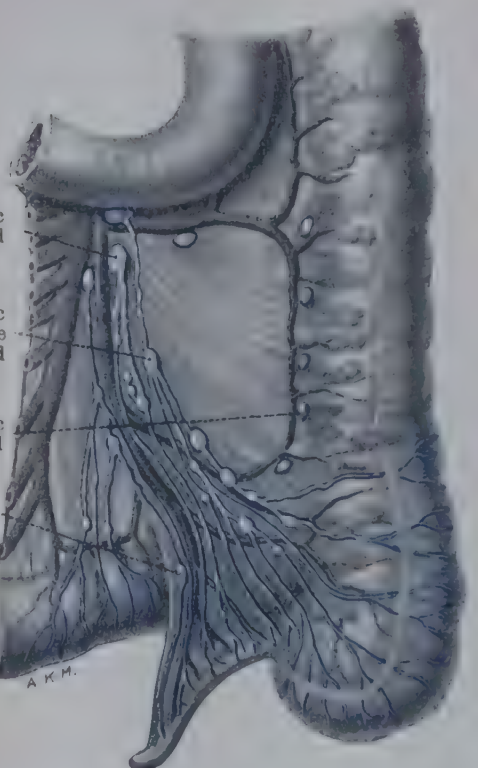

Fig. 1167.—Lymph-Vessels and Lymph-Glands of Cæcum and Appendix from behind. (Jamieson & Dobson, 1907 *b*, redrawn.)

Lymph-Vessels of Pancreas. — The pancreas is drained by vessels which enter the suprapancreatic glands above, the superior mesenteric root glands below, and the aortic glands behind.

Lymph-Vessels of Liver. — Interlobular collecting vessels are formed from capillaries in the lobules of the liver. They mostly come to the surface at innumerable points and form the peritoneal lymph-vessels. From the greater part of the right, superior, and anterior surfaces they run in large numbers to the falciform ligament, which they traverse and then turn upwards to pass along the superior epigastric blood-vessels into the retrosternal glands (see p. 1423). Those from the lower inch or so of the right and anterior surfaces turn round the lower edge of the liver and sweep towards the porta hepatis, where they pick up the vessels of the visceral surface and the **gall-bladder**, and a deep stream of vessels from the interior of the liver, some of which end in the hepatic glands of the porta. They pass into the lesser omentum and descend in it to end in the biliary chain of glands, but many pass to the left to reach the left gastric glands. Other vessels emerge from the back of the liver and follow the right phrenic vessels to the cœliac

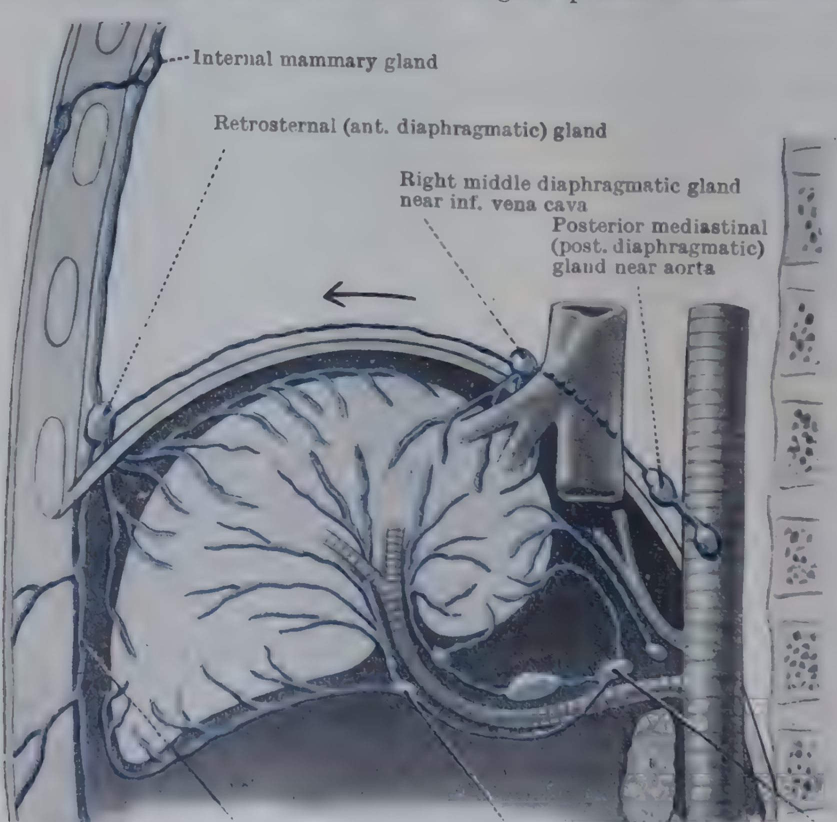

Fig. 1168.—Diagrammatic Sagittal Section showing Lymph-Drainage of Liver.

glands. Deep vessels, from the interior of the liver in the region of the main hepatic veins, emerge with these veins and pass up with the inferior vena cava to middle

diaphragmatic glands in the thorax (see below). It will be noted that there are two main currents of lymph from the liver—one ultimately passing into the cisterna, the other via the internal mammary route to the mediastinal trunks of both sides (Fig. 1168).

Lymph-Vessels of Spleen.—The vessels of the spleen pass to the splenic lymph-glands, which lie near the hilum of the spleen, and to the left suprapancreatic glands.

INTERCOSTAL AND MEDIASTINAL LYMPH-TRUNKS

There are numerous lymph-trunks in the thorax. A large **mediastinal lymph-trunk** is the chief pathway of both the parietal and visceral lymph-vessels; it receives the efferents of the glands associated with the internal mammary artery as well as those situated in the mediastinum. It may unite in various ways with other trunks in the root of the neck (see pp. 1405, 1406), but usually opens separately into the innominate vein.

In addition to the *descending intercostal lymph-trunks*, a number of independent **intercostal lymph-trunks** join the thoracic duct directly (see below and p. 1405). The thoracic duct receives directly a number of efferent vessels from posterior mediastinal lymph-glands also.

Lymph-Glands of Thorax

The groups of lymph-glands in the thorax are (*a*) intercostal, (*b*) diaphragmatic, (*c*) posterior mediastinal, (*d*) internal mammary, (*e*) innominate, and (*f*) tracheo-bronchial.

The **intercostal lymph-glands** are small nodules (1 or 2) situated in the vertebral end of each intercostal space in series with the lateral lumbar glands. They receive *afferents* from (*a*) the parietal pleura of the posterior thoracic wall; (*b*) vessels which accompany the intercostal arteries, mainly derived from the costo-vertebral and intervertebral synovial joints, and from the skin by a few vessels that penetrate deeply with the posterior and lateral cutaneous blood-vessels.

The *efferents* of the glands of the upper six or seven spaces of both sides run independently to the thoracic duct. Those of the glands of the lower four or five spaces join on each side to form a **descending intercostal trunk** which, after receiving the efferents of the glands in the lowest part of the posterior mediastinum, passes through the aortic opening to enter the upper part of the cisterna chyli.

The **posterior mediastinal lymph-glands**, few and variable, lie around the lower thoracic part of the œsophagus. They receive *afferents* from the œsophagus, the back of the pericardium and the back of diaphragm, on which their lowest members rest. Their *efferents* pass directly to the thoracic duct and to the descending intercostal lymph-trunks; and they are connected above with the paratracheal glands.

The **diaphragmatic lymph-glands** (Figs. 1168, 1169) may be subdivided into: (1) a *posterior* group, better considered as the lowest members of the posterior mediastinal group; (2) an *anterior* group better considered under the name "retrosternal" as part of the internal mammary chain; (3) a *middle* group, which on the left side is found as a small cluster around the phrenic nerve as it enters the diaphragm. The middle diaphragmatic glands receive *afferents* from the lateral portion of the diaphragm, and send *efferents* forwards to the retrosternal and backwards to the lower posterior mediastinal glands. On the right side the group is larger, lies in near relation to the inferior vena cava, and receives in addition a certain number of afferents from the liver which issue with the hepatic venous trunks (p. 1422).

The **retrosternal lymph-glands** (Fig. 1169) are the lowest members of the internal mammary chain and consist of a number (3-6) of relatively large glands situated on the sternal and costal origins of the diaphragm behind the base of the xiphoid

anterior part of the diaphragm, and those which accompany the superior epigastric blood-vessels. The last of these streams is the most important and is derived not only from the perforating lymph-vessels of the anterior abdominal wall (few) but from numerous vessels which pass from the upper and anterior surfaces of the liver through the falciform ligament and account for the number and size of the retrosternal group of glands. The *efferents* pass up to the next group.

The **internal mammary lymph-glands** (Fig. 1169) form a chain consisting of one or two glands in each of the upper four intercostal spaces close to the sternum (Stibbe, 1918): they receive the efferents of the retrosternal glands and the lymph-

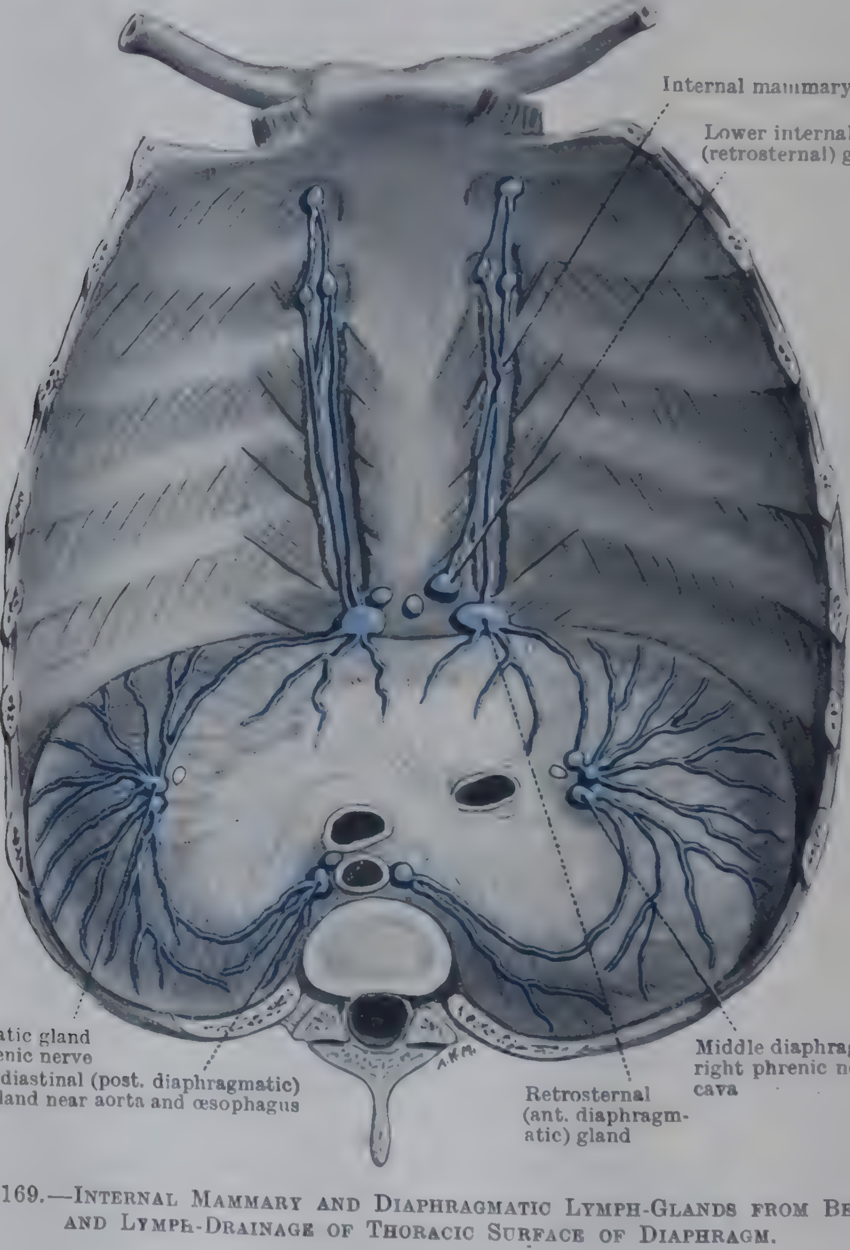

Fig. 1169.—Internal Mammary and Diaphragmatic Lymph-Glands from Behind, and Lymph-Drainage of Thoracic Surface of Diaphragm.

vessels which accompany the intercostal and perforating branches of the internal mammary artery. These vessels require special mention: the anterior intercostal afferents of the internal mammary chain drain the parietal pleura almost as far back as the angles of the ribs; and along the perforating arteries some cutaneous lymph-vessels come from the skin of the mamma and from the stroma of the medial part of the mammary gland. Hence the great surgical importance of the internal mammary chain.

The *efferents* of the internal mammary glands usually join to form a single vessel which unites with the efferents of the tracheo-bronchial and innominate glands to form the mediastinal lymph-trunk. An *internal mammary trunk* may also open independently into the veins (see p. 1406).

The lymph-glands associated with the pulmonary system and the heart lie

in the superior and middle mediastina. A rather irregular arrangement may be reduced for descriptive purposes to the following scheme: (1) glands of the roots of the lungs—(*a*) broncho-pulmonary, (*b*) inferior tracheo-bronchial, (*c*) superior tracheo-bronchial; (2) paratracheal glands; (3) innominate glands.

The **broncho-pulmonary lymph-glands** are embedded in the hilum of the lung and in the intervals between the pulmonary vessels and the bronchus as they enter the root. Small outlying *pulmonary glands* may be found on the larger bronchi in the substance of the lung.

The **inferior tracheo-bronchial lymph-glands** are situated in the angle of bifurcation of the trachea, and unite the other groups of glands of the two sides.

The **superior tracheo-bronchial lymph-glands** are continuous with the upper broncho-pulmonary glands in the angle between the trachea and the bronchus on each side.

The **glands of the root** of the lung receive the lymph-vessels of the lung (including the visceral pleura), and from the bronchi and lower end of the trachea; and vessels from the left side of the heart end in the inferior tracheo-bronchial group. Their *efferents* pass upwards on the trachea.

The **paratracheal lymph-glands** extend upwards along each side of the trachea into the neck. They drain the trachea and the corresponding part of the œsophagus.

The **innominate lymph-glands** are a few small glands scattered in the superior mediastinum in the vicinity of the innominate veins and the aortic arch. They receive lymph-vessels from the thymus and the upper part of the pericardium, and also from the right side of the heart.

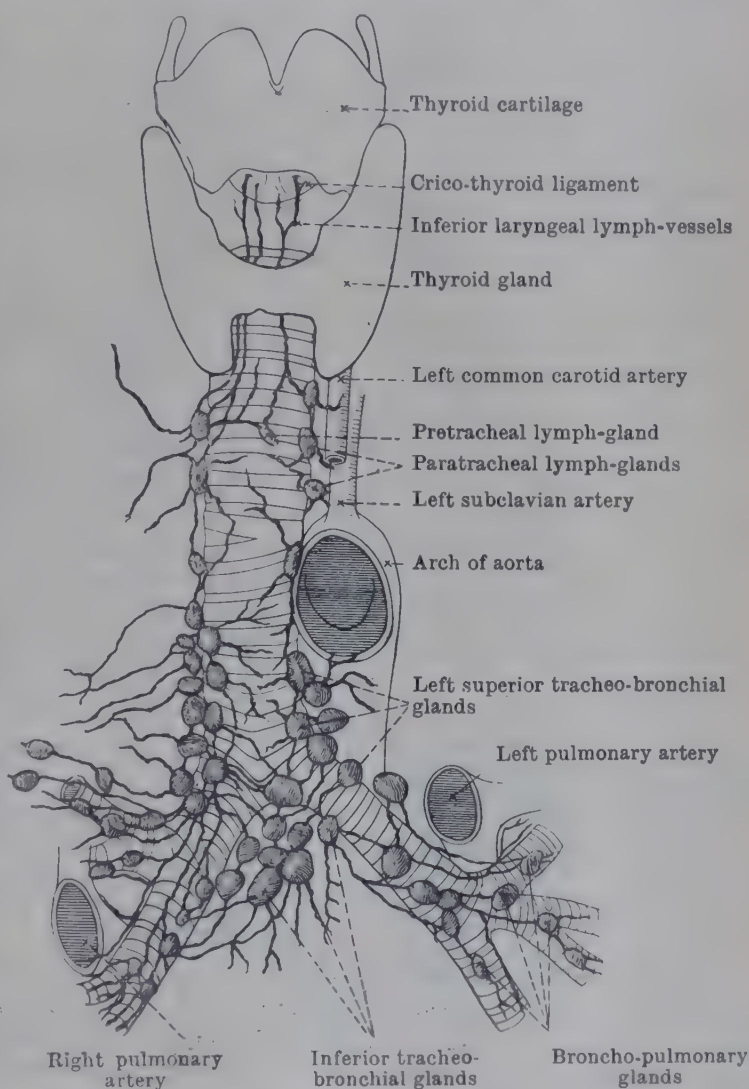

FIG. 1170.—LYMPH-GLANDS IN RELATION TO TRACHEA AND MAIN BRONCHI.

The ultimate *efferents* of all these lymph-glands unite to form a single vessel on each side of the trachea which usually joins the single efferent of the internal mammary glands to form the **mediastinal lymph-trunk**. This trunk usually enters the front of the junction of the subclavian and internal jugular veins, but the left trunk may join the thoracic duct and the right may join the jugular or the subclavian lymph-trunk or unite with them to form a right lymphatic duct (see pp. 1405, 1406).

LYMPH-VESSELS OF DIAPHRAGM AND THORAX

Lymph-Vessels of Diaphragm (Fig. 1169).—An extensive lymph-plexus is present on each surface—abdominal and thoracic—of the diaphragm. The subserous parts of the plexuses (beneath the parts of the diaphragm covered with peritoneum and pleura) are

surface also pierce the diaphragm to join with vessels from the thoracic surface on their way to the retrosternal (anterior diaphragmatic) lymph-glands. From the lateral and posterior parts of the abdominal surface, vessels may take a similar course through the diaphragm to reach the middle diaphragmatic glands, and a comparatively small number follow the course of the phrenic arteries to end in upper aortic glands on the crura of the diaphragm.

Lymph-vessels from the thoracic surface of the diaphragm run in three directions to glands situated within the thorax: (1) from the anterior part to the retrosternal lymph-glands; (2) from the lateral part to the middle diaphragmatic glands; and (3) from the posterior part of the surface to the posterior mediastinal (posterior diaphragmatic) glands. Some vessels of the posterior part of the thoracic surface may pierce the diaphragm and run with vessels of the abdominal surface to aortic glands.

The lymph-vessels that pass from the abdominal surface of the diaphragm to the middle and anterior (retrosternal) diaphragmatic glands are in communication with lymph-vessels of the liver.

Lymph-Vessels of Parietal Pleura.—The parietal pleura is drained by vessels which issue from its outer surface and form larger collecting vessels in the extrapleural areolar tissue. The collecting vessels from the **costal pleura** in general run in two directions—backwards with the intercostal blood-vessels to the intercostal glands, and forwards to the retrosternal and internal mammary glands. But vessels from the pleural lining of the axillary parts of the second and third intercostal spaces usually—and from the fourth and fifth spaces sometimes—pierce the intercostal muscles and emerge with the lateral cutaneous branches of the intercostal nerves to end in axillary lymph-glands (Rouvière, 1932). Vessels from the costal pleura of the first space run upwards through the thoracic inlet and end with those of the **cervical pleura** in lower deep cervical glands. One of them may cross the first rib with the subclavian vein and end in an apical axillary gland. Vessels from the **mediastinal pleura** pass to the tracheo-bronchial and mediastinal glands; and those from the **diaphragmatic pleura** run with the vessels of the corresponding parts of the diaphragm.

Lymph-Vessels of Lungs and Pulmonary Pleura.—Each lung possesses a plexus of vessels on the bronchial tree as far as the smallest bronchioles: there are no lymph-vessels on the alveoli. The vessels of the pulmonary (visceral) pleura penetrate the lung to join the bronchial lymph-vessels, and all emerge at the hilum and end in the glands of the root (for details see p. 720).

Lymph-Vessels of Bronchi and Trachea.—The bronchi and the intrathoracic part of the trachea drain into the lymph-glands that lie around them in the roots of the lungs and the mediastinum—broncho-pulmonary, tracheo-bronchial, and paratracheal.

Lymph-Vessels of Pericardium.—The pericardium drains into the nearest glands in front of and behind it—posterior mediastinal, retrosternal, innominate.

Lymph-Vessels of Heart.—A wide-meshed plexus of minute vessels under the endocardium—not to be confused with the injected sheath of the Purkinje network, see p. 1237 and Fig. 1068—gives rise to efferents which pierce the myocardium to join others from the richer plexus under the epicardium. The subepicardial plexus of the ventricles is easily injected, but on the atria the plexus is relatively scanty and not easily demonstrated. In consequence, the destination of the lymph-vessels of the **atria** is not well known; only a few seem to pass into the atrio-ventricular groove and join the vessels of the ventricles; it is probable that the chief drainage is from the upper parts of the atria to tracheo-bronchial glands. The collecting vessels from the **ventricles** pass into the atrio-ventricular groove and follow the coronary arteries towards their origin. Those associated with the right coronary artery usually form a single trunk which passes upwards in front of the ascending aorta to the innominate glands; those associated with the left coronary artery (draining a part of the right ventricle, as well as the whole of the left) also usually end in a single vessel which passes on the left of and behind the pulmonary trunk to one or other of the tracheo-bronchial glands—usually a member of the right superior group (Shore, 1929). (Consult also the monograph by Aagaard, 1924, and Patek, 1939.)

Lymph-Vessels of Œsophagus.—The œsophagus is drained into different groups of lymph-glands according to the situation of its parts. Its lymph-vessels run (*a*) from the *abdominal part* to the left gastric glands, (*b*) from the *lower thoracic part* to the posterior mediastinal glands, and (*c*) from the *upper thoracic* and *cervical parts* to the paratracheal glands with the vessels of the trachea.

Lymph-Vessels of Thymus.—The thymus sends vessels to the innominate glands and to the internal mammary glands of both sides.

SUBCLAVIAN LYMPH-TRUNKS

The area of drainage of the **subclavian lymph-trunk** comprises the upper limb and a cutaneous area of the trunk extending from the umbilical plane to the level of the clavicle in front and half-way up the neck behind; the vessels of the mammary gland also are included. The subclavian trunk ends in a variety of ways (see p. 1406), but very often it enters the corresponding subclavian vein directly.

Superficial and Deep Lymph-Glands of Upper Limb

The glands in the territory of the subclavian lymph-trunk comprise a few superficial glands and a greater number of deep glands including the important axillary group.

The **superficial glands** are (*a*) supratrochlear, (*b*) infraclavicular (including delto-pectoral and interpectoral): the **deep glands** are (*a*) small and inconstant nodules in the cubital fossa and on the upper parts of the arteries of the forearm, (*b*) brachial, (*c*) axillary.

Superficial Lymph-Glands of Upper Limb.—The **supratrochlear lymph-glands** are found on the medial side of the basilic vein a little above the medial epicondyle of the humerus: they receive *afferents* from the fingers and hand on the medial side of the mid-finger line and from a strip on the ulnar side of the forearm: their *efferents* join the deep stream along the basilic vein.

The **infraclavicular lymph-glands** (1-2) lie in the infraclavicular fossa on the upper end of the cephalic vein and drain some vessels from the skin of the "vaccination area" and of the shoulder, and from the upper part of the mammary gland: their *efferents* perforate the clavi-pectoral fascia to join the apical axillary glands. Outlying members of this group are found in two situations. A **delto-pectoral lymph-gland** is occasionally found in the groove between the deltoid and the pectoralis major muscles. It receives *afferents* from the skin of the lateral part of the upper arm and of the shoulder, and gives *efferents* to the infraclavicular glands and to the subclavian trunk. Small, more deeply placed, **interpectoral lymph-glands** are sometimes found between the great and small pectoral muscles. They lie in the path of the lymph-vessels which pass from the upper part of the mammary gland to the infraclavicular glands or direct to the apical glands of the axilla (Fig. 1171).

Deep Lymph-Glands of Upper Limb.—The **deep lymph-glands of the forearm** are small, inconstant, immature nodules on the radial, ulnar, and interosseous arteries and in the cubital fossa; they interrupt a few of the deep lymph-vessels. The **brachial lymph-glands** are merely outlying members of the axillary glands found occasionally along the upper part of the brachial artery. The *efferents* of all these glands pass to the lateral axillary group.

The **axillary lymph-glands** are very numerous and widely distributed in the axillary fatty tissue. They may be divided into groups below and above the pectoralis minor tendon. The lower group is subdivided into (*a*) lateral, (*b*) pectoral, (*c*) subscapular, (*d*) central. The upper group is called (*e*) apical.

The **lateral axillary glands** lie in the fatty tissue along the axillary vein. From this group the **anterior** or **pectoral** and the **posterior** or **subscapular glands** radiate along the lower border of the pectoralis minor on the chest wall with the lateral thoracic artery, and along the lateral border of the scapula with the subscapular artery. The **central group** is composed of loose members of the former three groups; they lie under the axillary fascia, and one of them frequently projects through an opening in that fascia.

The *afferents* of the lower axillary glands are (*a*) the deep vessels of the whole limb, (*b*) the cutaneous vessels of the limb and trunk above the umbilical plane, (*c*) the vessels of the mammary gland. It must be noted that all the groups

the lateral lower deep cervical glands (see p. 1433), so that some of the lymph from the axilla may go through these glands to the jugular lymph-trunk but their *efferents* go mainly to form the **subclavian lymph-trunk**, which enters

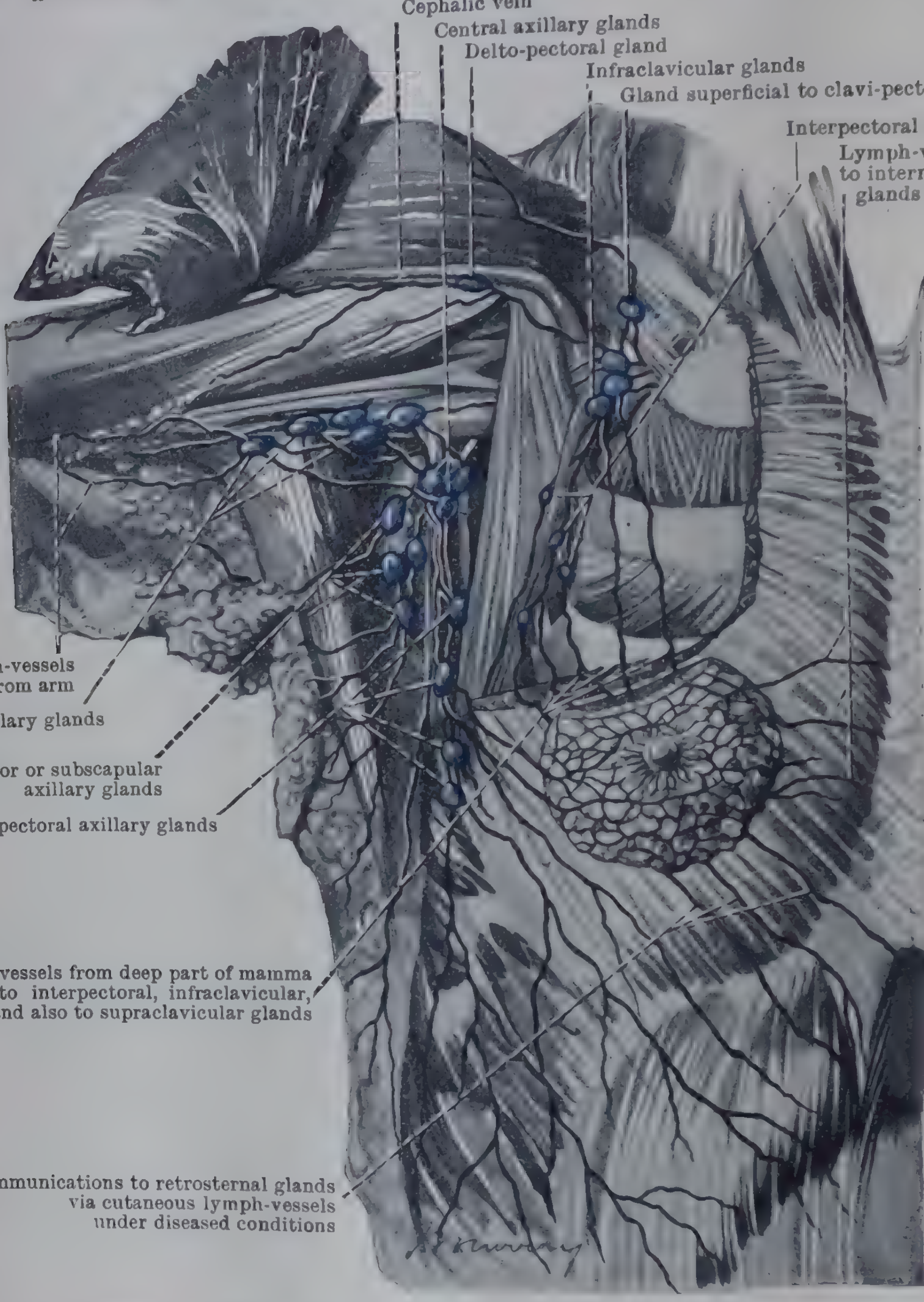

FIG. 1171.—DISSECTION OF AXILLA AND ANTERIOR PART OF THORACIC WALL, SHOWING LYMPH-GLANDS AND LYMPH-VESSELS. (Semi-diagrammatic, with only a portion of the mamma represented.)

independently into the junction of the great veins or may join the thoracic duct on the left side or unite with either the jugular or the mediastinal trunk or with both on the right side.

SUPERFICIAL LYMPH-VESSELS OF UPPER LIMB AND TRUNK

The **superficial lymph-vessels of the subclavian-trunk territory** must be considered as a whole, those of the upper limb being taken with those of the trunk above the umbilicus (including the mammary gland).

The **superficial lymph-vessels of the upper limb** begin in a rich cutaneous plexus from which vessels stream upwards irrespective of the veins. On the front of the forearm they run almost parallel to one another but with an inclination towards the axilla, and they are reinforced by vessels that slope upwards and forwards from the back of the limb round its margins. As they ascend into the upper arm some vessels on the medial side are interrupted by the supratrochlear glands, and some pass through the deep fascia with the basilic vein to join the deep stream ; but nearly all run to the axilla before they

pierce the deep fascia. The vessels from the front and back of the upper arm become more and more horizontal as they join the main stream, and some take a descending course from the front and back of the shoulder region (Figs. 1172, 1173). On the back

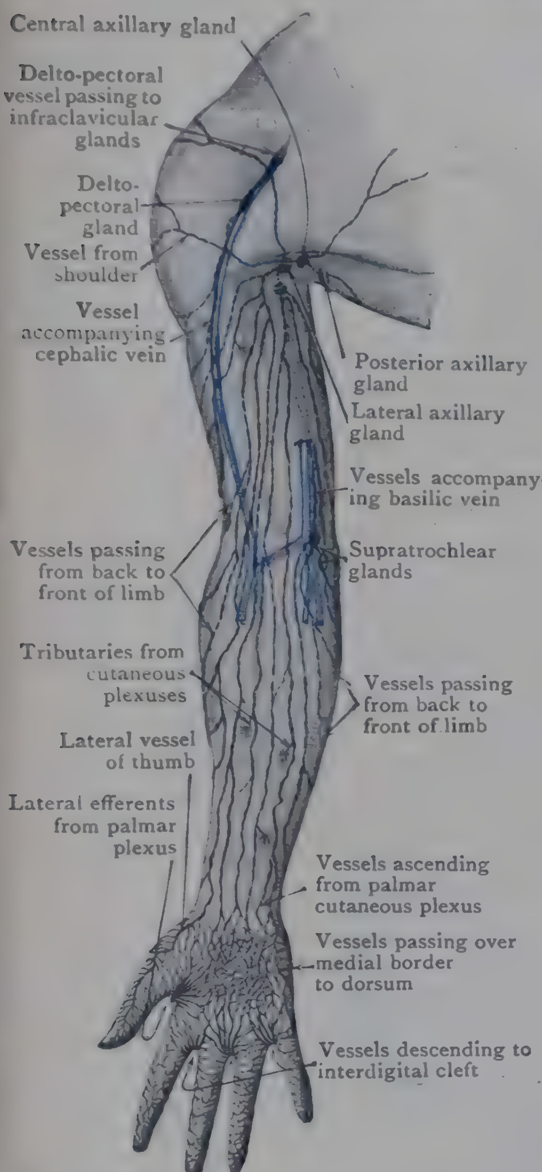

Fig. 1172.—Superficial Lymph-Vessels and Lymph-Glands of Front of Upper Limb.

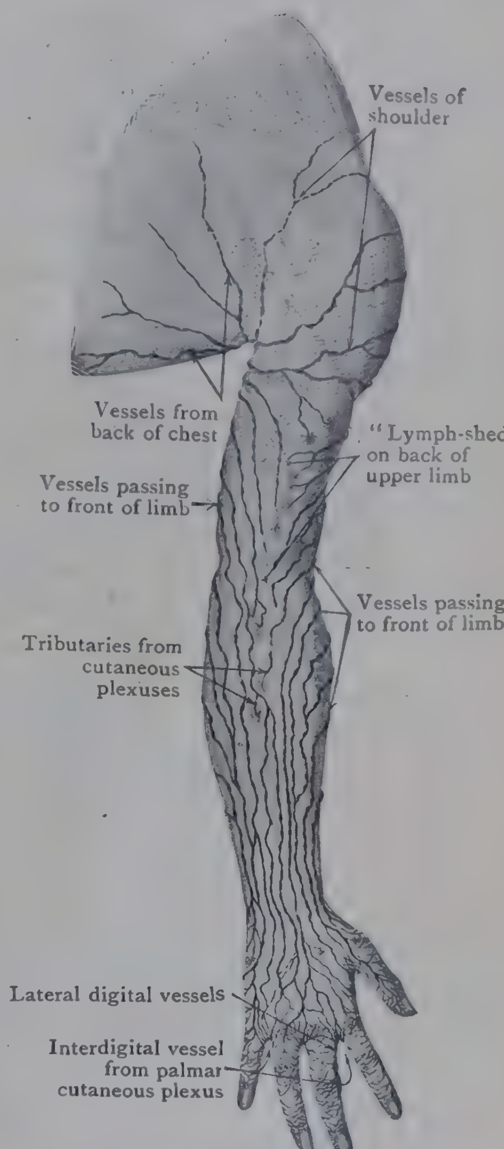

Fig. 1173.—Superficial Lymph-Vessels of Back of Upper Limb.

of the upper arm and of the elbow there is a "lymph-shed" from which vessels pass round the lateral and medial margins to the front. A few vessels from the skin over the upper part of the cephalic vein follow that vein to the infraclavicular glands, and may be interrupted in delto-pectoral glands.

The cutaneous plexuses are finest and most dense on the palmar surfaces of the fingers and hand. The efferents from the palmar digital plexus of each finger pass to the dorsum of the digit. There they form dorsal digital vessels, 2-4, which run to the dorsum of the hand, where they unite together to form new vessels.

The efferents from the palmar plexus of the hand run upwards, downwards, and to the lateral and medial margins of the hand. The lateral efferents, as they turn round the lateral border of the hand, join the efferents of the thumb. The medial efferents turn round the medial border of the hand, and join the efferents of the little finger. The efferents which run upwards are few and variable; when they are present they lie along the line of the median vein of the forearm. The efferents which run downwards pass to the interdigital clefts, where they turn backwards and join the vessels on the dorsum of the hand (Figs. 1172, 1173).

The **superficial lymph-vessels of the trunk** are arranged in a great whorl which begins at the shoulder. Behind, the vessels run downwards from the lower part of the neck, horizontally from the scapular region, and upwards from the back above the iliac crest (Fig. 1152), to converge round the posterior fold of the axilla. The vessels from the side of the trunk ascend vertically, whilst those in front gradually incline more and more horizontally until the whorl is completed by the vessels over the upper part of the

pectoral region as they descend to curve round the anterior axillary fold (Fig. 1151). The plexus of origin is continuous over the median line, and many of the vessels of one side begin on the other side. There are also several vagrant vessels which penetrate deeply along the cutaneous branches of the intercostal arteries behind and laterally, and with the perforating branches of the internal mammary and cutaneous branches of the superior epigastric in front, and thus reach the intercostal, retrosternal, and internal mammary glands. Others run with the cutaneous branches of the acromio-thoracic artery to end in the axillary and infraclavicular glands, and a few ascend over the clavicle with small blood-vessels to reach the lower deep cervical glands.

Lymph-Vessels of Mamma.—The mammary gland is a modified skin-gland; its lymph-vessels therefore run to the axillary glands like other cutaneous lymph-vessels of the region. In the infant there is already present beneath the areola of the mamma a specially developed part of the general cutaneous plexus; to this *subareolar plexus* (Sappey, 1874) the lymph-vessels of the rudimentary gland converge, and from it two or more special collecting vessels pass to the axilla. These vessels continue to be the principal route of lymph-drainage from the gland. As the gland grows, its rudimentary acini

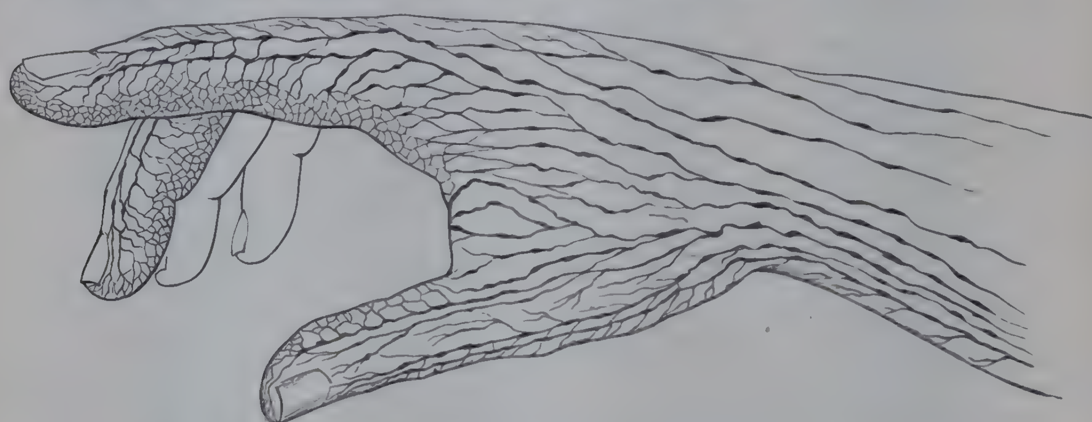

FIG. 1174.—SUPERFICIAL LYMPH-VESSELS OF THUMB AND FOREFINGER.

develop and thrust themselves radially into the subcutaneous fat to form the lobules. The glandular lymph-vessels develop *pari passu* with the lobules; perilobular plexuses are formed from which vessels pass to the surface along the lactiferous ducts; and the subareolar plexus continues to receive them.

From the subareolar plexus two main vessels (Fig. 1171) run round the axillary fold and follow the lower border of the pectoralis minor to the upper members of the anterior (pectoral) group of axillary glands situated along the lateral thoracic vein. The greater part of the mammary gland is drained by this route, but from the peripheral lobules other vessels pass in different directions to other groups of lymph-glands. From the lower part of the gland some follow the route taken by the principal vessels to the axilla. They end also in the anterior group of lymph-glands; but it should be noted again that all the groups of axillary lymph-glands are interconnected, and that lymph-vessels from the mamma may pass *directly* to any group, even to the lateral group along the axillary vein. From the upper part of the gland and from its deep surface, vessels run over or through the pectoral muscles to the apical axillary lymph-glands, either directly or via the infraclavicular group; some of these vessels are interrupted in the small interpectoral lymph-glands (see p. 1427). From the medial part of the mammary gland a few vessels pierce the pectoralis major and pass through the anterior ends of the intercostal spaces to reach the internal mammary chain of lymph-glands.

The cutaneous vessels must be remembered as an important part of the lymph-drainage of the mamma. These are included in the account already given of the superficial lymph-vessels of the trunk: and it should be noted that some of them pass deeply between the lobules of the gland. They may thus appear to issue from its substance and give the impression that the direct drainage from the periphery of the gland is more extensive than it really is. These cutaneous vessels pass to the axillary, infraclavicular, and internal mammary lymph-glands, and a few ascend from the skin of the upper part of the mamma to the lower deep cervical glands. From the skin of the medial part of the mamma, vessels may pass across the median plane to internal mammary and axillary lymph-glands of the opposite side. No path has been found from the mamma via the superior epigastric vessels to the retrosternal glands in health;

but when diseased conditions have spread into the cutaneous plexus below the gland, these lymph-glands may be affected (Fig. 1171).

Deep Lymph-Vessels of Upper Limb

The **deep lymph-vessels of the upper limb** accompany the deeper blood-vessels. Some of the deep lymph-vessels of the hand and forearm may be interrupted in the deep glands which are occasionally present in the forearm, but most of them either end in the cubital or brachial glands, or pass directly to the lateral group of axillary glands.

JUGULAR LYMPH-TRUNKS

The area of drainage of the **jugular lymph-trunk** comprises the head and neck—except the skin of the lower part of the back of the neck—and the parts drained by such deep lymph-vessels as may accompany the transverse cervical artery. The trunk is formed by the union of the efferents of the superior and inferior deep cervical lymph-glands; the right trunk enters the angle of union of the internal jugular and subclavian veins, and the left trunk joins the thoracic duct.

Lymph-Glands of Head and Neck

The arrangement of lymph-glands and vessels in the head and neck is less simple than in other parts of the body, and there is some added difficulty of description from the facts that the apical group of axillary glands merges with

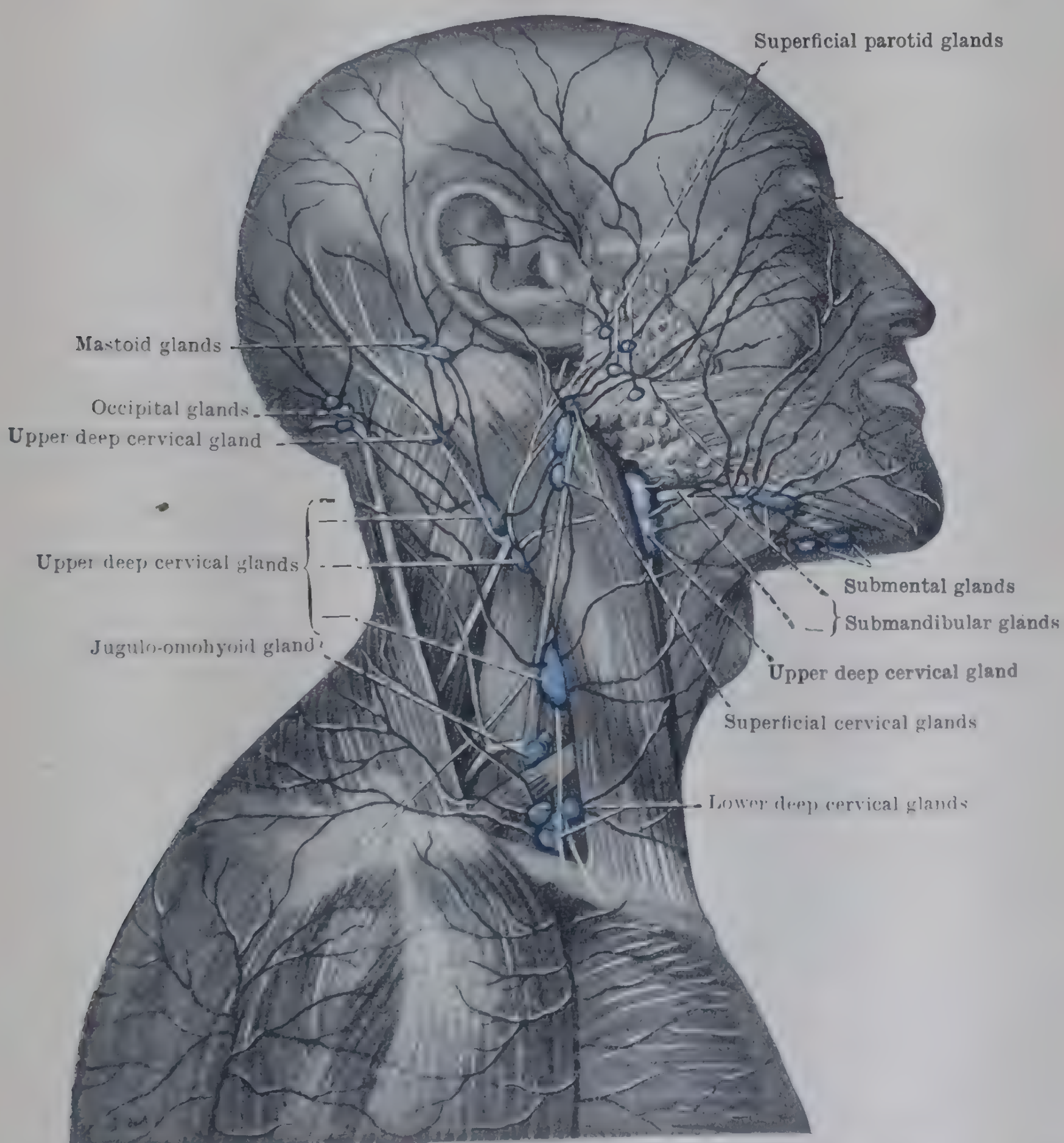

Fig. 1175.—Lymph-Glands of Head and Neck as seen with Sterno-Mastoid in Position. The occipital, mastoid, and superficial parotid glands are inserted in accordance with descriptions. The other glands were present in one or other of the two bodies from which the drawing was made. Compare Fig. 1177.

the glands in the root of the neck, and that the paratracheal group extends upwards from the thorax into the neck, and sends its upper efferents to join the jugular lymph-trunk. Further, the lymph-glands of the neck in reality form one continuous group with numerous offshoots. It is convenient, however, in order that a bird's-eye view of the whole system may be obtained, to describe a main chain of glands along the great vessels of the neck and subsidiary groups along the course of the branches of the external carotid artery and on the inferior thyroid artery.

The glands thus arranged are:—

(1) Deep cervical glands (jugular chain).

(2) Glands associated with the scalp and face, forming a "collar-chain" between the head and the neck: (*a*) occipital; (*b*) mastoid; (*c*) parotid and superficial cervical; (*d*) submandibular, with facial glands; (*e*) submental.

(3) Anterior cervical glands: (*a*) infrahyoid; (*b*) prelaryngeal; (*c*) pretracheal; (*d*) paratracheal.

Deep Cervical Lymph-Glands.—The deep cervical lymph-glands extend from the base of the skull to the root of the neck, along the path of the great vessels

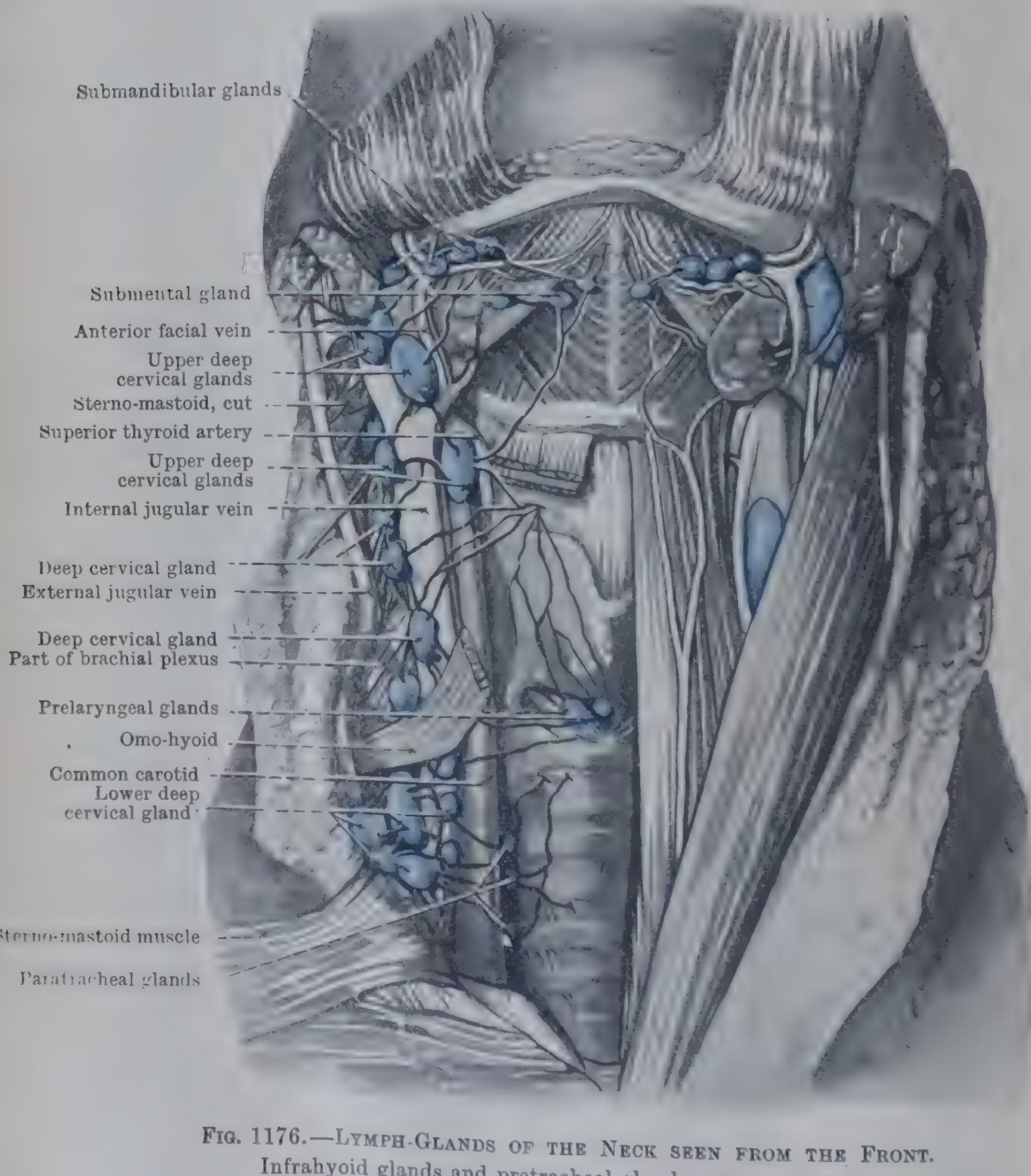

FIG. 1176.—LYMPH-GLANDS OF THE NECK SEEN FROM THE FRONT.
Infrahyoid glands and pretracheal glands were not present.

on each side of the pharynx and gullet. Most of them are concealed by the sterno-mastoid, but the oblique direction of the muscle leaves uncovered the lower end of the chain, which thus invades the lower part of the posterior triangle of the neck. Numerous members also project at the posterior border of the

sterno-mastoid and stray backwards into the posterior triangle. When enlarged by disease the row of bulging glands forms an obvious swelling along the posterior border of the sterno-mastoid. It is customary to divide the chain into superior and inferior parts, but only for the same reason as in the axilla—the fact that a muscle (omo-hyoid) crosses the chain. Nevertheless, the chain is continuous: its division into groups is a topographical convenience only. It is likewise convenient to subdivide each part of the chain into medial and lateral groups.

Superior Deep Cervical Lymph-Glands.—(1) The *medial group* of upper deep cervical lymph-glands lies on the superficial surface of the internal jugular vein and in the carotid triangle of the neck. The highest members of the group are slightly separated from the rest; they are known as **retropharyngeal glands**, and lie behind the lateral border of the naso-pharynx on the prevertebral fascia in front of the rectus capitis anterior. They receive *afferents* from the naso-pharynx, the pharyngo-tympanic tube and the atlanto-occipital and atlanto-axial joints. Below these a few, small **deep parotid lymph-glands** are embedded in the deep surface of the parotid salivary gland and even in its substance (see p. 1434). Below the parotid the chain becomes exuberant; its numerous members are mainly associated with the internal jugular vein under the sterno-mastoid; but they stray forwards so as to appear in the anterior triangle of the neck—notably one group, the largest member of which is frequently palpable below the angle of the jaw. This gland lies under the common facial vein in the interval between the digastric muscle and the internal jugular vein, and hence it has been named the *jugulo-digastric lymph-gland* (Leaf, 1898) (Fig. 1177); it is specially associated with the lymph-drainage of the tongue and of the tonsil. The lowest gland of the group projects beyond the posterior border of the sterno-mastoid immediately above the tendon of the omo-hyoid muscle—the *jugulo-omohyoid gland* (Jamieson & Dobson, 1920) (Fig. 1175); it receives efferents from the submental glands and also lymph-vessels from the tongue, including one direct from the tip. (2) The members of the *lateral group* of upper deep cervical lymph-glands lie under cover of the posterior part of the upper portion of the sterno-mastoid and in the upper part of the posterior triangle of the neck. They are embedded in the fat-laden fascia which covers the roots of the cervical plexus and the upper part of the brachial plexus, and the levator scapulæ and the scalene muscles, and several of them are in close relation with the accessory nerve (Figs. 1175, 1177).

The upper deep cervical glands receive *afferent* vessels from various subsidiary groups of glands (see pp. 1434, 1435). They receive lymph, directly or indirectly, from the skin of the head and neck, from the nose, the mouth, the tongue, the pharynx and larynx, the tonsil, the upper part of the thyroid gland, the submandibular, sublingual, and parotid salivary glands. Their *efferents* pass partly to the lower deep cervical glands and partly to the jugular lymph-trunk.

Inferior Deep Cervical Lymph-Glands (Figs. 1176, 1177).—These glands are situated below the level of the omo-hyoid muscle. They are mainly under cover of the sterno-mastoid, the trapezius and the clavicle, but some of them appear in the lower part of the posterior triangle of the neck. (1) The members of the *medial group* lie in relation with the lower part of the internal jugular vein, opposite the interval between the sternal and clavicular heads of the sterno-mastoid. They receive *afferents* from some of the upper deep cervical glands and from the pretracheal and the paratracheal glands. Their *efferents* unite with some of the efferents of the upper medial group and pass with them to the jugular lymph-trunk.

(2) The members of the *lateral group* of lower deep cervical glands lie in the fatty tissue superficial to the brachial plexus and the third part of the subclavian artery, and they extend beneath the trapezius along the transverse cervical blood-vessels. They receive lymph from the skin of the back of the neck and a few vessels which ascend over the clavicle from the skin of the pectoral region, including the upper part of the mamma, and they are in communication with the apical group of axillary glands. Their *efferents* join the jugular lymph-trunk.

The subsidiary offshoots of the deep cervical glands are found in the track of the smaller arteries.

The **anterior cervical lymph-glands** are in small outlying groups—

(1) With the superior thyroid artery: (*a*) the *infra-hyoid glands* on the thyro-hyoid membrane; (*b*) *prelaryngeal glands* on the crico-thyroid ligament.

(2) With the inferior thyroid artery: (*a*) *pretracheal glands* at the lower end of the thyroid gland; (*b*) the upper *paratracheal glands* in the groove between trachea and œsophagus. These glands receive lymph from the larynx, the trachea and œsophagus in the neck and the thyroid gland; and they transmit it to the lower deep cervical glands.

(3) With the lingual artery in relation to the hyo-glossus, a few small occasional

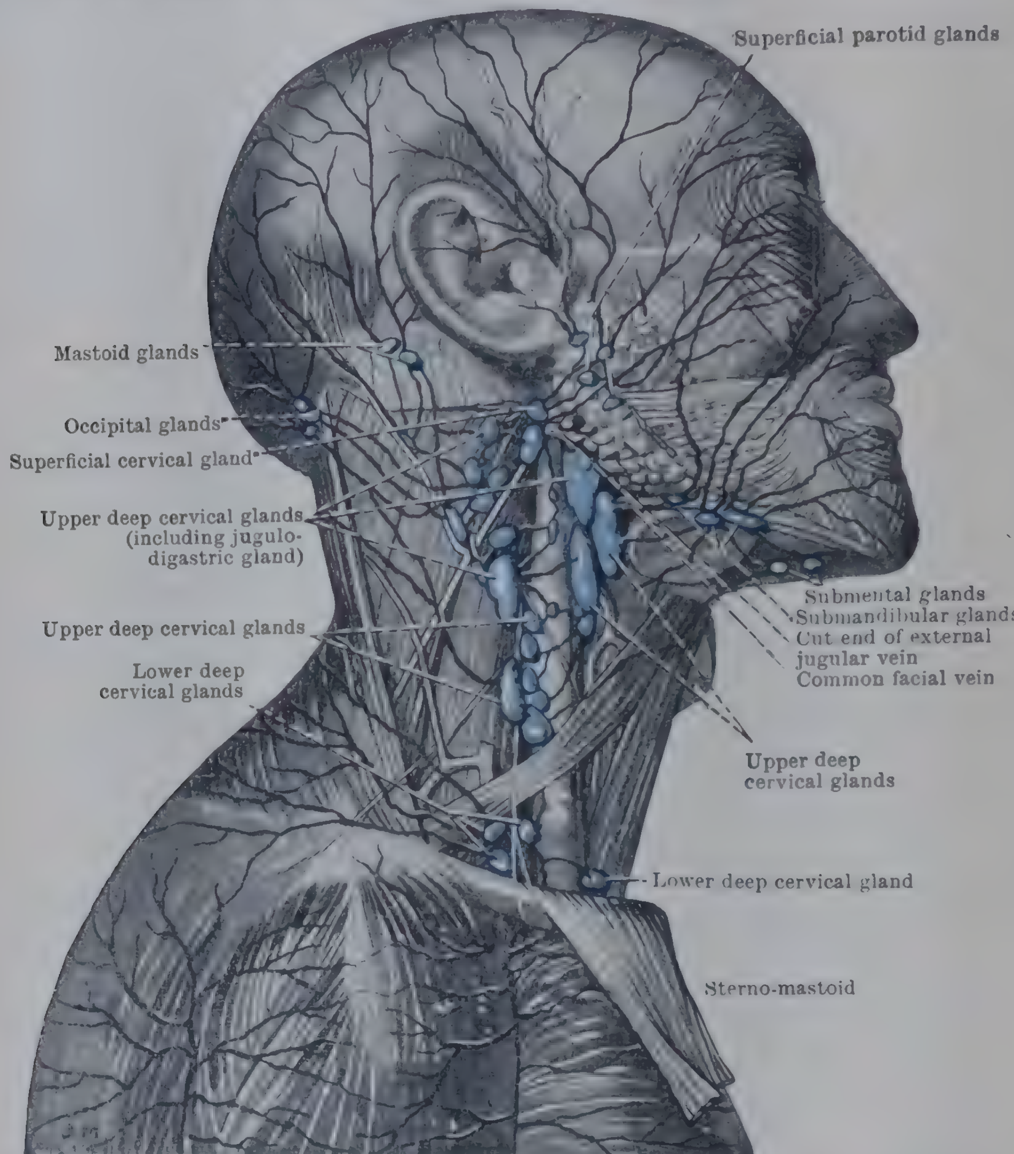

FIG. 1177.—LYMPH-GLANDS OF HEAD AND NECK AS SEEN AFTER REMOVAL OF STERNO-MASTOID MUSCLE. The occipital, mastoid, and superficial parotid glands are inserted in accordance with descriptions. The other glands were present in one or both of the bodies from which the figure was made. Compare Fig. 1175.

lingual glands on the course of some of the lymph-vessels of the tongue; and with the maxillary artery, occasional small glands in the infratemporal region.

The "collar" glands in the course of the facial, superficial temporal, posterior auricular and occipital blood-vessels require particular description.

The **occipital lymph-glands** (1-2) are situated on the occipital vessels as they emerge through the trapezius; their *afferents* come from the scalp, and their *efferents* pierce the deep fascia to join the deep cervical glands.

The **mastoid lymph-glands** (2-3) lie on the mastoid process; the largest is a flat coin-like gland frequently palpable. Their *afferents* come from the scalp and the back of the auricle, and the *efferents* run round the edge of the sterno-mastoid muscle or through it to the deep glands.

The **parotid lymph-glands** are embedded partly in the superficial surface of the

parotid salivary gland under the deep fascia and partly in its substance. The more superficial (pre-auricular) glands receive numerous afferents from the front of the auricle and from the scalp, forehead, eyebrow, eyelids and cheek; and their *efferents* pass to the deeper glands and to the upper deep cervical glands (jugulo-digastric). The deeper parotid lymph-glands receive *afferents* from the external auditory meatus, the pharyngo-tympanic tube and the tympanum, the soft palate, the posterior part of the nasal cavity and the deeper portions of the cheek. Their *efferents* pass to the upper deep cervical glands.

The **superficial cervical lymph-glands** (Fig. 1175) are merely the lower end of the superficial parotid group and may stray some distance down along the external jugular vein; they are small and become conspicuous only when diseased.

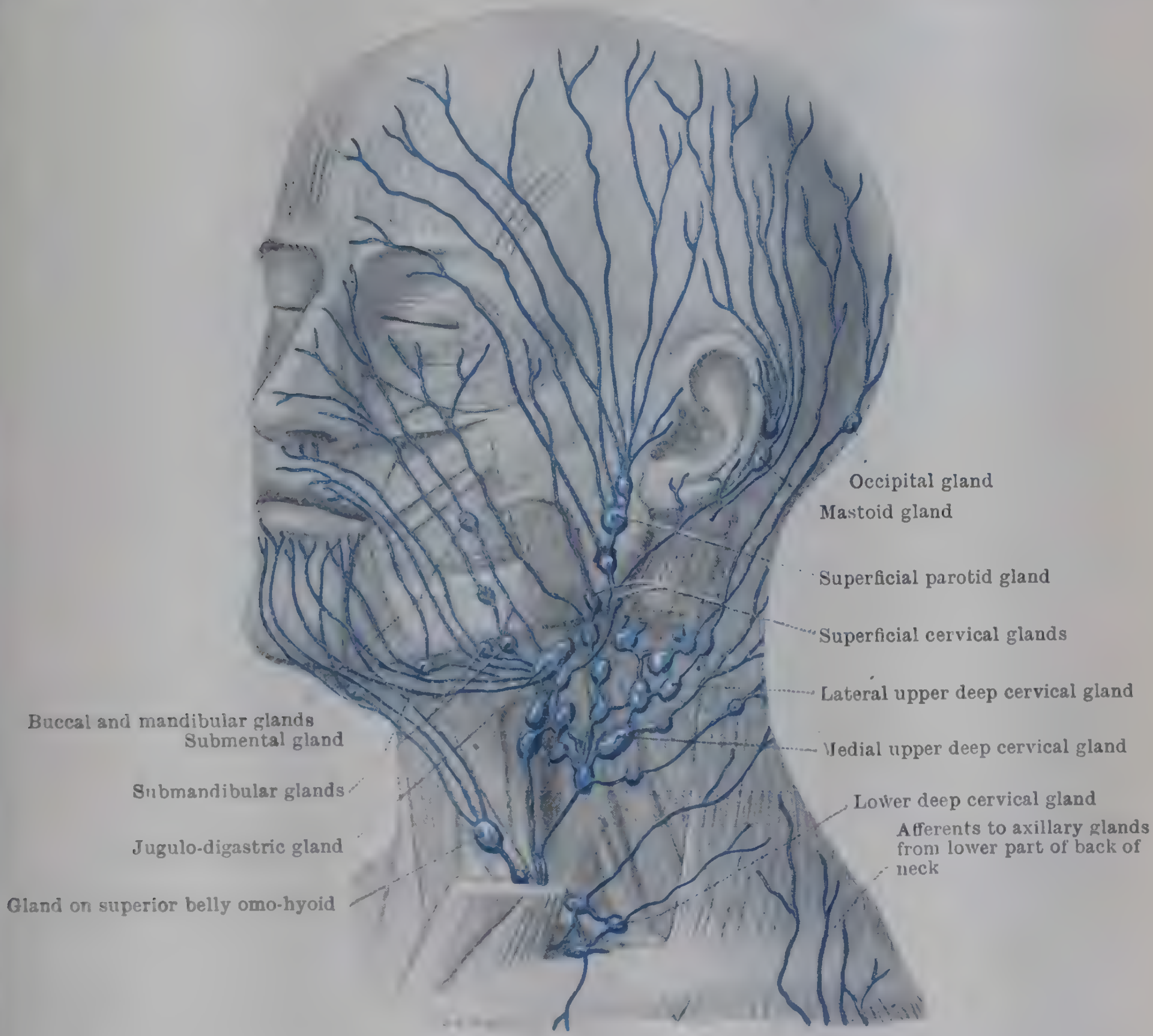

Fig. 1178.—Superficial Lymph-Vessels of Scalp and Face, and Superficial ("Collar") Lymph-Glands between Head and Neck

The **submandibular lymph-glands** (4-6) lie in the chink between the jaw and the submandibular salivary gland; the larger members are in contact with the facial vessels, and one may be placed between the salivary gland and the digastric. They receive the cutaneous vessels of the face below the eye, and many of the vessels of the tongue; the *efferents* run to the deep cervical glands, notably the jugulo-digastric and jugulo-omohyoid.

Minute glands are not infrequently found on the course of the vessels of the face, and may be named *infra-orbital*, *buccal*, and *mandibular* according to their position (Fig. 1178).

The **submental lymph-glands** (1-4) of the two sides form a composite group that lies on the mylo-hyoid muscles midway between the symphysis and the hyoid bone; their *afferents* are derived from the lower lip and chin, mingled with those passing to the submandibular lymph-glands, and from the tip of the tongue; their *efferents* run to the deep cervical glands as far down as the jugulo-omohyoid gland.

Lymph-Vessels of Head and Neck

The **superficial lymph-vessels** of the **scalp** and **forehead** run on the general lines of the occipital, posterior auricular, and superficial temporal blood-vessels to the *occipital, mastoid,* and *parotid* lymph-glands; from the **eyelids** and **cheeks** they pass to the *parotid* and *submandibular* lymph-glands; from the **nose, lips,** and **chin** to the *submandibular* and *submental* glands (Figs. 1175, 1178). These glands constitute the "collar chain" of glands; but it is important to note that it is not a complete barrier; many vessels from all parts of the scalp and face slip past these glands and run into the deep cervical chain (Fig. 1178). The superficial vessels of the **neck** perforate the deep fascia at numerous points to enter the deep cervical glands; a few on the upper part of the back of the neck

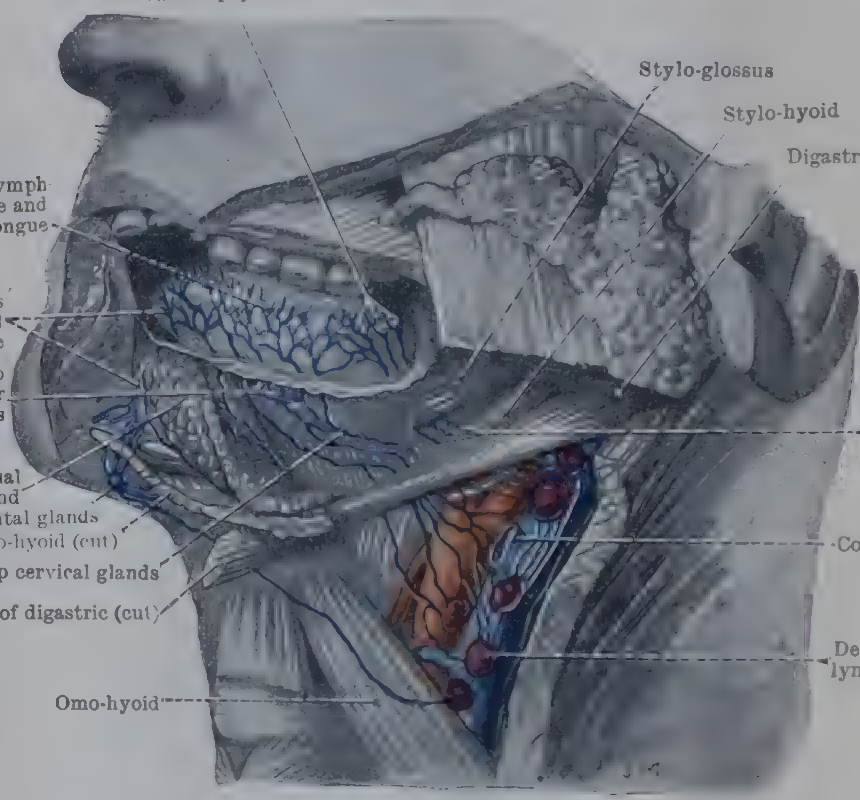

Fig. 1179.—Lymph-Vessels of Tongue.

are interrupted first by a few minute nodules that lie on the trapezius; and those from the lower part of the back of the neck join the stream which runs to the axillary glands around the posterior fold of the axilla.

Lymph-Vessels of Eyelids and Conjunctiva.—These vessels arise from cutaneous and sub-conjunctival plexuses, and form two groups, a medial and a lateral; some run superficial to the orbicularis oculi, and others deep to it. (*a*) The *medial vessels* drain a very small part of the skin only of the upper eyelid, and about one half of the skin and conjunctiva of the lower eyelid; they follow the course of the anterior facial vein to the submandibular lymph-glands, and some of them may be interrupted in the infra-orbital and buccal glands. (*b*) The *lateral vessels* (6-7) drain the greater part of the skin of the upper eyelid and the whole of its conjunctiva, and about one half of the skin and conjunctiva of the lower eyelid. They pass backwards, more or less along the line of the transverse facial vessels, and end in the parotid and superficial cervical lymph-glands. (See also p. 1175 and Burch, 1939.)

Lymph-Vessels of Orbit.—It is doubtful if any true lymph-vessels exist in the **eyeball**. Lymph-spaces have been described in the coats of the eyeball, and lymph-vessels are stated to exist in the choroid coat, but their existence is uncertain.

The lymph-vessels of the **lacrimal gland** run with the lateral palpebral lymph-vessels to the parotid lymph-glands (Orts, 1929). Those of the **lacrimal sac** separate, one running laterally beneath the conjunctiva to pass to a parotid lymph-gland, others joining medial palpebral vessels to reach the submandibular lymph-glands.

Lymph-Vessels of Ear.—The lymph-vessels from the anterior portion of the lateral surface of the upper part of the **auricle** end in the parotid lymph-glands. Those from the lower part of the auricle go to the superficial cervical glands. Those from the medial surface and from the posterior portion of the upper part of the lateral surface of the

auricle end in the mastoid glands, but some of them may establish direct communication with the upper deep cervical glands. The lymph-vessels of the **external auditory meatus** are associated with those of the auricle and end in the parotid and mastoid glands.

The lymph-vessels of the **middle ear** pass in two directions. Those from the lateral wall of the cavity join the vessels of the **tympanic membrane** and of the external auditory meatus and end in the parotid glands. The lymph-vessels which drain the medial wall and the **pharyngo-tympanic tube** end in the retropharyngeal and upper deep cervical glands.

It is doubtful if any lymph-vessels exist in the **internal ear**. It is possible that the perilymph drains into the subarachnoid space of the posterior fossa of the skull along the line of the ductus endolymphaticus, and that the endolymph reaches the subarachnoid space along the fibres of the auditory nerve.

Lymph-Vessels of Nose.—The lymph-vessels from the **external nose** pass mainly to the submandibular lymph-glands, but a vessel from the root of the nose may pass with those of the upper eyelid to a parotid gland. The vessels of the **nasal cavity** arise from a plexus in the muco-periosteum. Those from the anterior part of the cavity accompany the vessels of the lower portion of the external nose and end in the submandibular glands. Those from the posterior part end partly in the medial upper deep cervical glands and partly in the retropharyngeal glands.

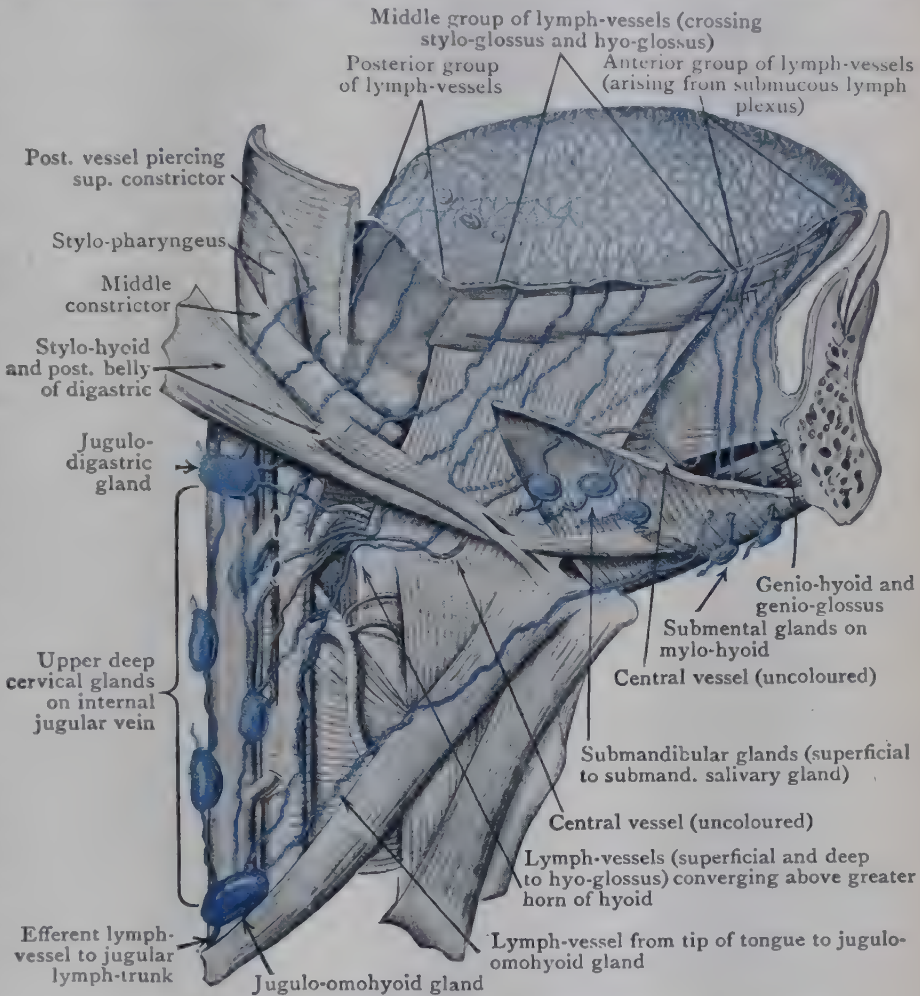

Fig. 1180.—Diagram of Course of Lymph-Vessels of Tongue.

Only one central vessel is shown (uncoloured). Central vessels and one or more of the posterior group may cross the median plane and end in deep cervical glands of the opposite side.

It has been shown by experiment that dyes applied to the nasal mucous membrane appear very rapidly in the cervical glands (Yoffey & Drinker, 1938).

There is little definite knowledge regarding the lymph-vessels of the **paranasal sinuses**, but it is probable that they follow the vessels of the nasal cavities and end in the same glands. Spaces of lymphatic character accompany the olfactory nerves into the cranium.

Lymph-Vessels of Lips.—The lymph-vessels of the lips arise from cutaneous and mucous plexuses. Those from the skin of the medial part of the lower lip pass to the submental glands and often cross the median plane. The cutaneous vessels from the lateral part of the lower lip unite with those from the upper lip and end in the submandibular glands, but some from the upper lip may end in the superficial cervical glands.

The lymph-vessels from the mucous membrane of the lips take the same course and end in the same glands as those of the skin; but they tend to spread more widely. Those of the upper lip, though ending mainly in the submandibular glands, may reach parotid and submental glands; and those from the medial part of the lower lip pass to submandibular as well as to submental lymph-glands.

Lymph-Vessels of Cheeks.—Most of the superficial and deep lymph-vessels of the cheeks pass to the submandibular lymph-glands, but some of them may reach the superficial cervical or the upper deep cervical glands. They may be interrupted in the buccal glands.

Lymph-Vessels of Gums.—The vessels from the outer parts of both mandibular and maxillary gums end in the submandibular glands. Occasionally a vessel from the anterior part of the mandibular gum ends in a submental gland. The vessels from the inner part of the mandibular gum end in the submandibular and upper deep cervical glands; those of the inner part of the maxillary gum run with the vessels of the hard and the soft palate, and end mainly in the upper deep cervical glands.

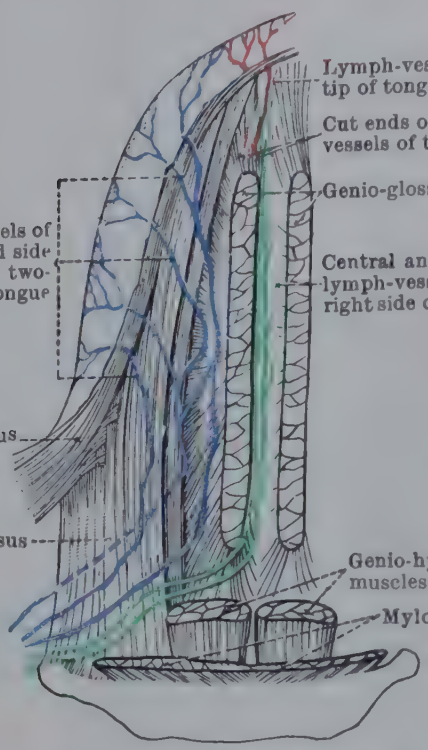

Fig. 1181.—Diagram of Lymph-Vessels of Anterior two-thirds of Tongue, seen from below. (After Poirier & Cunéo, 1902, modified.) Anterior vessels, *red*; middle vessels, *blue*; central vessels, *green*.

Lymph-Vessels of Teeth.—Lymph-vessels have been injected in the pulp of the teeth (Schweitzer, 1907; Noyes & Dewey, 1918). Those of the lower teeth run in the mandibular canal and end in the submandibular or the upper deep cervical glands. Those of the upper teeth emerge from the infra-orbital foramen and pass with vessels of the face to the submandibular glands.

Lymph-Vessels of Palate.—These vessels run backwards to join those of the inner parts of the maxillary gums and end mainly in upper deep cervical glands. But vessels from the palate may occasionally continue backwards to reach the retropharyngeal glands or pass downwards in the cheek to the submandibular glands.

Lymph-Vessels of Tongue.—The lymph-vessels of the tongue arise from a rich capillary plexus in the mucous membrane; and they end in the submental, submandibular and upper deep cervical lymph-glands. The vessels are arranged in four groups—anterior, middle, posterior, and central (Jamieson & Dobson, 1920).

The *anterior vessels* drain the tip and the inferior (free) surface. They pierce the mylo-hyoid muscle and end in the submental lymph-glands—all except one vessel which passes the submental glands, crosses the hyoid bone and ends in the jugulo-omohyoid gland.

The *middle vessels* drain the anterior two-thirds of the dorsum and margins (except the tip). They pass downwards, at different depths, to end in the submandibular and upper deep cervical glands. Those that end in the submandibular glands pass superficial to the sublingual salivary gland and pierce the mylo-hyoid muscle. Others run in a deeper plane, over both surfaces of the hyo-glossus, and end in any of the deep cervical glands between the digastric muscle and the omo-hyoid.

The *posterior vessels*—larger than the others—drain the posterior third of the dorsum. They first run backwards beneath the mucous membrane, and then turn laterally to pierce the wall of the pharynx below the tonsil; they also end in the deep cervical chain—principally in the jugulo-digastric gland.

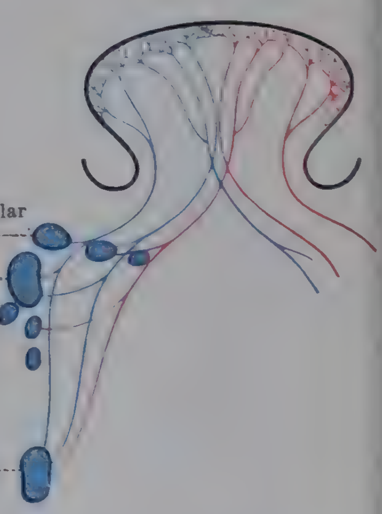

Fig. 1182.—Diagram of course of Central Lymph-Vessels of Tongue to show Crossing of Median Plane. (Jamieson & Dobson, 1920.)

The *central vessels* arise in the dorsal plexus near the median plane. They descend between the genio-glossi, and are joined by vessels from the deep parts of the tongue. They then run laterally and backwards, with the veins of the tongue, and end in upper deep cervical glands below the digastric muscle (Fig. 1181).

It is important to note that any of the upper deep cervical glands below the digastric may receive lymph-vessels direct from the tongue; and that, in general, the farther forward the origin of the vessel the lower down is the gland in which it ends. Note also that some

members of the anterior, posterior, and central groups cross the median plane to end in glands of the opposite side (Fig. 1182).

Lymph-Vessels of Floor of Mouth.—The capillary plexus of the mucous membrane of the tongue is continuous across the floor of the mouth with the plexus of the mandibular gum. The lymph-vessels that arise from that part of the mucous membrane of the mouth run with the anterior, middle and posterior vessels of the tongue to the same lymph-glands —submental, submandibular, and upper deep cervical.

Lymph-Vessels of Salivary Glands.—The lymph-vessels of the **parotid gland** end in the neighbouring parotid lymph-glands. One or two lymph-vessels of the **submandibular gland** end in the submandibular lymph-glands, but most of them go to the upper deep cervical glands. Lymph-vessels from the anterior part of the **sublingual gland** end in the submandibular lymph-glands, and others from the posterior part run to upper deep cervical glands between the digastric and the omo-hyoid muscles.

Lymph-Vessels of Pharynx.—From the nasal part of pharynx, including the **naso-pharyngeal tonsil,** and from the posterior wall and lateral borders of the oral and laryngeal parts, the lymph-stream flows to the median line posteriorly. There the larger vessels pierce the walls of the pharynx; they then turn laterally and end in the retro-pharyngeal and upper deep cervical glands.

From the anterior wall of the laryngeal part of the pharynx, that is, from the region of the piriform fossæ and the posterior surface of the larynx, the lymph-vessels pass along the course of the superior laryngeal artery, pierce the thyro-hyoid membrane, and end in the upper deep cervical glands.

The lymph-vessels of the **tonsil** and the adjacent parts of the palato-glossal and palato-pharyngeal arches pierce the lateral wall of the pharynx and end in upper deep cervical glands immediately below the posterior belly of the digastric—many of them in the jugulo-digastric gland.

Lymph-Vessels of Thyroid Gland.—These vessels arise in the intervesicular tissue of the gland and form a dense subcapsular plexus on its surface (Figs. 694, 695, p. 813), common to both lobes and the isthmus; therefore the lymph can pass from the lobe of one side to the terminal glands of the opposite side. The collecting vessels from the upper part of each lobe and of the isthmus end in the upper deep cervical glands and one of them may pass to a retropharyngeal gland; those from the lower part of the isthmus and of each lobe end in the pretracheal and paratracheal glands and one of them may pass down to an innominate gland; those from the side of each lobe pass to the deep cervical glands. It has been stated that a lymph-vessel from the right lobe occasionally ends directly in the right subclavian vein (Mahorner *et al.*, 1927), and that one from the left lobe may end in the thoracic duct without the intervention of a lymph-gland (Rouvière, 1932).

Lymph-Vessels of Larynx.—The lymph-plexus of the larynx is separable into upper and lower portions; they are connected together on the posterior wall of the cavity, but are separated, laterally and anteriorly, by the vocal folds, which contain only a few fine capillary vessels. The lymph-vessels of the upper part pass mainly along the superior larnygeal artery; they pierce the thyro-hyoid membrane with lymph-vessels of the pharynx, and end in the upper deep cervical glands; some of them may be interrupted in the infrahyoid glands. The efferent vessels from the lower part of the larynx emerge in two groups. Those from the anterior region pierce the crico-thyroid ligament and end in the prelaryngeal, the pretracheal and the deep cervical glands. The efferents from the postero-lateral region pierce the crico-tracheal membrane and end in the paratracheal and lower deep cervical glands (Fig. 1176).

Lymph-Vessels of Cervical Parts of Trachea and Œsophagus.—The collecting vessels of the cervical parts of the trachea and œsophagus end in the paratracheal and the inferior deep cervical glands. From the upper part of the trachea some vessels pass to the prelaryngeal glands also.

DEVELOPMENT OF LYMPHATIC SYSTEM

The lymphatic system is an adjunct of the venous system, sharing its absorbent function and emptying into the great veins in the root of the neck. The main question in the development of lymph-vessels is whether they were originally independent formations which secondarily acquired connexions with the veins, or were derived primarily from the veins as endothelial outgrowths which spread into the body from one or more definite sites.

The first obvious sign of the development of the lymphatic system is the appearance of the structures known as **lymph-sacs** which are closely related to the veins in certain situations. The first of these to appear is the jugular lymph-sac, which is present in the human embryo

of 10-11 mm., and six of them are present in the 30 mm. embryo (Sabin, 1909). Whatever the origin of these sacs, there is agreement about their position and their subsequent history.

An *anterior* or *jugular lymph-sac* is found at the union of the chief vein of the upper limb with the anterior cardinal vein; a *posterior lymph-sac* appears at the union of the chief vein of the lower limb with the posterior cardinal vein; a *retroperitoneal lymph-sac* develops at the root of the primitive mesentery; and another on the posterior wall of the abdomen is identified with the *cisterna chyli*. It may be noted that the anterior and posterior lymph-sacs are developed in the same positions as the "lymph-hearts" of the Amphibia.

Four of the lymph-sacs are thus situated at the junctions of the limbs with the trunk and the other two on the back of the abdomen. All of them—with the exception of the anterior part of the sac from which the cisterna chyli is developed—become broken up into anastomosing channels and converted later into groups of lymph-glands; and the jugular sacs acquire secondary connexions with the veins which remain as the permanent terminations of the lymph-trunks.

According to Sabin (1909, 1912, 1916), the lymph-sacs are developed as outgrowths of the endothelium of the veins near which they appear, and from the sacs all the lymph-vessels of the body sprout—radiating from them to the parts drained by the principal lymph-trunks. Thus, from the jugular sacs vessels spread into the head and neck, the upper limbs and upper part of the trunk; from the posterior sacs they spread into the lower part of the trunk and the lower limbs; and from the retroperitoneal sac at the root of the mesentery they grow towards the intestines, and from the sac which forms the cisterna to other abdominal organs. According to this view, the lymph-sacs lose their primary connexions with the veins, and only later, at the root of the neck, do the jugular sacs acquire connexions again.

According to Huntingdon (1911) and M'Clure (1915), on the other hand, all lymph-vessels are originally formed as clefts in the mesenchyme exactly as blood-vessels are formed (see p. 89). These clefts acquire an endothelial lining and unite into plexuses of capillary vessels. At first they are indistinguishable from developing veins, and indeed contain blood-cells. Later the blood in those vessels destined to become lymph-channels disappears or is discharged into the veins. According to this view, the lymph-sacs are formed by the running together of parts of the capillary plexuses which develop along the primitive venous trunks, the thoracic duct is developed by the formation of channels in these plexuses, and all the peripheral lymph-vessels arise locally by the fusion of mesenchymal spaces. For example, according to Heuer (1909), the deep plexus of the small intestine develops independently and gives rise to the superficial plexus by its growth.

There is a parallel between these two contrasting views and the older conflict on the single or multiple origin of the blood-vessels themselves. Formerly it was maintained (His) that all the blood-vessels of the embryo grow into it from those primarily developed in the wall of the yolk-sac; but it is now agreed that blood-vascular channels arise from the mesenchyme not only on the yolk-sac, in the body-stalk and in the chorion, but in exactly the same manner in the body of the embryo also, where they run together to form anastomosing channels from which the primitive blood-vessels take form. The essential feature of Huntington and M'Clure's view of the origin of lymph-vessels is the belief that endothelium may be formed directly from mesenchyme anywhere; and since that is true in the case of blood-vascular channels, it is difficult to deny that lymph-vascular channels also may arise independently in the mesenchyme. The technique of the investigation of these questions is admittedly difficult, but it may be that the chief difficulty is in the interpretation of results. The injection methods on which Sabin relied certainly appear to show that lymph-vessels radiate from the lymph-sacs; but they demonstrate only those vessels that are in communication with the sacs; they do not prove that there are no developing lymph-channels farther afield that have not yet acquired their central connexions. It is true that endothelium grows, so that capillary plexuses may sprout; but it is probable that the apparent spread of lymph-vessels from centres is due to progressive fusion rather than to peripheral outgrowth.

Lymph-Glands.—Lymph-glands are developed by the aggregation of lymphocytes in the mesenchymal strands of plexuses of lymph-vessels. As the lymphocytes accumulate they form a nodule of lymphoid tissue, and the vessels around it are transformed into the peripheral portion of the lymph-sinus. The lymphoid tissue is then broken up into cords by anastomosing lymph-channels which grow into it from the sinus, mainly on the side of the efferent vessels. The capsule is formed by condensation of areolar tissue on the surface of the peripheral sinus, and the trabeculæ of the larger glands grow inwards from it.

The great majority of lymph-glands are developed in central positions, and those that form in relation to peripheral lymph-vessels are smaller and often rudimentary. Groups of numerous glands develop in the plexuses formed by the breaking up of the lymph-sacs, including the lower part of the cisterna chyli from which cœliac and aortic glands are thus derived.

In early stages of development lymph-glands possess blood-vascular as well as lymph-capillary networks, and if the blood-vascular network preponderates over the lymph-vascular, the developing gland has a reddish appearance and is known as a hæmal gland. Such glands are found in Man as well as in other mammals, and it would appear, from the observations of Vincent & Harrison (1897), that hæmal glands are merely rudimentary forms of true lymph-glands.

Thoracic Duct.—A rich plexus of lymph-vessels is formed in the thorax around the aorta but principally behind and at its sides. The plexus, whether developed *in situ* or as anastomosing outgrowths from the sacs, communicates below with the lymph-sac that forms the *cisterna chyli*

and above with both jugular lymph-sacs. From the plexus two longitudinal vessels, with numerous transverse anastomoses, are developed. Each of these vessels may persist and terminate above in the innominate vein of its own side, and there are then two thoracic ducts. Usually the continuity of each vessel is broken at the level of the fifth thoracic vertebra, where one of the transverse anastomoses enlarges. The lower part of the left vessel and the upper part of the right disappear. The component parts of the thoracic duct are, therefore, the lower part of the right longitudinal vessel, the upper part of the left longitudinal vessel, and a transverse anastomosis between them. Its origin from the cisterna chyli may remain plexiform or double.

It is obvious that from the primitive condition many varieties of the thoracic duct might be evolved and the majority of the various possible variations have been found in adult bodies (Davis, 1915).

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SURFACE AND SURGICAL ANATOMY

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With an Appendix on RADIOGRAPHIC ANATOMY

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SURFACE Anatomy and Surgical Anatomy are associated studies which occupy an important and significant place in the medical curriculum, as they are an expression of the application of anatomical knowledge to the everyday practice of Medicine and Surgery. Their inclusion in a text-book of Anatomy is therefore fully justified; and it may serve to remind students of the importance of that study of the living body which has been mentioned in the General Intorduction as their chief aim (p. 2).

Surface Anatomy fulfils a twin-purpose; it is a description of the topography of the body-surface as influenced by the conformation of superficial structures (including skeletal landmarks), combined with a surface-orientation of related structures that lie at a deeper level. It is therefore the essential basis for the primary physical examination of a patient and for the appreciation of the significance of the symptoms and signs of disease in general.

Surgical Anatomy is directed towards a more special purpose. It is a presentation of the anatomical facts which have a local significance in relation to injury and particular diseases or to the surgical interference which these may entail.

The use of X-rays is of the greatest value in the study of both these practical aspects of Anatomy. Frequent reference is therefore made to radiographic observations and to the Plates which illustrate them—supplementing the relevant paragraphs throughout the text-book; and, since the interpretation of radiographs requires some elementary acquaintance with the methods employed in their production and some knowledge of the meaning of the appearances which they present, an Appendix has been added on the Principles of Radiography and of Radiographic Anatomy.

The Section itself is arranged on a regional basis.

HEAD AND NECK

CRANIUM

Scalp.—The first and third layers of the scalp, namely, the **skin** and the **occipito-frontalis muscle**, are firmly united by fibrous processes which pass from the one to the other through the second or subcutaneous **fatty layer**. These three layers are separated from the pericranium by a **layer of loose areolar tissue** which supports the small vessels passing between the scalp proper and pericranium. The **pericranium**, although regarded anatomically as periosteum, possesses limited bone-forming properties; over the vertex it can be readily separated from the skull-cap

except along the lines of the sutures, where it is united by sutural ligaments to the external layer of the dura mater.

The free **blood-supply of the scalp** nourishes its abundant hair-follicles and glands. The main vessels lie in the dense subcutaneous tissue, and are therefore superficial to the occipito-frontalis muscle (Fig. 1183). The arteries that supply the frontal region are derived from the internal carotid, and those for the remainder of the scalp spring from the external carotid. The two groups of vessels anastomose with one another, and also with those of the opposite side—hence it is impossible to control bleeding from one side of the scalp by ligature of the corresponding external carotid artery.

Wounds of the scalp bleed freely, and the vessels are difficult to ligature on account of the fixation of their walls to the dense subcutaneous tissue. In extensive flap-wounds and in

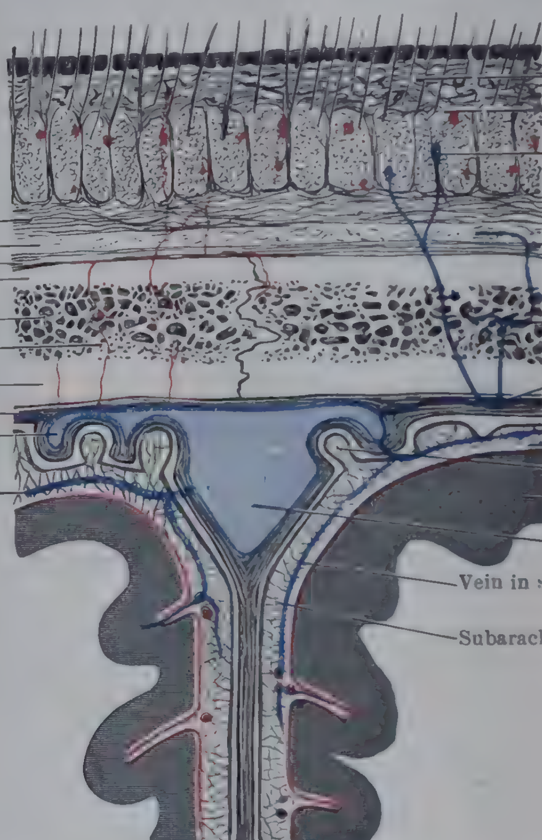

FIG. 1183.—DIAGRAMMATIC REPRESENTATION OF CORONAL SECTION THROUGH SCALP, CRANIUM, MENINGES, AND CEREBRAL CORTEX.

diffuse suppuration deep to the occipito-frontalis muscle there is little danger of sloughing of the scalp. **Abscesses** and **hæmorrhages** superficial to the occipito-frontalis muscle are usually limited on account of the density of the subcutaneous tissue. Hæmorrhage deep to the occipito-frontalis muscle is seldom extensive on account of the small size of the vessels, but suppuration in that situation may rapidly undermine the whole muscle and its aponeurosis—the epicranial aponeurosis. The area under cover of the occipito-frontalis is sometimes termed "the dangerous area", and in cases of extensive infection the swelling may extend from the superior nuchal lines to the superciliary arches, and from one zygomatic arch to the other. Incisions to evacuate the pus are made early, parallel to the main vessels of the scalp (Fig. 1076) and at a level which will ensure dependent drainage. Extravasation of blood deep to the pericranium leads to a hæmatoma which is limited by the sutures (cephalhæmatoma).

The **veins** of the scalp communicate with the intracranial venous sinuses: (1) directly through their anastomoses with the large emissary veins—the parietal, which open into the superior sagittal sinus, and the mastoid and condylar, which open into the sigmoid sinus; (2) through the anastomoses of the supra-trochlear and supra-orbital veins with the ophthalmic vein, which opens into the cavernous sinus; (3) through the veins of the diplöe, which connect the veins of the scalp and the pericranium with those of the dura mater and the venous sinuses; (4) through small veins which pass from the pericranium through the bones and the sutural ligaments to the dura mater. It is along these various channels that pyogenic infection may extend from the scalp and pericranium, through the bone, to

the dura mater and venous sinuses, and from the sinuses to the cerebral veins, the pia-arachnoid, and the substance of the brain. More rarely infection spreads from the skull or from the cranial cavity along the emissary veins to the scalp.

The **lymph-vessels** of the anterior part of the scalp join the facial lymph-vessels; those of the temporal and parietal regions end in the parotid lymph-glands, situated in front of and below the ear, and in the mastoid glands on the insertion of the sterno-mastoid muscle. The lymph-vessels of the occipital region end in the occipital glands, which lie close to the occipital artery and the greater occipital nerve after they have pierced the origin of the trapezius (Figs. 1177, 1178).

Bony Landmarks of Cranium (Fig. 1184).—At the root of the nose there is the fronto-nasal suture, the mid-point of which is the **nasion**; and immediately above is the **glabella**—a slight prominence which connects the superciliary arches. About 2·5 cm. below the posterior pole of the cranium, and 5 cm. above the spine of the axis vertebra, is the external occipital protuberance (the centre of which is the **inion**). In the child this protuberance is not developed; but its position is identified as a point at the junction of the upper and middle thirds of a line drawn from the posterior pole of the skull to the spine of the axis vertebra.

About a third of the distance from the nasion to the inion is the **bregma** or junction of the coronal and sagittal sutures; with the head in the natural erect posture the bregma is at, or close to, the middle of a line carried across the vertex from one tragus to the other. At birth the position of the bregma is occupied by the **anterior fontanelle**—a rhomboidal membranous area which is usually completely ossified towards the end of the second year. The size and date of closure of the fontanelle, as well as its tension and pulsation, are points to be carefully noted in the clinical examination of children (Fig. 174, p. 208, and Pl. V, p. 150).

The **lambda**, or junction of the sagittal and lambdoid sutures, situated 6·5 cm. above the inion, can generally be felt through the scalp as a slight depression; a line drawn from it to the **asterion**—the articulation of the postero-inferior angle of the parietal bone with the temporal and occipital bones—corresponds to the **lambdoid suture**.

The **parietal eminence**, which varies considerably in the definiteness with which it can be recognized, overlies the **termination of the posterior ramus** of the **lateral sulcus** of the cerebrum. The **frontal eminence** (better marked in the child) overlies **the middle frontal gyrus**.

Crossing the supra-orbital margin, a finger's breadth from the median line, are the **supratrochlear nerve** and **vessels**; the artery nourishes the flap in the operation of rhinoplasty. On the supra-orbital margin, two finger-breadths from the median line, is the **supra-orbital notch** or **foramen**—the guide to the **supra-orbital nerve** and **vessels**. A little above the level of the lateral angle of the eye is the **fronto-zygomatic suture**, immediately above which is the **zygomatic process** of the frontal bone. At the posterior end of the suture, the **zygomatico-temporal nerve** pierces the temporal fascia to reach the skin; and 1·3 cm. above the suture is the **lower margin** of the **cerebral hemisphere**. The **temporal line** marks the upper limit of the temporal muscle. It begins at the zygomatic process of the frontal bone, arches upwards between the temple and the forehead; then, curving backwards, it skirts the lower part of the parietal eminence, and, finally, turning downwards, it joins the supramastoid crest near the top of the root of the auricle; the anterior part of the line is the only part easily felt. The **supramastoid crest** curves upwards and backwards from the external auditory meatus for 2·5 cm., but it is obscured by the auricle.

The **zygomatic arch**, an important landmark, is horizontal when the head is in the natural position, and it is at the same level as the inferior margin of the orbit and the inion; its upper border is at, or not infrequently a little above, the level of the infero-lateral margin of the cerebral hemisphere. The upper border of the zygoma may be traced backwards immediately above the tragus and the external auditory meatus to become continuous with the supramastoid crest. The **superficial temporal vessels** and the **auriculo-temporal nerve** cross the zygoma immediately in front of the tragus. The termination of the auriculo-temporal nerve in the neighbour-

conditions at the external auditory meatus—the meatus being in part supplied by that nerve.

Five centimetres vertically above the middle of the zygomatic arch is the **pterion.** This is a point which cannot be felt, but is nevertheless of topographical importance, as it overlies the point where the lateral sulcus of the cerebrum breaks up into its three rami and the point where the **anterior branch** of the **middle meningeal artery** is most deeply embedded in the bone.

Fractures of Skull.—The thickness of the skull-cap varies at different parts and in different subjects. The inner table is only half the thickness of the outer table, but both possess the same degree of elasticity. When the vault is fractured from direct violence, the inner table is more extensively fissured than the outer table, the reason being that the force having passed through the outer table shows a wider distribution in respect of the inner table. The weak areas at the base of the skull through which fractures are liable to extend are:—(1) In the anterior cranial fossa—the orbital plates of the frontal bone, and the cribriform plate of the ethmoid. (2) In the middle cranial fossa—the region of the articular fossa and of the foramen ovale. (3) In the posterior fossa—the fossæ of the occipital bone. The petrous part of the temporal bone, though strong, is weakened by the tympanic cavity and by the jugular fossa.

Cranio-Cerebral Topography.—While there are methods by which cranio-cerebral topography is indicated in considerable detail, it is better to employ a scheme by which the primary sulci of the brain may be outlined on the skull. It should be pointed out that the position of the cerebral landmarks may vary within normal limits, and that when pathological cerebral conditions are present they are usually displaced. The lines which are used to indicate their position are only approximate, though they are sufficiently reliable for clinical and operative purposes. The following scheme is recommended (Figs. 1185, 1186). **A base-line** is drawn from the lower margin of the orbit backwards through the upper border of the external auditory meatus to the occipital region; the cerebrum lies entirely above the level of this line, while the greater part of the cerebellum occupies a position below the level of the posterior third of the line.

Primary Sulci.—The position of the **central sulcus** is now outlined by a line which begins 1·3 cm. behind the mid-point of a sagittal line passing from the nasion to the inion and extends downwards and forwards to the mid-point of the posterior ramus of the lateral sulcus.

The stem of the **lateral sulcus** reaches the lateral surface of the cerebrum opposite the *pterion.* It divides there into three rami; the **anterior two rami** are short, and pass forwards and upwards, diverging from each other; the **posterior ramus** is the most important part of the sulcus. It is indicated by a line that begins at the pterion, is drawn backwards and slightly upwards to a point below the parietal eminence, and is curved sharply upwards to end at that eminence.

The upper end of the **parieto-occipital sulcus** is 1·3 cm. or less above the lambda in the adult, and a line drawn laterally from this point for a distance of 2·5 cm. indicates the position of the part of the sulcus which appears on the supero-lateral surface of the cerebral hemisphere.

Lobes.—By means of the lines for these sulci, the position of the lobes can be gauged roughly. The **frontal lobe** is the part in front of the central sulcus; the **temporal lobe** is below the posterior ramus of the lateral sulcus and extends from the margin of the orbit to the lower half of a line from the parieto-occipital sulcus to the back of the root of the auricle. The **occipital lobe** is behind that line; the **parietal lobe** is between the central sulcus and the upper half of that line (Fig. 1186).

Gyri and Secondary Sulci.—Each lobe is divided into gyri by secondary sulci. In the frontal lobe the **pre-central sulcus** runs parallel to the central sulcus 1·5 cm. in front of it, cutting off the **pre-central gyrus.** The remainder of the frontal lobe is divided into the *superior*, *middle*, and *inferior frontal gyri* by two sulci—*superior* and *inferior frontal.* The lower part of the inferior frontal gyrus is divided into three portions by the anterior rami of the lateral sulcus. These three portions, together with the lower part of the pre-central gyrus, comprise the **motor speech-centre**, which is developed on the left side of the brain in right-handed people.

In the parietal lobe the **post-central sulcus** is 1·5 cm. behind and parallel to the

central sulcus, and delimits the **post-central gyrus**. The *intra-parietal sulcus* runs backwards from the post-central sulcus, and divides the rest of the lobe into two parts named the *superior* and *inferior parietal lobules*. The inferior lobule is divided into three parts that surround the upturned ends of the lateral sulcus and the temporal sulci. These parts contain centres for the interpretation of printed and written words ; and it should be noted that the anterior part underlies the parietal eminence of the skull.

The **motor area** for individual movements occupies the anterior wall of the

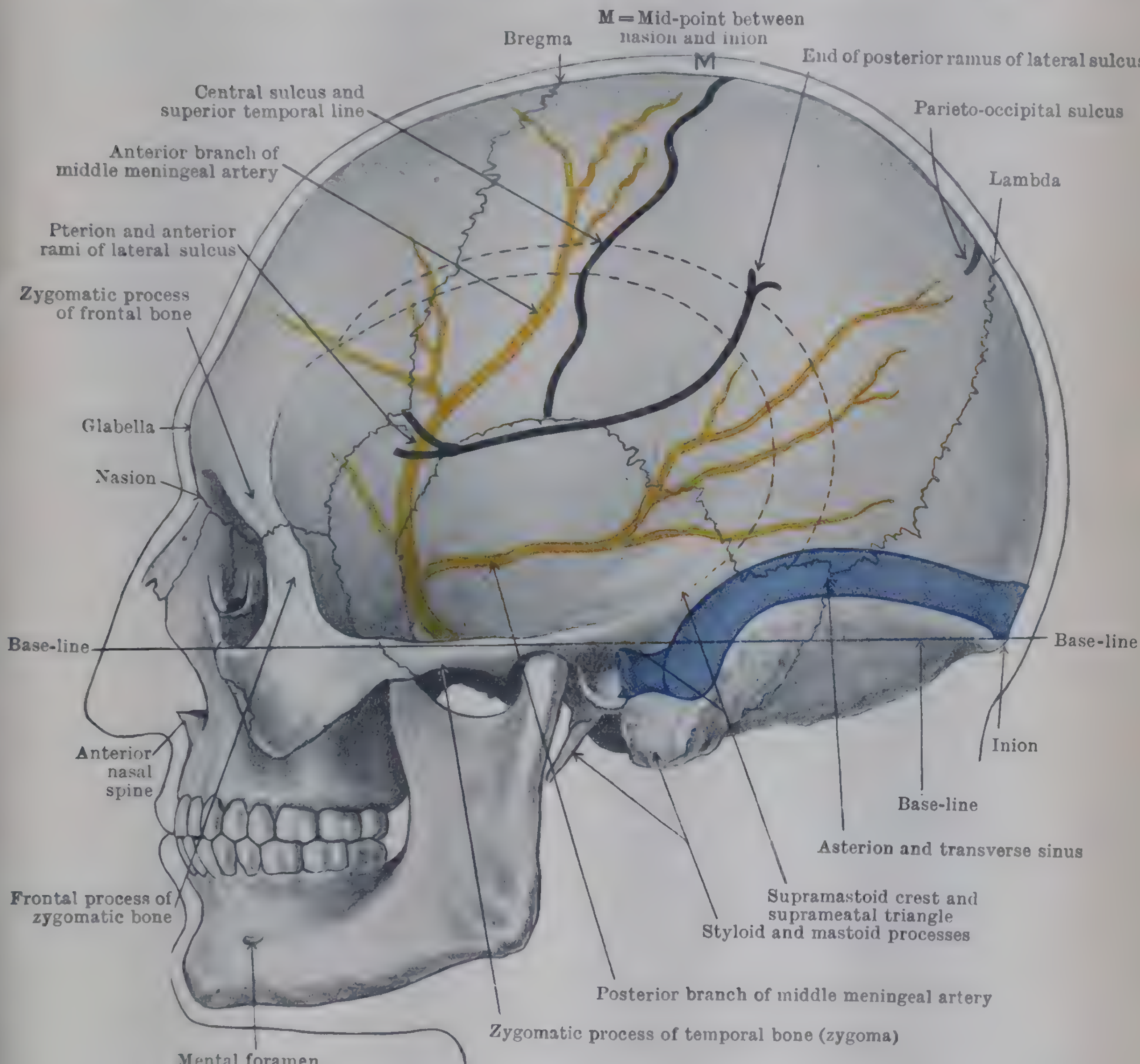

FIG. 1184.—CRANIO-CEREBRAL TOPOGRAPHY I : Landmarks of Skull ; Chief Sulci of Cerebrum ; Transverse and Sigmoid Venous Sinuses ; Middle Meningeal Artery.

central sulcus and the adjoining free surface of the pre-central gyrus ; it also extends into the paracentral lobule on the medial surface. The body is inverted in this area, and the relative position of the parts as represented in the cortex is shown in Fig. 1186. The **sensory area**—that is the centre for the reception of common sensation—is in the posterior wall of the central sulcus and the adjoining free surface of the post-central gyrus ; in it also the body is inverted.

The lateral surface of the temporal lobe is divided into *superior*, *middle*, and *inferior temporal gyri* by the *superior* and *inferior temporal sulci*, which are parallel to the posterior ramus of the lateral sulcus. The **auditory area**—that is, the centre for the mere reception of sound—is in the middle of the superior tmeporal gyrus.

The arrangement of sulci and gyri in the lateral surface of the occipital lobe

of light—is on the medial surface of the lobe in relation to the calcarine and post-calcarine sulci, but in some hemispheres the post-calcarine sulcus extends on to the supero-lateral surface, carrying a portion of the centre for sight with it. This portion is immediately above the external occipital protuberance.

Lateral Ventricle.—The central part of the lateral ventricle occupies a level between the posterior ramus of the lateral sulcus and the middle part of the

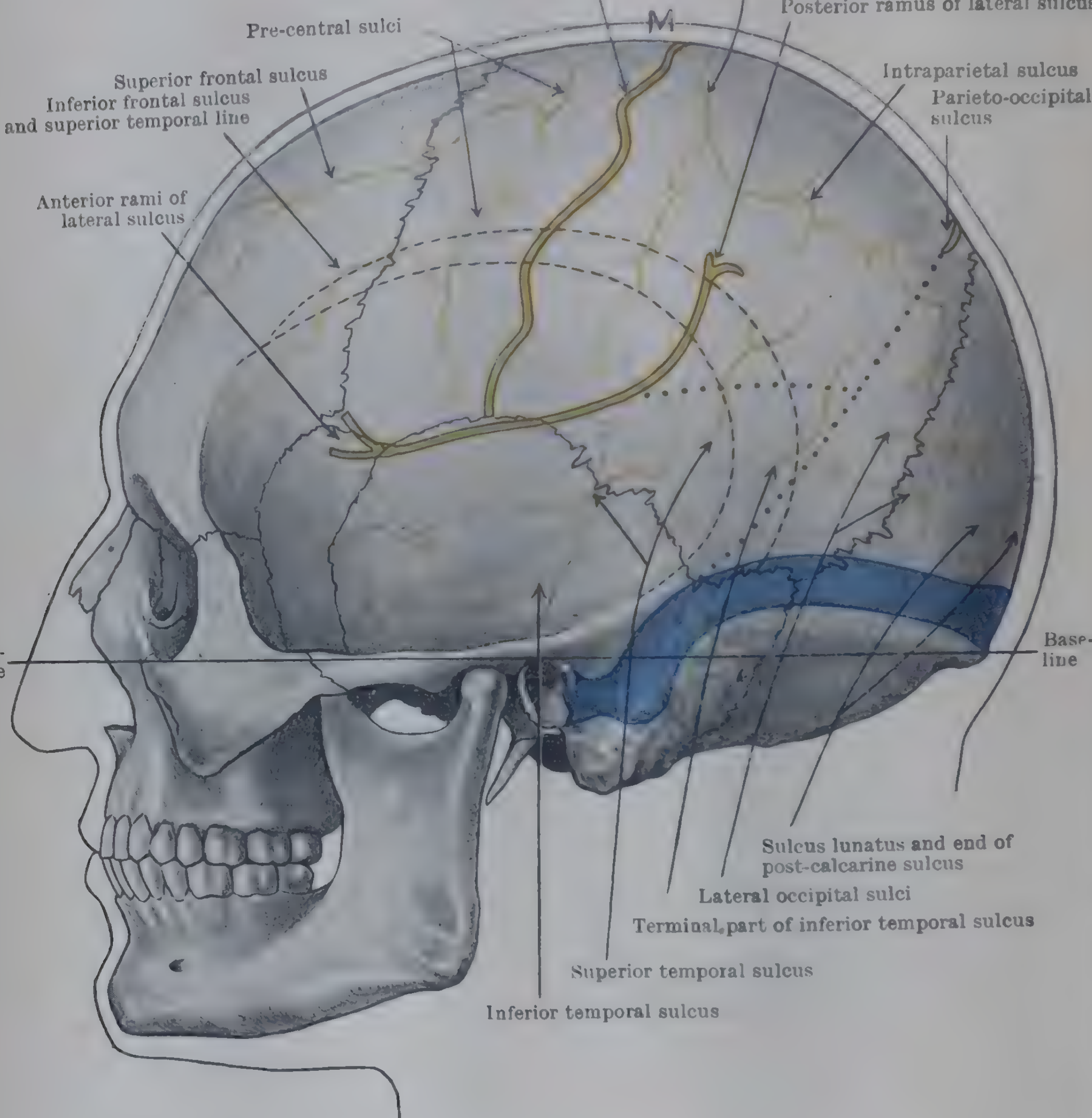

FIG. 1185.—CRANIO-CEREBRAL TOPOGRAPHY II: Venous Sinuses (blue); Chief Sulci (thick yellow); Secondary Sulci (thin yellow); Artificial Boundaries between Lobes (dotted lines); Temporal Lines (curved lines of dashes).

temporal line. The anterior horn of the ventricle is immediately above the level of the pterion; the posterior horn is opposite the posterior part of the temporal line but is very variable both in length and width; the inferior horn corresponds to the middle temporal gyrus.

The lateral ventricles may be tapped or drained after holes have been drilled 9 cm. anterior to the inion and 4 cm. from the midline. Cannulæ are inserted anteriorly, slightly downwards and parallel to the sagittal plane; they enter the ventricles at the junction of body and posterior horn, at a depth of 7-8 cm. from the skin (Dott, 1928). The procedure of *ventriculography* is carried out by positioning the head so that cerebro-spinal fluid escapes through the lower of the two cannulæ, while a corresponding volume of oxygen or air is introduced through the upper. When replacement is complete, stereoscopic radiographs are taken in various planes. The ventricles are outlined by the oxygen, and changes in their size and shape may be used to identify the site of a pathological process (p. 1557, Pl. LXXIV, p. 945 and Pls. LXXV, LXXVI p. 960).

The **cerebello-medullary** cistern is situated between the under surface of the cerebellum and the medulla oblongata; it may be tapped by suboccipital puncture—the needle passing through

the posterior atlanto-occipital membrane. The needle is inserted close to the median line immediately above the atlas vertebra, and its direction is from the point of insertion towards the nasion.

To expose both hemispheres of the cerebellum, two flaps are reflected by a "cross-bow" incision. The curved, horizontal limb is made a little above and parallel to the superior nuchal lines, and, if possible, the ends of the incision should not reach the mastoid emissary vein (a finger's breadth behind the root of the auricle at the level of the meatus), for it may give rise to

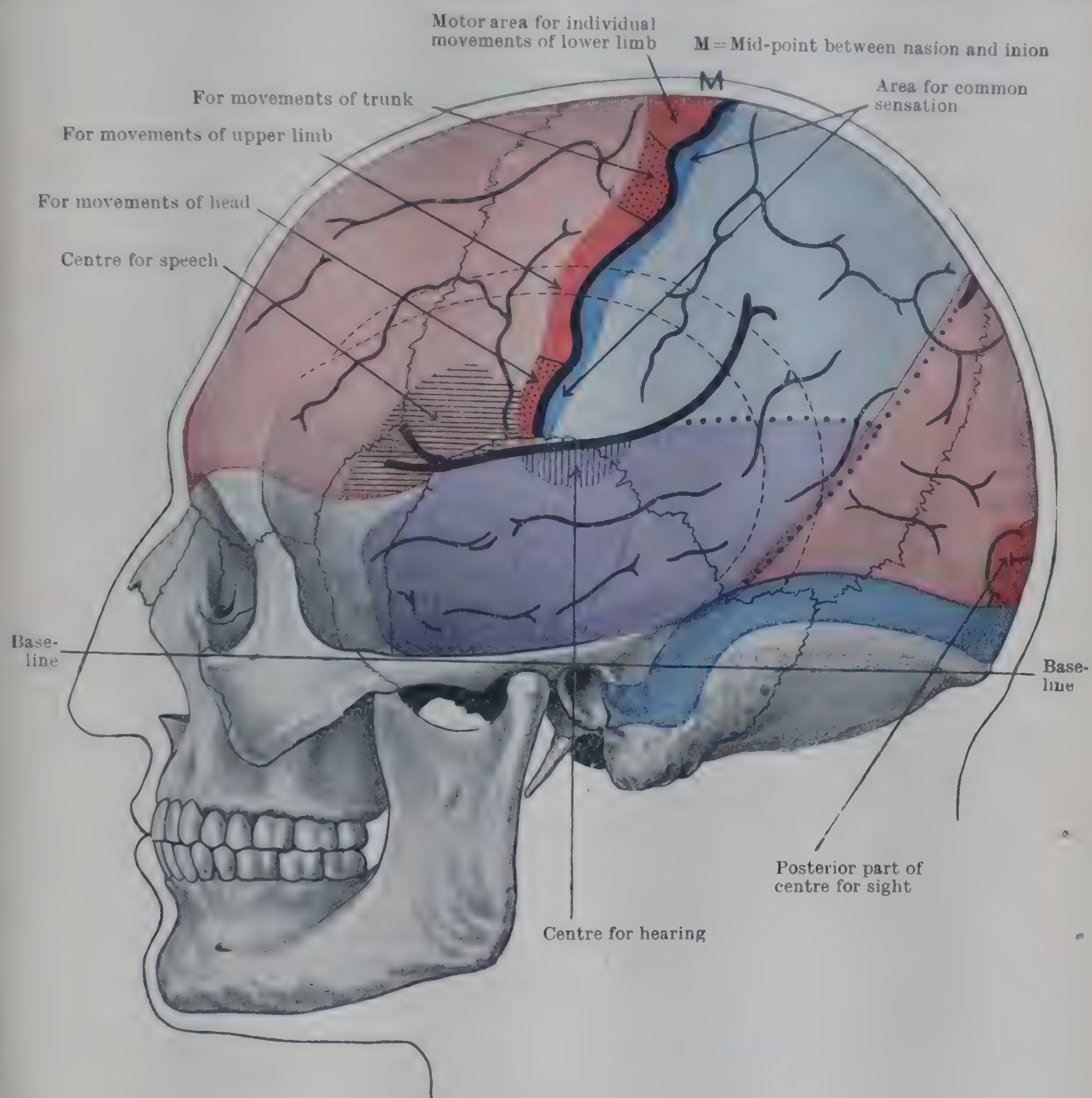

FIG. 1186.—CRANIO-CEREBRAL TOPOGRAPHY III: Lobes of Cerebrum; Motor and Sensory Areas; Centres for Speech, Hearing, and Sight. *Frontal* and *occipital* lobes (red); *parietal* lobe (blue); *temporal* lobe (purple).

troublesome bleeding. The occipital arteries (2·5 cm. lateral to the inion) are divided. The vertical limb of the incision descends in the median line to the level of the spine of the axis vertebra. The occipital sinus is divided between two ligatures. After division of the dura, either hemisphere of the cerebellum may be displaced towards the median plane to expose a tumour of the auditory nerve, which occupies the angle between the cerebellum and the pons.

Meningeal Arteries.—When the calvaria is removed the **meningeal arteries** remain attached to the dura mater, for they are in its outer layer. Of these vessels the middle meningeal artery is the only one of surgical importance. It may be lacerated in fractures of the skull; the blood is generally extravasated between the dura and the bone, and the bleeding point is deep to the clot. After entering the cranial cavity through the foramen spinosum, the *main trunk* runs laterally and slightly forwards to divide into anterior and posterior branches at or a little above the level of the zygomatic arch, midway between the orbit and the auditory meatus (Fig. 1184).

convexity) to the pterion and then upwards and backwards towards the mid-point between the nasion and the inion, giving off branches on its way. Its main trunk is opposite and parallel to the motor area and is therefore encountered in operations on that part (Pl. VII, p. 154).

The *posterior branch* passes backwards and upwards towards the lambda.

To expose the *trunk* of the vessel and its bifurcation, bone is removed immediately above the middle of the zygomatic arch. At the pterion, the artery frequently runs in a canal for a distance of 1·5 cm., and during the removal of bone bleeding may occur from the artery as it lies in the canal. The trunk of the vessel may be traced proximally to the foramen spinosum, where it is secured.

Venous Sinuses of Dura Mater.—The **superior sagittal sinus**, which enlarges as it extends backwards, occupies the median plane of the vertex from the glabella to the internal occipital protuberance, where it becomes continuous usually with the right transverse sinus. Opening into the sinus, especially in the posterior part of the parietal region, are the **lacunæ**, into which arachnoid villi and granulations project.

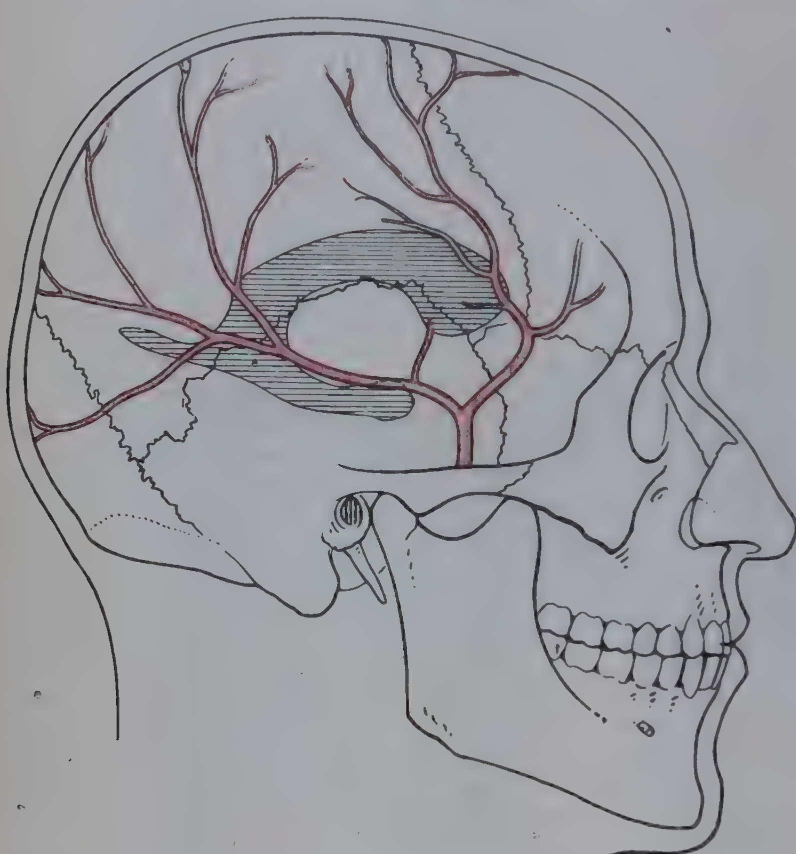

Fig. 1187.—Topography of Normal Lateral Ventricle and Middle Meningeal Artery. (Fraser & Dott, 1922.) See also Pls. VII, p. 154, LXXIV, p. 945 and LXXV, p. 960.

The **transverse sinus** may be mapped out on the surface by a line, slightly convex upwards, *drawn* from a point a little above the inion to the upper part of the back of the root of the auricle. The **sigmoid sinus** is indicated by a line which begins at this point and is drawn downwards along the back of the root of the auricle to the level of the lower margin of the meatus, and then forwards to the margin of the meatus, which is opposite the jugular foramen. In wounds of the sinus the hæmorrhage is very free, owing to the inability of its walls to collapse.

Cerebral Arteries.—Of the **cerebral arteries**, the *middle* supplies almost the whole of the motor area, and one of its striate branches, which enter the brain at the anterior perforated substance, is called "*the artery of cerebral hæmorrhage*" from the frequency of its rupture in apoplexy. The extravasated blood involves the motor part of the internal capsule. The postero-medial central branches of the *posterior cerebral* artery, which enter the brain at the posterior perforated substance, supply the thalamus and walls of the third ventricle; hæmorrhage from one of those branches is apt to rupture into the ventricle. The postero-lateral central branches of the posterior cerebral artery supply the thalamus, and when one of these vessels ruptures the hæmorrhage is apt to invade the posterior part of the internal capsule, where the fibres for *sight* and *hearing* are situated. (For radiography of the cerebral arteries during life, see Pl. LXXX, p. 1217.)

Trigeminal Ganglion.—The topography of the trigeminal ganglion is important in relation to the operation of division of its sensory root for the relief of

trigeminal neuralgia. The ganglion is situated between the layers of the dura mater in the middle cranial fossa, at the apex of the petrous portion of the temporal bone.

The surgeon reaches it by an extradural route through an opening immediately above the zygomatic arch. The bone is removed down to the level of the infratemporal crest, which forms the boundary line between the lateral wall and floor of the middle cranial fossa. The dura mater is elevated from the floor of the fossa so as to admit of the ligature of the middle meningeal artery immediately after its entrance through the foramen spinosum. The dura mater is separated from the bone still farther in a medial and backward direction till the mandibular nerve is reached. The sheath of the nerve is then incised horizontally, and the upper surface of the ganglion is exposed. The sensory root passes backwards from the ganglion, and is enclosed in a tube of arachnoid mater. The arachnoid is incised posterior to the

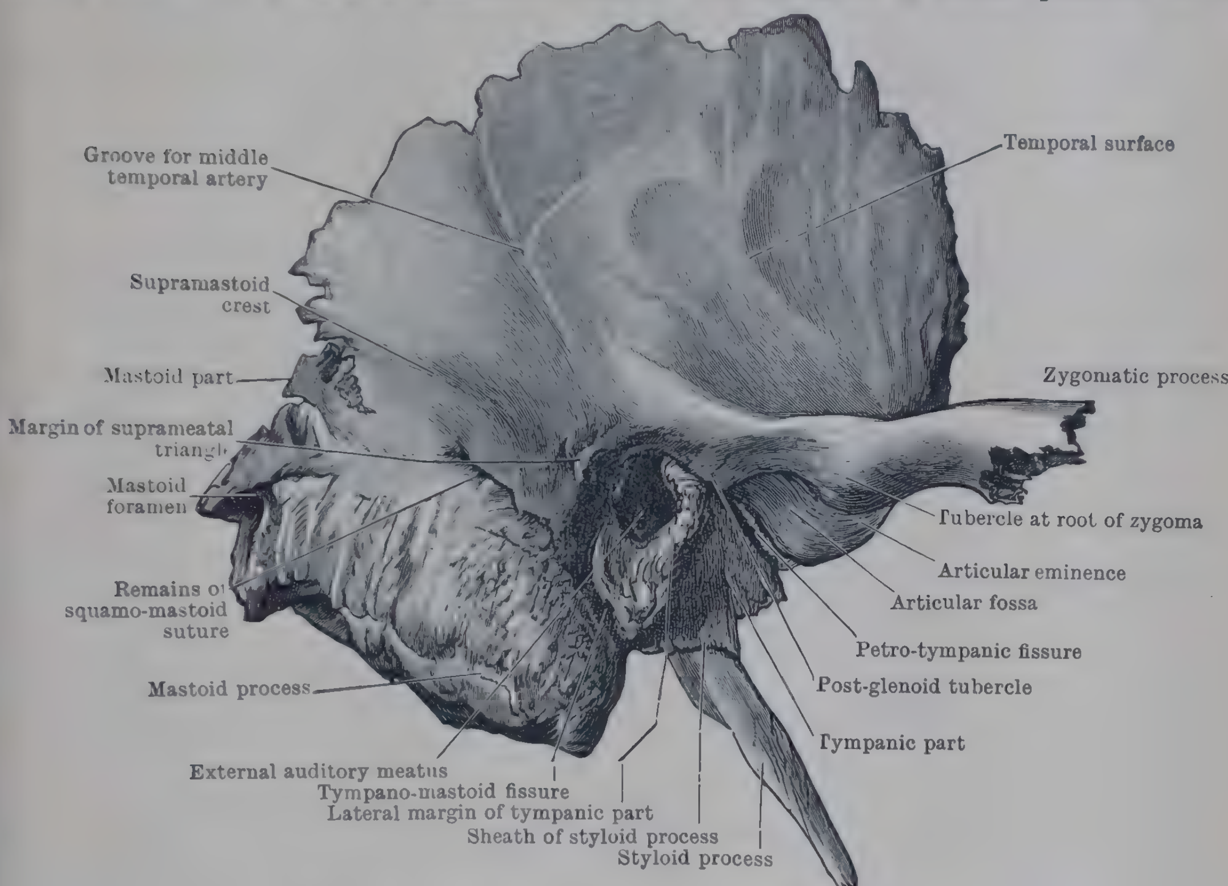

FIG. 1188.—LATERAL ASPECT OF RIGHT TEMPORAL BONE.

ganglion. The sensory root is then gently raised on a hook and its bundles carefully divided without injury to the motor root, which lies deep to the sensory root.

Ear.—The skin of the lateral surface of the **auricle** is tightly bound down to the perichondrium; and inflammations of it are attended therefore with little swelling but much pain. The **posterior auricular artery**, which ascends along the groove at the posterior attachment of the auricle, is immediately in front of the incision for opening the tympanic antrum.

The general direction of the **external auditory meatus** is medially, forwards, and downwards; it is thus curved both vertically and horizontally. The highest part of the upward convexity, which is also the narrowest part of the canal, is situated at the middle of its osseous portion; beyond that the floor sinks to form a recess in which foreign bodies are apt to be imprisoned. Of the two horizontal curves the lateral is convex forwards, the medial concave forwards. The skin of the osseous portion of the canal is thin and adherent to the periosteum. Boils in the canal are extremely painful; when situated on the posterior wall and associated with cellulitis the condition may be difficult to distinguish from mastoiditis.

The relations of the osseous walls of the meatus are of importance to the surgeon. The whole of the upper wall and the upper half of the posterior wall, developed from the squamous portion of the temporal bone, consist of two layers of compact bone, an upper and a lower, which are continuous with the inner and

outer tables of the skull. The upper plate passes medially to the petro-squamosal suture, where it becomes continuous with the lateral edge of the tegmen tympani, which roofs over the epitympanic recess and the tympanic antrum; the lower plate bends downwards and medially at its deepest part to form the infero-lateral wall of the recess and the anterior part of the lateral wall of the antrum. On the upper and posterior segment of the external auditory margin is the **suprameatal spine**. It occupies the middle of the base of a small depression, called the **suprameatal triangle**, which lies between the supramastoid crest and the postero-superior quadrant of the external osseous meatus. The spine can sometimes be felt in the living subject if the forefinger is placed in the external meatus and pressed upwards and backwards.

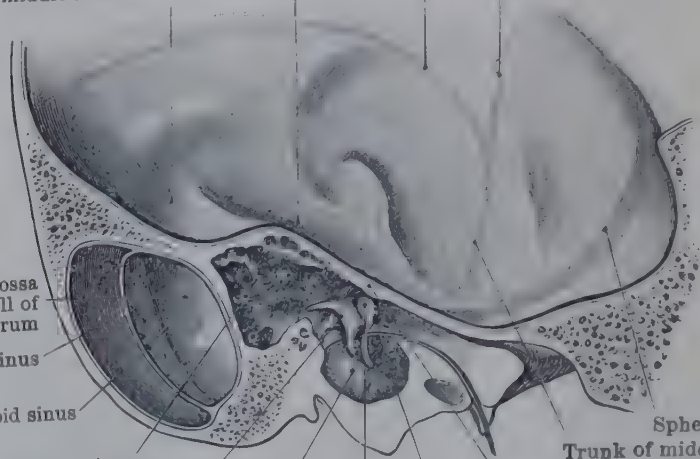

FIG. 1189.—VIEW OF LATERAL WALL OF MIDDLE EAR.

Section through the left temporal bone of a child, to show the relations of the tympanum and tympanic antrum to the middle and posterior fossæ of the skull.

The lower half of the posterior wall of the osseous meatus (posterior part of the tympanic plate) is fused with the anterior part of the mastoid portion of the temporal bone, and closes the lower and anterior set of mastoid air-cells (border cells).

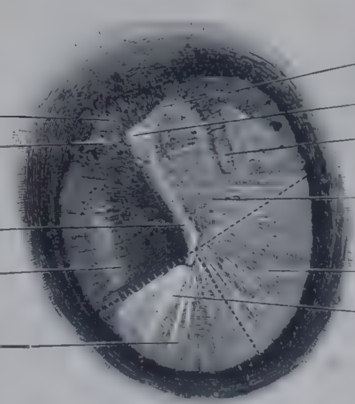

FIG. 1190.—LEFT TYMPANIC MEMBRANE VIEWED FROM EXTERNAL AUDITORY MEATUS. ×3.

Anteriorly and inferiorly the osseous meatus is related respectively to the **mandibular joint** and the **parotid gland**. Hence it follows: that blows upon the chin may fracture the tympanic plate as well as the base of the skull; that pain on mastication is usually complained of in acute inflammatory affections of the meatus and middle ear; and that in young children, in whom the tympanic plate is incompletely ossified, suppurative inflammation is apt to extend from the parotid region into the external auditory meatus.

To obtain a view of the **tympanic membrane** a speculum and a reflecting mirror are employed or the membrane is illuminated by direct light. The auricle is pulled upwards, backwards, and laterally in order to straighten the cartilaginous part of the meatus. The healthy membrane is pearly grey, semi-opaque, slightly concave, and obliquely

placed, the upper and posterior portion being nearer to the observer than the anterior and inferior part.

The handle and lateral process of the malleus, both embedded in the tympanic membrane, are the only objects distinctly seen when the healthy ear is examined with the speculum. The lateral process of the malleus projects laterally, and presents itself, therefore, as a distinct knob-like projection at the upper part of the membrane; passing forwards and backwards from that process are the **anterior** and **posterior malleolar folds** of the membrane; they form the lower limit of the *flaccid part* of the membrane, and correspond to the line of the chorda tympani nerve. The handle of the malleus, situated at the junction of the upper two quadrants, is seen passing downwards and backwards to the point of maximum convexity of the membrane (umbo), situated a little below its centre (Fig. 1190); passing downwards and forwards from

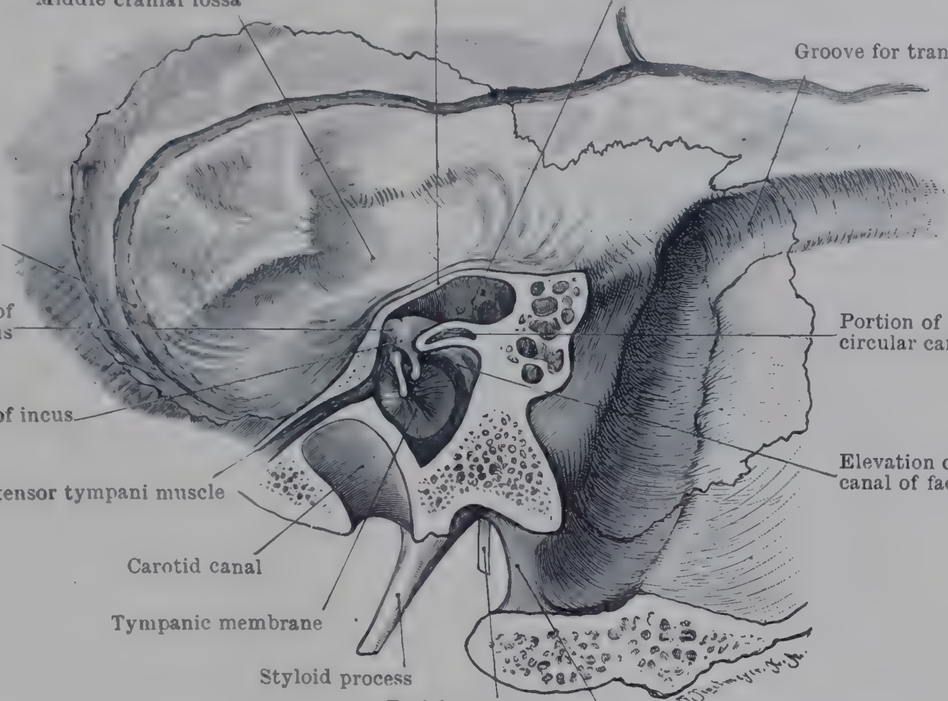

Fig. 1191.—Section through Petrous Portion of Right Temporal Bone of Adult viewed from the Deep Surface.

Showing the relation of the tympanum to the middle and posterior fossæ of the skull.

the umbo is the *triangular cone of reflected light*, to which too much importance must not be attached, since its appearances vary considerably in healthy ears. Normally, the long process of the incus is but faintly visible, and still less so are the promontory and fenestra cochleæ; in the condition of obstruction of the pharyngo-tympanic tube, however, in which the membrane is indrawn, those structures, along with the malleolar folds, become more distinct.

In the operation of *paracentesis of the tympanic membrane* the incision is made through the two posterior quadrants, as, in addition to good drainage being provided, they are farthest removed from important structures such as the chorda tympani nerve.

In order that the clinical importance of the parts seen through the translucent membrane may be understood, it is necessary to study the relative position of the structures in that part of the tympanum which lies opposite the tympanic membrane. The head of the malleus and the body and short process of the incus are altogether above the tympanic membrane, and they occupy the **epitympanic recess** (Fig. 1191). At the junction of the upper two quadrants of the membrane is the **handle** of the **malleus**, which is directed downwards, backwards, and medially; the tendon of the tensor tympani muscle crosses the tympanic cavity from its medial wall to be attached to the upper part of the handle. The **lateral process** of the **malleus** is directed laterally a little below the deepest part of the roof of the osseous external auditory meatus. Opposite the postero-superior quadrant are the **long process** of the **incus**, which descends behind and almost parallel to the handle of the malleus, and the **stapes**, which is directed medially and also slightly upwards and backwards to the fenestra vestibuli. The **chorda tympani**

nerve runs from behind forwards between the lateral surface of the upper part of the long process of the incus and the medial surface of the neck of the malleus. At the deepest part of the roof of the osseous external meatus, above the chorda tympani nerve and the lateral process of the malleus, is the **tympanic notch**, which is occupied by the flaccid, highest portion of the tympanic membrane; the notch is due to a deficiency in the tympanic ring, which forms only about five-sixths of a circle. Opposite the postero-inferior quadrant of the drum-head is the **promontory** caused by the first coil of the **cochlea**, below and behind which is the **fenestra cochleæ**. Opposite the antero-superior quadrant are the **cochleariform process**, the **tendon** of the **tensor tympani**, and the passage leading towards the **pharyngo-tympanic tube**.

The *medial wall* of the tympanic cavity is related to the internal ear. The *roof* separates the tympanic cavity (epitympanic recess) from the middle cranial fossa and the brain. It is formed by the **tegmen tympani**—a thin plate of bone which is continued backwards to roof over the tympanic antrum, and forwards to form the roof of the canal for the tensor tympani muscle immediately above the osseous portion of the pharyngo-tympanic tube. Laterally the tegmen is limited by the **petro-squamous suture**, which may persist for some years after birth, thus affording a channel along which pyogenic infection may spread from the middle ear to the meninges and brain. Infection may spread also along the small veins which convey blood from the tympanum to the superior petrosal and transverse sinuses, and to the posterior fossa of the skull along the vessels which pass from the medial wall of the tympanic antrum through the subarcuate fossa, beneath the dome of the superior semicircular canal.

The floor of the tympanum is constituted mainly by the bone bounding the **jugular fossa**, which is occupied by the upper bulb of the internal jugular vein. When the sigmoid sinus is large and unusually far forward the bulb also is large; the fossa is consequently deeper, and arches up into the floor of the tympanic cavity, from which it may be separated merely by a thin and translucent plate of bone which occasionally shows an osseous deficiency. In cases where that condition existed the jugular bulb has been wounded in the operation of paracentesis of the tympanic membrane.

Anteriorly the tympanic cavity leads into the **pharyngo-tympanic tube**, which brings it into communication with the nasal part of the pharynx. In the child the tube is shorter and wider than in the adult; inflammations of the pharynx are therefore more apt to reach the tympanum along this route in an infant than in an adult.

Above the level of the tympanic membrane is the **epitympanic recess**, which communicates posteriorly by means of a triangular opening (*aditus ad antrum*) with the tympanic antrum. The epitympanic recess contains, from before backwards, the head of the malleus, the body and short process of the incus—the process being attached by a ligament to the floor of the aditus. When these structures are covered with inflamed mucous membrane or granulations, drainage from the tympanic antrum into the tympanum is interfered with. The *boundaries of the aditus*, important surgically, are as follows: superiorly, the tegmen tympani; medially, an eminence of compact bone containing the lateral semicircular canal; below and in front of them is a second smaller prominence, corresponding to that portion of the canal for the facial nerve which curves immediately above and behind the fenestra vestibuli. The wall of the facial canal in that situation is thin or even deficient, so that inflammation may readily spread from the tympanum to the facial nerve. The lateral wall of the aditus is formed by the deepest part of the upper wall of the osseous external auditory meatus.

The *posterior wall* of the tympanum, below the aditus ad antrum, is formed by diploic bone which contains the descending portion of the canal for the facial nerve. Immediately below the floor of the aditus, on the posterior wall of the tympanum, is the pyramid, through which the tendon of the stapedius muscle emerges to be attached to the neck of the stapes (Fig. 1192).

The lymph-vessels from the auricle and external meatus open into the mastoid and parotid lymph-glands—the latter receiving also the lymph from the middle ear. The efferent vessels from these glands open into the glands that lie deep to the upper part of the sterno-mastoid muscle; hence it is that these groups of glands are so frequently found to be diseased secondary to tuberculosis of the middle ear; and care must be taken not to mistake an abscess in one of the mastoid glands for subperiosteal mastoid suppuration associated with middle-ear disease.

The **labyrinth** may become infected in cases of suppurative otitis media. In acute cases the infective process may pass into the inner ear through the fenestra vestibuli or fenestra

cochleæ. In chronic cases, on the other hand, the route of infection is by way of the prominence of the lateral semicircular canal, which not infrequently becomes eroded in cases of chronic purulent otitis media associated with accumulation of cast-off epithelium in the tympanic antrum —a condition known as *cholesteatoma*.

Tympanic Antrum.—The tympanic antrum is a backward and upward extension of the tympanum (Fig. 1192), and it is relatively larger and more superficial in the child than in the adult. Situated above and behind the tympanic cavity proper, its *lateral wall* is a triangular plate of bone which descends behind the external auditory meatus from the squamous temporal. Posteriorly, that triangular plate is separated in the child from the petro-mastoid element by the **squamo-mastoid suture**, which overlies the posterior part of the antrum and transmits small veins to the surface. The suture does not disappear until a year or two after birth, and remains of it may frequently be detected in the adult bone. The anterior and upper portion of the triangular plate turns medially at an angle to

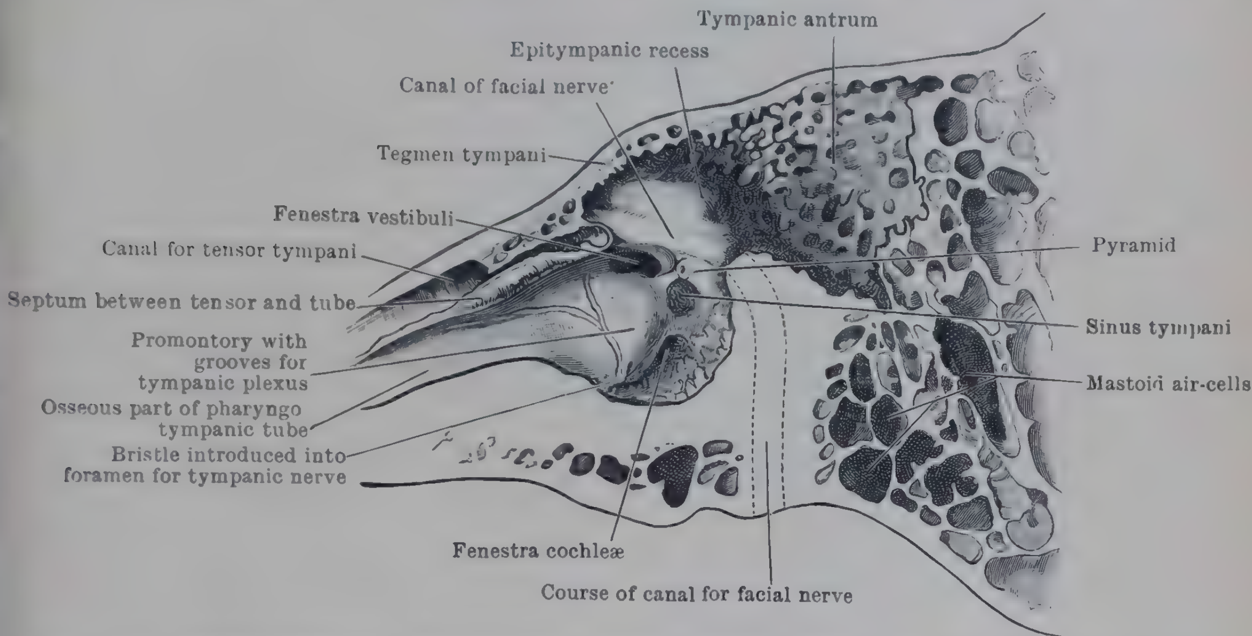

FIG. 1192.—SECTION THROUGH LEFT TEMPORAL BONE, SHOWING MEDIAL WALL OF TYMPANIC CAVITY.

form the upper and posterior wall of the rudimentary osseous meatus, as well as the floor of the epitympanic recess.

In the adult the lateral wall of the tympanic antrum is a plate of bone, from 1·3 to 1·9 cm. in thickness, that separates the antrum from the suprameatal triangle, and may therefore be felt through the skin as a slight depression. It occupies the centre of a triangle formed by the supramastoid crest, the posterior-superior quadrant of the auditory meatus and an imaginary line drawn vertically through the posterior margin of the meatus. The supramastoid crest, which varies considerably in its obliquity, is sometimes situated a little above the level of the roof of the antrum; it is safer, therefore, when operating on the antrum, to take the level of the upper border of the osseous meatus as the guide, in order to avoid opening the middle fossa of the skull.

The *medial wall* of the antrum is a thick plate of spongy bone which separates the antrum from that portion of the posterior fossa which lies between the aqueduct of the vestibule and the groove for the sigmoid sinus, and contains the posterior semicircular canal.

The *roof* slopes downwards and forwards, and is the posterior and thinnest part of the tegmen tympani.

The *floor* is on a lower level than the aditus, and is therefore unfavourably placed for natural drainage.

To open the **tympanic antrum** the surgeon makes a curved incision a little behind the attachment of the auricle, and removes, with a hammer and gouge, the bone immediately above and behind the postero-superior quadrant of the external osseous meatus. The operator avoids: (1) the *middle fossa* of the *skull* by keeping below the supramastoid crest; (2) the *sigmoid sinus* by

keeping close to the postero-superior arc of the external auditory meatus and by directing the chisel slightly forwards as well as medially in opening the mastoid cells; (3) the descending portion of the *facial nerve* by not encroaching upon the inferior half of the deepest part of the posterior wall of the osseous meatus. If the operation is extended from the tympanic antrum through the aditus into the epitympanic recess, care must be taken not to injure either the *lateral semicircular canal* or the *facial nerve*, both of which lie in relation to the medial wall of the aditus.

Mastoid Part of Temporal Bone.—The **mastoid process** begins to develop in the second year. As development advances the diploë surrounding the antrum in the child becomes excavated to form the **mastoid air-cells**, which radiate from the antrum, and either directly or indirectly communicate with it by small openings. In the pneumatic type of mastoid the whole of the mastoid part of the temporal bone is occupied by these cells; and they extend also upwards into the squamous portion, forwards to the posterior wall of the osseous meatus (border-cells and posterior root of the zygoma), and backwards into the occipital bone. Pus retained within the "*border-cells*" may penetrate the posterior wall of the osseous meatus, and rupture through it. Less frequently the mastoid cells are absent, the bone consisting either of osseous tissue similar to that of the diploë, or of dense bone (sclerosed type).

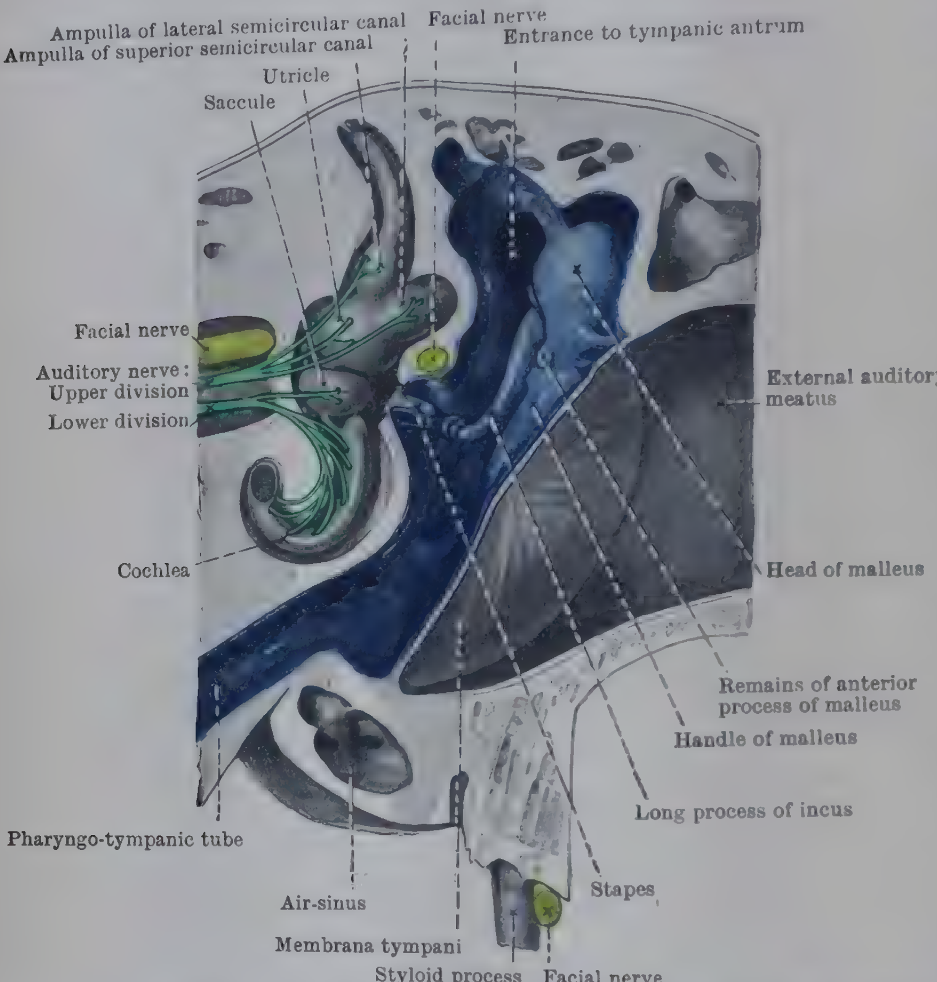

FIG. 1193.—SECTION THROUGH LEFT TYMPANIC CAVITY AND ADJACENT PARTS VIEWED FROM THE FRONT (SEMI-DIAGRAMMATIC).

In the infant the mastoid portion of the temporal bone is composed of sclerotic or sclero-diploic bone. The tympanic antrum is always present and there are a few small air-cells in its lateral wall. In the adult the sclerotic or sclero-diploic type of bone persists in about 20 per cent of skulls; that is to say, that the lateral wall of the antrum is formed either of dense bone, or of bone whose spaces are filled with marrow. In the remaining 80 per cent the mastoid part of the temporal bone is cellular or pneumatic, owing to the extension of the air-cells from the antrum. The difference in anatomical structure is of great importance in cases of mastoiditis because, if a patient with a pneumatic mastoid suffers from severe otitis media and mastoiditis, the inflammatory process extends to all these air-cells and usually comes to the surface on the lateral surface of the mastoid-temporal, giving rise to a subperiosteal abscess. On the other hand, if the patient has a sclerotic or sclero-diploic mastoid—the so-called "persistent infantile" form of mastoid—the inflammatory process is confined to the tympanic antrum and does not manifest itself on the surface. It is in the latter cases that an attack of acute

suppurative otitis media, with infection of the tympanic antrum, is specially liable to become chronic or to result in infection of the labyrinth or an intracranial complication. In operating on cases of chronic middle-ear suppuration the surgeon almost invariably meets with the persistent infantile type of mastoid-temporal, for the reason given above. Formerly it was erroneously supposed that the chronic infection of the mastoid resulted in sclerosis of the bone. We now know that cause and effect were transposed and that it is the sclerotic type of mastoid which has resulted in the chronic inflammatory condition and not the chronic inflammatory condition which has resulted in sclerosis of the mastoid.

The mastoid portion of the temporal bone is grooved, on its medial surface, by the **sigmoid sinus**. The average distance of the foremost part of the sinus from the suprameatal triangle is 1 cm. The right sinus usually receives the superior sagittal sinus, and it is then larger and farther forward than the left; in extreme cases it may reach to within 2 or 3 mm. of the meatus. The average distance of the sigmoid sinus from the *lateral* surface of the mastoid temporal is about 10 mm., but when the sinus is large and far forward the thickness may be reduced to 1 or 2 mm.

Facial Nerve.—The facial nerve, after entering the facial canal at the bottom of the internal auditory meatus, lies immediately above and behind the fenestra vestibuli, between it and the prominence of the lateral semicircular canal; thence it descends almost vertically in the posterior wall of the tympanum 3 mm. behind and medial to the lower half of the deepest part of the posterior wall of the external osseous meatus; and it emerges through the stylo-mastoid foramen (Fig. 1193).

In the infant, in consequence of the absence of the mastoid process, the exit of the facial nerve from the stylo-mastoid foramen is exposed on the lateral surface of the skull rather than on the base, at a point immediately behind the posterior segment of the tympanic horse-shoe. It follows, therefore, that, in infancy, the incision to expose the antrum should not be curved too far downwards and forwards, else the facial nerve may be divided. In the infant the position of the tympanic antrum is relatively higher than in the adult, because in the infant the upper wall of the auditory meatus inclines towards the vertical plane instead of being horizontal.

Paranasal Sinuses.—The **frontal sinuses** are a pair of cavities situated immediately above the root of the nose between the two tables of the frontal bone (Fig. 1194). Each sinus at its most dependent part communicates, by means of the infundibulum, with the middle meatus of the nose. A bony septum, rarely incomplete, separates the two sinuses; it is usually median below, but it may deviate to one or other side above (Pl. LXXVII, p. 1200).

The sinuses vary considerably in their size and shape, independently of the degree of development of the glabella and superciliary arches. Average dimensions are approximately 2·5 cm. in height and in breadth and over 2·5 cm. in depth along its floor. On the other hand, the sinus may exist merely as a small recess above the nose or it may extend upwards into the frontal bone for more than 5 cm., laterally to the side of the skull, while its inferior part may extend backwards, in the orbital roof, as far as the optic foramen. The anterior wall is the thickest, but the thickness may vary from 1 to 5 mm. The floor is the thinnest wall; when pus is retained within the cavity it tends to point, therefore, at the upper and medial angle of the orbital opening. Intracranial suppuration may arise in connexion with sinus-disease by extension through the roof of a sinus. The muco-endosteal lining is thin and pale, and readily strips from the bone.

In many subjects, by the aid of *transillumination*, the extent of the sinuses and the position of the intervening septum may be mapped out upon the forehead. For that purpose a small electric lamp is placed against the floor of the sinus, beneath the medial third of the supra-orbital margin.

The radiographic appearances of the frontal sinuses are of importance clinically and give more information than transillumination. Anterior radiographs (Pls. VIII, p. 155, and LXXVII, p. 1200) show the vertical extent of the sinuses, the degree of asymmetry, and the presence or absence of recesses, and their intervening septa. An orbital expansion is indicated by a well-defined dark area with a sharply defined upper

margin, extending laterally parallel to and immediately above the medial half or more of the supra-orbital margin. Lateral radiographs (Pls. VII, p. 154, LXXIII, p. 944, and LXXV, p. 960) show not only the height of the sinuses but also their antero-posterior diameter, as well as the degree to which their lower parts extend backwards in the roof of the orbit and the relation of the sinus to the underlying ethmoid sinuses. It is exceptional to meet with frontal sinuses before the age of five years, but they are almost invariably present by the seventh or eighth year.

When the sinus is explored, the opening in the bone should be made close to the median plane, immediately above the root of the nose. In marked cases of deviation of the septum one sinus may extend so far beyond the median plane as to reduce the other to a mere slit; in such cases the surgeon may fail to open the diseased sinus when the operation is

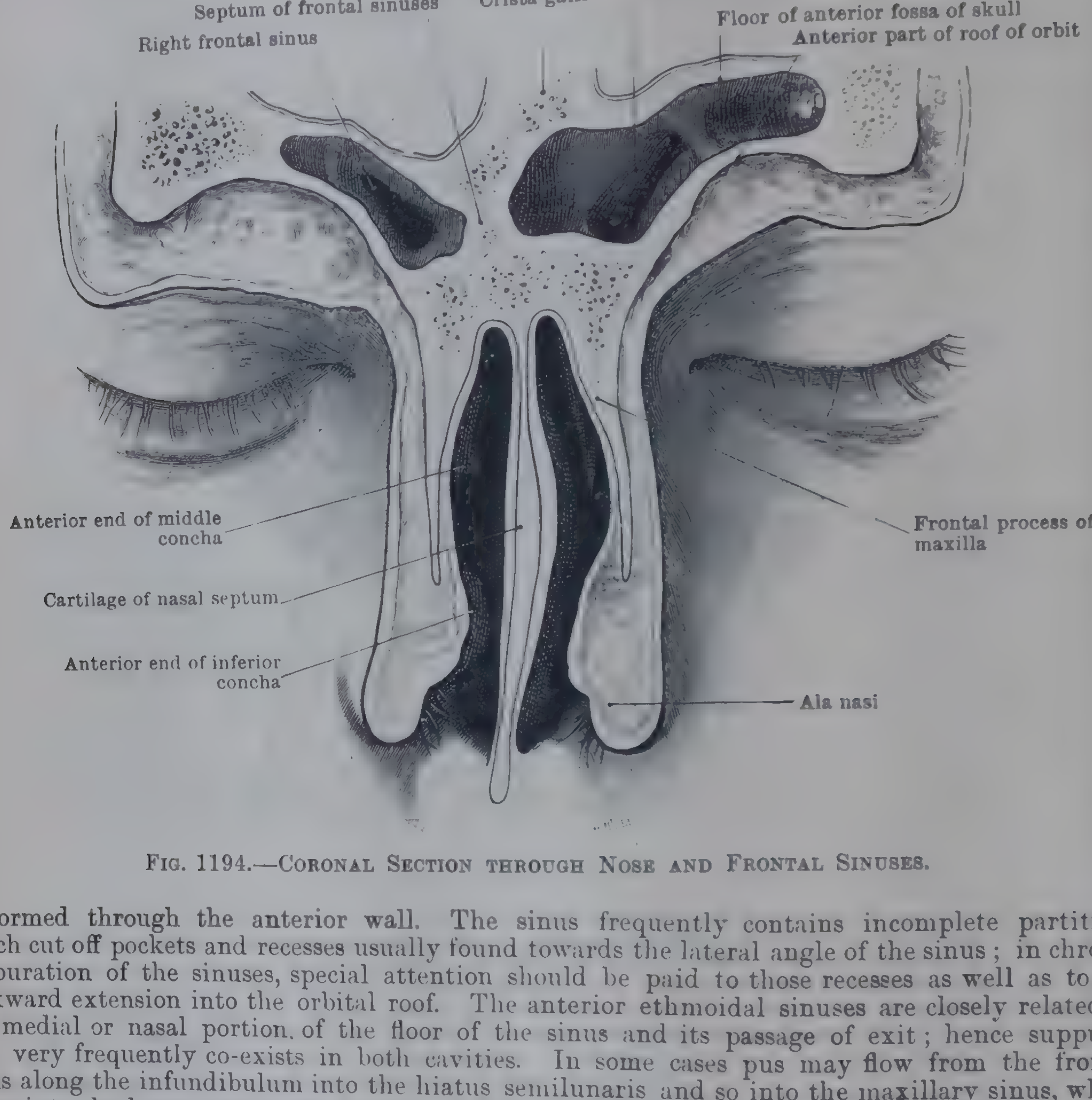

FIG. 1194.—CORONAL SECTION THROUGH NOSE AND FRONTAL SINUSES.

performed through the anterior wall. The sinus frequently contains incomplete partitions which cut off pockets and recesses usually found towards the lateral angle of the sinus; in chronic suppuration of the sinuses, special attention should be paid to those recesses as well as to the backward extension into the orbital roof. The anterior ethmoidal sinuses are closely related to the medial or nasal portion of the floor of the sinus and its passage of exit; hence suppuration very frequently co-exists in both cavities. In some cases pus may flow from the frontal sinus along the infundibulum into the hiatus semilunaris and so into the maxillary sinus, which opens into the lower part of the hiatus. Killian's operation for the cure of chronic suppuration in the sinus consists in removing its anterior and inferior walls—the supra-orbital margin being left to prevent the falling in of the eyebrow. By the removal of the frontal process of the maxilla good access may at the same time be obtained to the ethmoidal sinuses, and free drainage established between the frontal sinus and the nasal cavity.

In an anterior radiograph of the skull (Pl. VIII, p. 155), the dark areas formed by the **ethmoidal sinuses** are seen to occupy a well-defined position, bounded on each side by the still darker area of the orbital cavity and above by the dense horizontal shadow of the cribriform plate, which occupies the frontier line between those sinuses and the frontal sinuses. Anteriorly the ethmoidal sinuses are overlapped by the vertical shadow cast by the frontal processes of the maxillæ. Not infrequently the ethmoidal sinuses will be seen to extend into the roof of the orbit, while inferiorly and laterally they come into close relation to the upper and medial angle of the dark area that corresponds to the maxillary sinus. The comparative transparency of the ethmoidal sinuses is partly accounted for by the fact that they are superimposed upon the sphenoidal sinuses.

In a lateral radiograph the ethmoidal sinuses are seen to extend from the frontal processes of the maxillæ backwards across the orbits to the sphenoidal sinuses, with which they are contiguous (Pl. VII, p. 154). The area is crossed about its middle by the vertical shadow cast by the frontal processes of the zygomatic bones. In front of that, and occupying, therefore, the dark area of the orbital cavity, are the *anterior ethmoidal sinuses*; and behind it are the *posterior ethmoidal sinuses.* In a profile view of the skull, the posterior ethmoidal sinuses, the sphenoidal sinuses, and the hypophysial fossa all lie, from before backwards, in the axis of those rays which pass through the thinnest portion of the cranial box, namely, the anterior part of the temporal fossa; hence the

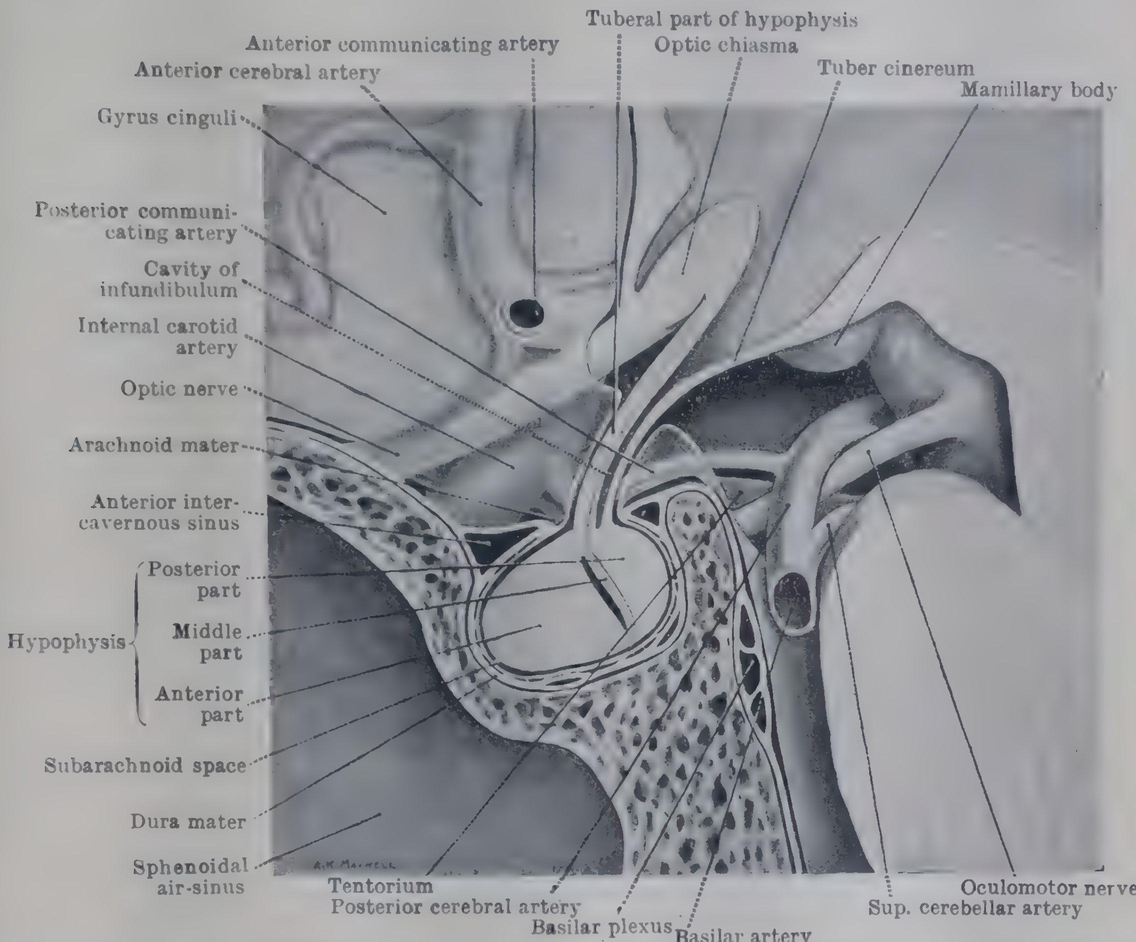

FIG. 1195.—DIAGRAMMATIC MEDIAN SECTION OF HYPOPHYSIS *IN SITU*, SHOWING THE PARTS OF THE ORGAN AND ITS RELATIONS TO ADJACENT STRUCTURES. (The existence of a subarachnoid space around the gland in the hypophysial fossa is doubtful.)

possibility of identifying them in a radiograph taken even from a living subject (Pl. LXXIII, p. 944).

The **sphenoidal sinuses** are distinguished with difficulty in an anterior radiograph owing to the superimposed shadows.

In lateral radiographs of the skull the dark area of the sphenoidal sinuses is seen immediately below and in front of the characteristic well-defined cup-shaped shadow thrown by the floor of the hypophysial fossa (Pls. VII, p. 154, LXXIV, p 945, and LXXV, p. 960). Inferiorly, the sinus-area is to some extent overlapped and obliterated by the dense shadow which corresponds to the zygomatic arch and the horizontal portion of the greater wing of the sphenoid — that is to say, to the floor of the middle cranial fossa. This shadow is continuous, posteriorly, with that caused by the petrous portion of the temporal bone. The posterior ethmoidal sinuses are seen in front of the area of the sphenoidal sinuses, while behind it is limited by the shadow produced by the part of the body of the sphenoid that lies below the dorsum sellæ.

Hypophysis Cerebri.—The *hypophysial fossa* is immediately behind the upper part of the sphenoidal sinuses; and, in a median section of the skull, the anterior half of the fossa is seen to project into what would correspond to the supero-posterior angle

of the sinuses (Fig. 164, p. 193). The more the sphenoidal sinuses project backwards below the hypophysial fossa, the thinner is that part of the floor of the posterior cranial fossa which separates the sinus from the basilar artery and the pons.

In lateral radiographs of the skull (Pls. VII, p. 154, LXXIV, p. 945 and LXXV, p. 960), the outline of the hypophysial fossa is marked out by a crescentic linear shadow, the anterior and posterior horns of the crescent being the shadows of the anterior and posterior clinoid processes. Below and in front of the fossa the outlines of the sphenoidal sinuses may be distinctly traced. In front of the fossa the shadow which outlines the roof of the sphenoidal sinus is formed from before backwards by (1) the tuberculum sellæ, (2) the optic groove, (3) the plane of the lesser wing of the sphenoid. Above the lesser wing there is a second horizontal shadow caused by the roof of the orbit. Below the sphenoidal sinus there is a curved shadow produced by the floor of the middle cranial fossa; and behind the dorsum sellæ a dense triangular shadow corresponds to the petrous portion of the temporal bone.

Enlargements of the hypophysis cerebri can often be clearly demonstrated by an increase in the depth and antero-posterior diameter of the radiographic outline of the hypophysial fossa, by the unusual extent to which the fossa encroaches on the sphenoidal sinus, by pressure atrophy of the clinoid processes, and by the thinning of the dorsum sellæ.

Adenomata and cysts of the hypophysis frequently enlarge upwards through the diaphragma sellæ towards the brain. After emerging from the fossa the tumour bulges upwards through the space bounded in front by the anterior segment of the circulus arteriosus, and behind by the optic nerves and the chiasma. As a result of the pressure upon the medial borders of the optic nerves and on the chiasma, a common sign of such a tumour is bitemporal hemianopia.

Tumours arising in the hypophysis or in its neighbourhood are usually approached by exposing the frontal lobe in its dural covering by an osteoplastic bone-flap above the superior border of the orbit. The frontal lobe is elevated upwards and backwards until the optic nerve is reached, or the tumour is identified. Rarely, when a hypophysial growth expands downwards and forwards towards the sphenoidal sinus, it is dealt with by the intranasal route, which requires removal of the cartilaginous and bony parts of the nasal septum.

THE FACE

Skin.—The skin of the face is thin, vascular, and rich in sebaceous glands and sweat-glands; it is intimately connected with the subcutaneous tissue, in which the facial muscles and the main blood-vessels are embedded. Owing to its mobility and to the presence of the main blood-vessels in the lax subcutaneous tissue, the face is an admirable site for plastic operations. The laxity of the tissues accounts for the marked swelling which attends œdematous and inflammatory conditions about the face. Whenever possible, incisions should be made along the line of the natural furrows and creases of the skin, in order that the resulting cicatrix may be less noticeable.

Landmarks.—The bony landmarks of the face which can be readily palpated are: the **superciliary arches** and the **glabella**, the **nasion**, the **bridge of the nose**, the **bony anterior aperture of the nose** and the **anterior nasal spine**, the **supra- and infra-orbital margins**, the **zygomatic** and **maxillary processes** of the **frontal bone**, the anterior part of the **temporal line**, the **zygomatic bone**, the **zygomatic arch**, and the region of the **canine fossa** of the maxilla (Fig. 154, p. 155, and Fig. 1184).

Immediately below the root of the zygoma, and in front of the upper part of the tragus, is the **head of the mandible**. If the finger-tip is pressed on the head while the mouth is being widely opened, the bone will be felt to glide forwards, while the finger sinks into the hollow corresponding to the **articular fossa**. The close relation of the first part of the **maxillary artery** to the medial side of the neck of the mandible must be kept in mind in operations calling for disarticulation or excision of the head. The **ramus of the mandible** is sandwiched between the masseter and the medial pterygoid muscles, and can be removed without opening

into the cavity of the mouth. Below the head, one can palpate the borders of the ramus and the **angle** and **body of the mandible**. The anterior border of the **coronoid process** is felt in front of the upper part of the anterior border of the masseter, immediately below the anterior part of the zygomatic arch.

A line dropped vertically from the supra-orbital notch to the lower border of the mandible opposite the interval between the two lower premolar teeth, will cross the **infra-orbital** and **mental foramina**—the former 5 mm. below the infra-orbital margin, the latter midway between the borders of the mandible.

Maxillary and Mandibular Nerves.—In the treatment of neuralgia of the trigeminal nerve, alcohol is sometimes injected into the maxillary or the mandibular nerve at its exit from the skull.

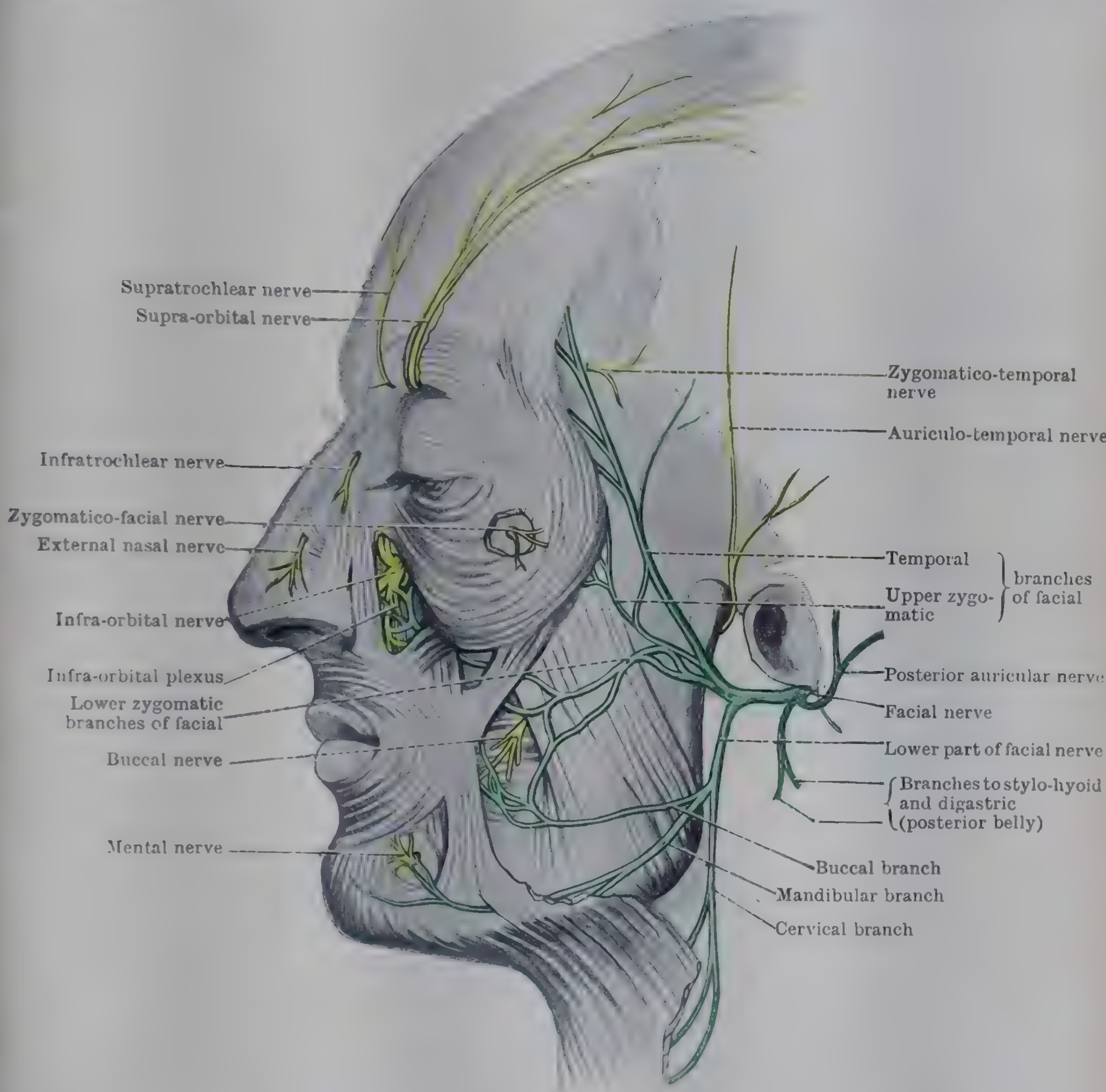

Fig. 1196.—Distribution of Trigeminal and Facial Nerves on the Face.

The **mandibular nerve** is injected immediately below the foramen ovale, which is about 5 cm. from the skin in the same coronal plane as the articular eminence. When the mouth is opened widely the head of the mandible travels forwards and can be distinctly felt immediately below the eminence. To avoid the mandibular joint the needle is introduced through the skin immediately below the zygoma, a little in front of the eminence, 3 cm. in front of the middle of the external auditory meatus. It is pushed medially, slightly upwards and backwards through the mandibular notch, and thence through, or immediately above, the lateral pterygoid muscle, into the nerve.

To reach the **maxillary nerve**, the needle is introduced at the same point on the cheek, and pushed medially and forwards in the direction of the external angle of the orbit, so that its point will impinge upon the lateral pterygoid plate. It is then directed a little anteriorly, and pushed onwards for 0·5 cm., when it will strike the nerve as it lies in the pterygo-palatine fossa, immediately below the foramen rotundum, at a distance of about 5 cm. from the skin.

Facial Artery.—The pulsation of the **facial artery** may be felt as the vessel crosses the lower margin of the mandible at the anterior border of the masseter, 3 cm. in front of the angle of the mandible (Fig. 1197). To map out the course of the artery on the face, a line is drawn from that point to a point 1·3 cm. lateral to the angle of the mouth, and thence to a point a little behind the ala nasi and along the side of the nose to the medial angle of the eye. The **anterior facial vein** is behind the facial artery, and takes a straighter course from the medial angle of the eye to the anterior inferior angle of the masseter. The vessel is devoid of valves; infective phlebitis and thrombosis are therefore apt to spread along it to the cavernous sinus by way of the ophthalmic and pterygoid veins.

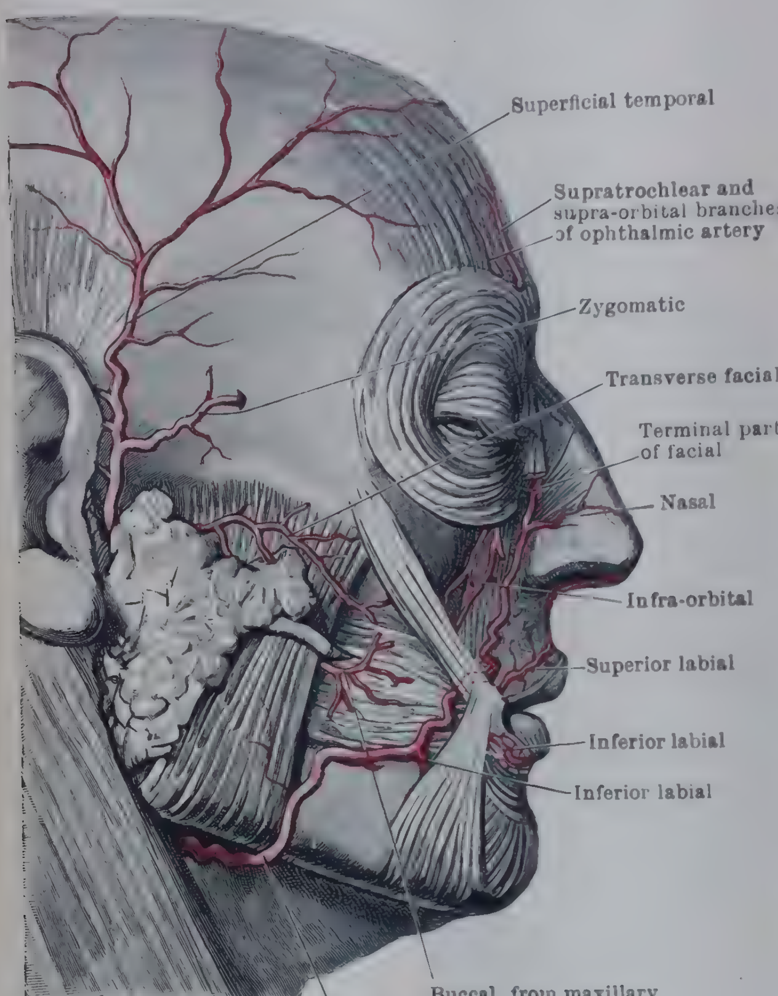

FIG. 1197.—ARTERIES OF THE FACE.

Facial Nerve.—The facial nerve, after emerging from the stylo-mastoid foramen, enters the substance of the parotid gland 2·5 cm. deep to the middle of the anterior border of the mastoid process. It is superficial to the external carotid artery. Branches of the nerve can be rolled under the finger as they cross the neck and head of the mandible (Fig. 1196); incisions continued along the mandible above that point should be only skin-deep if the branches are to be avoided. To expose the trunk of the nerve an incision is made along the anterior border of the upper third of the sterno-mastoid muscle. Dissection in the upper end of the wound exposes the posterior belly of the digastric muscle, along the upper border of which the nerve courses. Incisions on the cheek should, whenever possible, be planned so as to run parallel with the branches of the nerve, which radiate from the lower end of the tragus. The nerve may be paralysed by wounds of the cheek and by malignant tumours of the parotid, and also by intracranial and middle-ear lesions.

Parotid Gland and Duct.—The **parotid gland** (Figs. 1197, 1205) is surrounded by a fascial envelope, the strongest portion of which is continued from the deep cervical fascia over its lateral surface to become attached to the zygoma; hence abscesses in the parotid tend to burrow deeply towards the pterygo-palatine fossa and the upper part of the pharynx; the pus should therefore be evacuated early through an oblique incision through the skin only, a little behind and below the angle of the mandible. The abscess is opened by passing a blunt instrument (forceps) through the opening in the skin, in order to avoid injuring branches of the facial nerve (Hilton's method).

The **parotid duct** can be rolled beneath the finger as it crosses the masseter, rather less than a finger's breadth below the zygoma. After winding round the anterior border of the muscle it pierces the buccinator and opens into the mouth opposite the second upper molar tooth. The duct corresponds to the middle third of a line drawn from the lower margin of the concha of the auricle to a point midway between the ala nasi and the margin of the upper lip.

Superficial to the parotid and a little in front of the tragus there is a **parotid lymph-gland** which is frequently found to be inflamed in children suffering from eczematous conditions of the eyelids, face, scalp, and external ear. When an abscess connected with that gland is opened, the incision is made as low down as possible, in order to avoid the parotid duct.

The deep parotid lymph-glands, which lie partly in the substance of the parotid and partly deep to it, are especially liable to become infected secondary to tuberculous disease of the middle ear and to malignant affections about the root of the tongue, the throat, and the naso-pharynx. In their removal it is generally impossible to avoid the cervical branch of the facial nerve, which pierces the cervical fascia immediately below and behind the angle of the mandible. The cervical branch supplies the platysma and the depressor labii inferioris muscles; its division therefore results in inability to depress the lower lip on the affected side. At the same operation some trouble may be caused by bleeding from the posterior facial vein and its divisions, which traverse the substance of the parotid gland.

Eyelids.—The skin of the eyelids, more especially of the upper, is very thin and is connected with the orbicularis oculi muscle by delicate, lax subcutaneous tissue destitute of fat; hence the marked swelling which occurs in a "black eye" and in œdema of the lids. Along the anterior edge of the free margin of each lid are the eyelashes and the orifices of the ciliary glands, suppurative inflammation of which gives rise to a "*stye*"; along the posterior edge are the minute orifices of the **tarsal glands**. These glands, embedded in the deep surface of the tarsi, are seen through the palpebral conjunctiva as a row of parallel, yellowish, granular-looking streaks. From the deep position of the glands it follows that the skin over a *Meibomian cyst*—a retention cyst resulting from occlusion of the orifice of a tarsal gland—is freely movable, and that to reach the cyst an incision must be made through the conjunctival surface of the lid.

The **palpebral conjunctiva** is closely adherent to the ocular surface of the tarsi; at the fornix—the zone of reflexion of the conjunctiva from the deep surface of the eyelid on to the eyeball—it is loose and contains small lymph-follicles which become hypertrophied in the condition known as granular conjunctivitis. The **ocular conjunctiva** is thin, transparent, and loosely attached to the sclera, so that, in an operation on the eye, a fold of the membrane can be picked up with forceps to steady the eyeball.

In inflammatory affections of the eye the state of the visible vessels gives important information as to the seat of the mischief. For example, in inflammation of the *conjunctiva* the posterior conjunctival vessels (derived from the palpebral arteries)—scarcely visible normally—appear as a close network which fades away towards the corneal margin; those vessels move freely with the conjunctiva, and disappear under pressure. In superficial inflammations of the *cornea* the anterior conjunctival vessels (the most superficial of the terminal branches of the anterior ciliary arteries) are seen to spread in a freely branching manner into its superficial layers. In *iritis* and deep inflammations of the cornea there is a pink circumcorneal zone of vascular dilatation consisting of delicate straight vessels which do not disappear under pressure and do not move with the conjunctiva; they are the subconjunctival (episcleral) terminations of the anterior ciliary arteries; in health they are invisible.

Lacrimal Apparatus.—The **lacrimal gland**, situated behind the lateral part of the supra-orbital margin, cannot be felt unless enlarged. If the upper eyelid is raised and everted, the palpebral process of the gland is seen to bulge below the lateral third of the fornix, in which situation also the minute orifices of the lacrimal ducts may be detected.

When the lower lid is drawn gently downwards the **punctum lacrimale** is seen on a slight papillary elevation of its margin about 4 mm. from the medial angle of the eye; the corresponding orifice of the upper lid is a little more medial. Normally the puncta are directed towards the ocular conjunctiva, and are accurately applied to it immediately lateral to the lacrimal caruncle.

Drawing the lids laterally puts the **medial palpebral ligament** on the stretch, and it can be felt as a narrow, tense band passing medially to be attached

to the frontal process of the maxilla. The ligament is a guide to the position of the lacrimal sac, which it crosses a little above its middle. Continuous with the lower end of the lacrimal sac is the **naso-lacrimal duct**, which passes downwards and slightly backwards and laterally to open into the inferior meatus of the nose under cover of the anterior part of the inferior concha. The lacrimal sac and naso-lacrimal duct each measure about 1·3 cm. in length; the duct is slightly contracted at its beginning and end, and it is in those situations that pathological strictures of the duct are most common. Spontaneous rupture of an abscess of the lacrimal sac occurs almost invariably immediately below the medial palpebral ligament; it is in that situation that the abscess should be opened, the incision being made a little lateral to the terminal part of the facial artery.

The **lacrimal canaliculi**, which convey the lacrimal fluid from the puncta to the lacrimal sac, run for the first 1-2 mm. almost vertically from the free margins of the lids, and then parallel to them. The **lacrimal caruncle** is placed between those portions of the lids in which the canaliculi lie. In the various morbid conditions which give rise either to misdirection of the puncta or to stricture at any part of the lacrimal drainage apparatus, overflow of the tears (*epiphora*) is the chief sign. When a probe is passed along a lacrimal canaliculus, the instrument, in consequence of the bend of the canaliculus, is passed at first vertically from the margin of the lid, and afterwards parallel to it, until the point is felt to strike against the medial wall of the lacrimal sac; to pass the instrument onwards along the naso-lacrimal duct the handle is rotated forwards and upwards through a quarter of a circle, and then pushed gently downwards and slightly backwards and laterally into the inferior meatus of the nose.

The **tarsi** are attached to the periosteum of the orbital margins by the *palpebral ascia,* which shuts off the communication between the subcutaneous tissue of the eyelids and the fatty tissue of the orbital cavity. In fracture of the floor of the anterior cranial fossa involving the roof of the orbit, the blood extends forwards between the periosteum and the musculo-fascial envelope of the orbit, and appears under the conjunctiva.

To obtain free access to the cavity of the orbit, the surgeon first enlarges the palpebral fissure by making a horizontal incision from the lateral angle of the eye to the lateral margin of the orbit, and then, after everting the eyelid, divides the conjunctiva along the fornix of the upper or of the lower lid, or of both, as may be necessary.

Nose.—To examine the cavity of the nose from the front (*anterior rhinoscopy*) the nostril is dilated with a nasal speculum and the interior is illuminated by reflected or direct light. The **anterior end of the inferior concha** appears as a rounded body projecting from the side-wall of the nose; when its muco-periosteum is turgescent it is apt to come into contact with the nasal septum and so occlude the cavity. The **inferior meatus** is between the inferior concha and the side-wall of the nasal cavity; it is brought into view by tilting the head backwards. The **lower end of the naso-lacrimal duct** is concealed by the anterior part of the inferior concha. The **floor** of the nose is horizontal and is on a slightly lower level than the nostrils. The **septum**, generally more or less deviated to one or other side, is seen when the head is slightly rotated away from the side to be examined. The **anterior end of the middle concha**, which lies a little behind and medial to the infero-medial angle of the orbital margin, is seen when the patient's head is thrown well back; it is separated from the septum only by a slit-like interval. To bring the **anterior part of the middle meatus** of that side into view, the patient's face is rotated towards the shoulder; pus in that situation may originate from the frontal sinus, the anterior ethmoidal sinuses, or the maxillary sinus, all of which open into the middle meatus.

When bleeding from the nose (epistaxis) occurs it usually proceeds from the small vessels of the septum, and it may be arrested by compressing the superior labial arteries, by plugging the nostrils, or by grasping the cartilaginous part of the nose firmly between the finger and thumb.

Maxillary Sinus.—This sinus is a pyramidal cavity with its base formed by the side-wall of the nose and its apex directed towards the zygomatic bone. The cavity

is lined with a thin muco-endosteum, easily separable from the bone and in which mucous cysts may develop. The floor of the sinus, which is a little below the level of the floor of the nose, is separated from the roots of the upper premolar and molar teeth by a plate of bone of varying thickness. When that plate is thin and devoid of spongy bone, suppuration at the roots of one of the teeth may extend to the sinus. The *orifice* is situated at the highest part of the sinus, and is therefore unfavourably placed for natural drainage; it opens into the middle meatus of the nose through the lower part of the *hiatus semilunaris*. Not infrequently a second communication exists between the sinus and the middle meatus, the opening being situated behind and below the normal orifice; when that accessory aperture exists, pus from

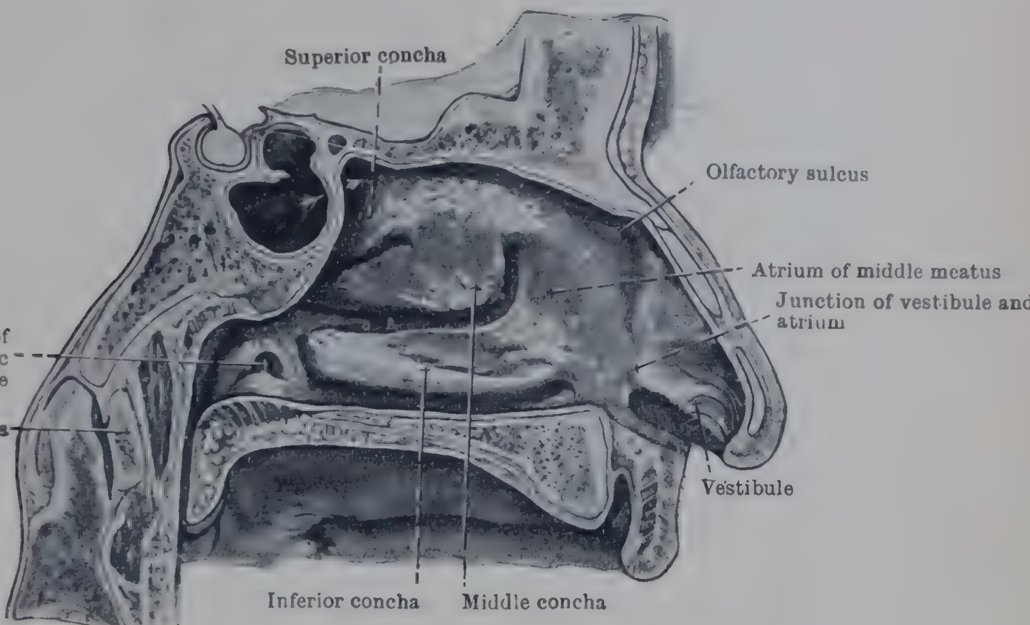

Fig. 1198.—Lateral Wall of Left Nasal Cavity.
The arrow passes from the sphenoidal sinus to the spheno-ethmoidal recess.

the sinus may drain backwards into the nasal part of the pharynx (Logan Turner, 1901).

In *empyema of the sinus* the opening to evacuate and drain the cavity may be made: (1) through the canine fossa; (2) through the side-wall of the inferior meatus of the nose.

In an anterior radiograph of the skull (Pl. VIII, p. 155), the maxillary sinus, presents a pyramidal outline, the base corresponding to the floor of the orbit and the rounded apex to the alveolar recess of the sinus. The medial outline of the sinus-area is the foreshortened shadow of the nasal wall of the sinus; laterally it is outlined by the zygomatic bone. The petrous part of the temporal bone throws a deep shadow across the upper half of the sinus. When the radiograph is taken, the head should therefore be tilted backwards so that the petrous part of the temporal is projected below the sinus which can then be seen clearly (Pl. LXXVII, p. 1200, Fig. 1).

In a lateral radiograph of the facial region of the dried skull (Pls. VII, p. 154, and XLVII, p. 558, Fig. 1), the outline of the maxillary sinus is well defined. It is represented below by the white line which crosses the tips of the roots of the molar teeth. Above, it is limited anteriorly by the white, curved shadow of the floor of the orbit; while above and posteriorly are the posterior ethmoidal cells. Behind the maxillary area are the vertical shadows of the pterygoid plates, overlapped by that of the coronoid process of the mandible. The anterior part of the sinus-area is overlapped and to a considerable extent obscured by the dense and more or less triangular shadow cast by the zygomatic bone.

MOUTH AND PHARYNX

Lips.—The lips are abundantly supplied with **mucous glands** which can be felt nearer their attached than their free borders immediately outside the mucous membrane; the glands are a frequent seat of mucous cysts; occasionally they undergo a congenital enlargement which results in one form of hypertrophy of the lip.

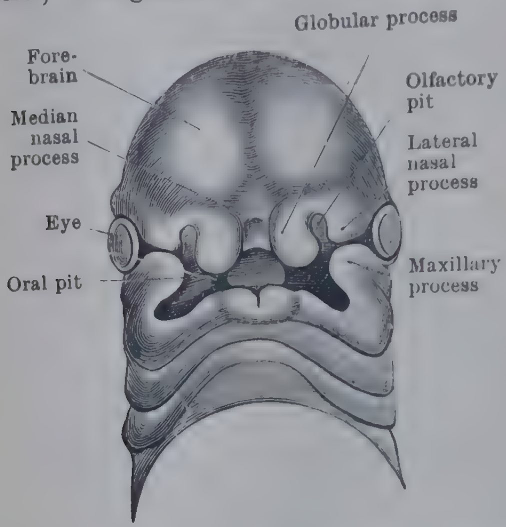

Fig. 1199.—Head of Human Embryo showing early stage of Development of Face.

Hare-lip is due to failure of the union of the superficial part of the maxillary process with the globular part of the median nasal process (Figs. 1199 and 1028, p. 1202). The deformity is spoken of as complete or incomplete according to whether the cleft extends into the nostril or involves merely a portion of the lip. The fissure may involve the lip only, or it may include the alveolar process of the maxilla; in the latter case the cleft may or may not be associated with a cleft of the palate. Lastly, the hare-lip may be single or double; when single, it is usually on the left side.

Palate.—Fig. 1200 shows how the mouth is shut off from the nasal cavities by the growth inwards from the deep surface of the maxillary process of a pair of horizontal plates (palatine processes) which unite in the median plane with each other and with the lower border of the septum of the nose; the septum, which develops as a downgrowth from the primitive basis cranii, is continuous anteriorly with that portion of the fronto-nasal process which forms the premaxillæ and the median portion of the upper lip. The various degrees of *cleft palate* are due to the more or less complete failure of union of the palatine processes with each other and with the premaxillary part of the median nasal processes. The cleft in the soft palate, which is always median, may be either partial or complete, and it may or may not extend forwards into the hard palate. The cleft in the hard palate is spoken of as single or double according to whether the palatine processes have failed to unite with the lower edge of the nasal septum on one side or on both sides. When the cleft extends forwards through the alveolar process to become continuous with a cleft of the lip, the medial (premaxillary) edge of the cleft is usually projected forwards in advance of the lateral (maxillary) edge. Closure of the labial cleft leads to correction of this deformity.

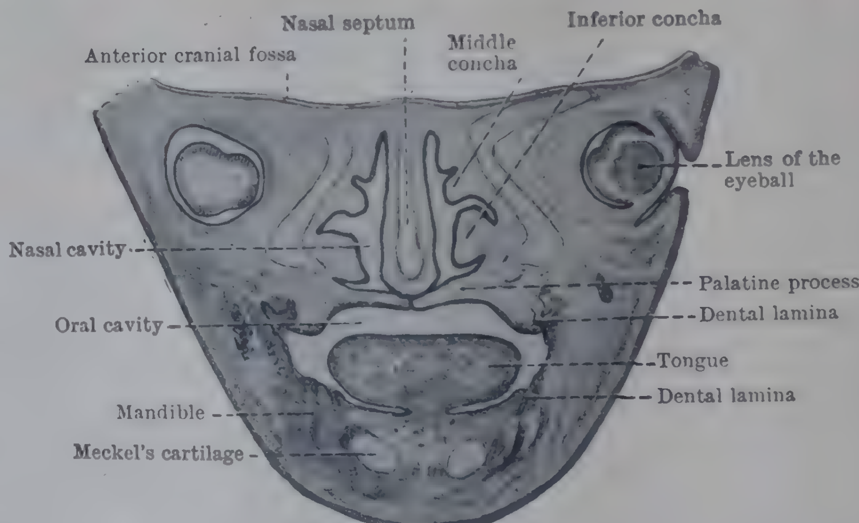

Fig. 1200.—Coronal Section through Face of Human Embryo about 9 Weeks Old.

In what is known as a complete double cleft palate, the palatine processes fail to join the nasal septum and the premaxillæ on both sides; the result is a wide median cleft which communicates with both nasal cavities. The free, lower border of the vomer extends along the middle of the cleft to be continuous anteriorly with the rounded premaxillary mass; that mass, along with the central portion of the upper lip, is projected forwards between the two labial clefts, often to such an extent that it appears to spring from the tip of the nose (Fig. 1201). In the operation for closure of such a double hare-lip, the problem of the correction of the premaxillary projection has to be

faced. Surgeons favour a preliminary closure of the lip-defect on the plea that the constant pressure of the restored lip-outline results in a gradual correction of the pre-

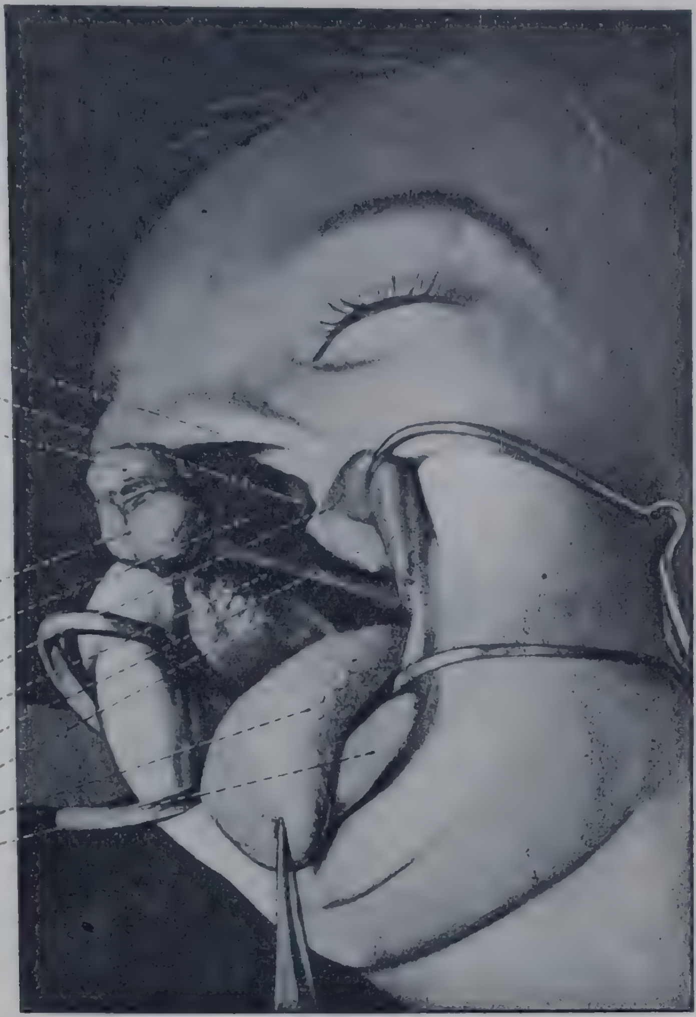

FIG. 1201.—PHOTOGRAPHIC ILLUSTRATION OF DOUBLE COMPLETE HARE-LIP AND CLEFT PALATE.

maxillary displacement. In the rare cases in which the maxillary plates meet in the median line, this method cannot be employed.

Teeth.—The **milk teeth** begin to appear about the sixth month—the first to emerge being usually the lower central incisors. The first dentition is completed about the thirtieth month. Of the **permanent set** the first to erupt are the first molars, which appear about the end of the sixth year; the third molars—the last to appear—may erupt any time between the seventeenth and the twenty-fifth year, or even later. As the permanent teeth push their way towards the surface, absorption of the roots of the first set takes place, and the first set either fall out of their own accord or are easily removed. Loss of the permanent teeth is followed by absorption of the alveolar margin of the jaw. The tooth-sockets are lined with a thin periosteum which is anatomically continuous both with the tissue of the teeth and with the dense fibrous tissue of the deep layer of the gum.

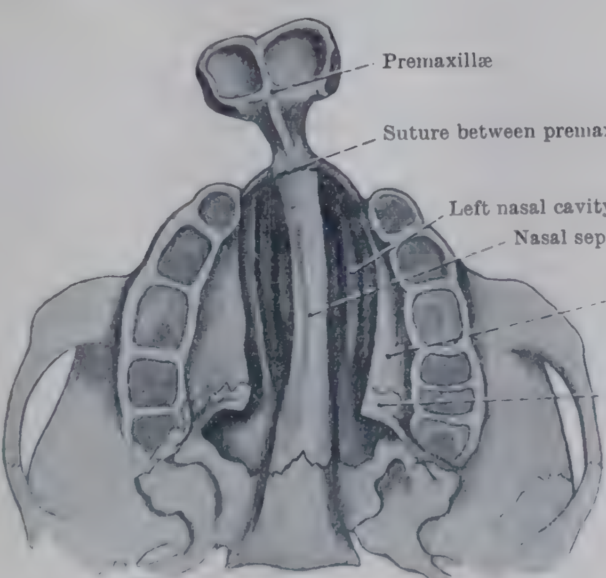

FIG. 1202.—ARRANGEMENT OF BONES IN DOUBLE CLEFT PALATE. (Bergmann, Bruns, & Mikulicz, 1904.)

The upper incisors and canines and the lower premolars have *cylindrical* roots; hence in extracting these teeth, they are first loosened by a slight rotary movement; the roots of the lower incisors and canines and of the upper premolars are *flattened*, and must therefore be loosened by a side-to-side movement. The roots of the third molars are *convergent*, generally welded together and curved backwards, especially in the mandible. The first and second upper molars have three roots, and they are often *divergent*.

Tongue.—For practical purposes, as well as on developmental and structural grounds, it is convenient to divide the tongue into an anterior two-thirds (the **oral part**) and a posterior third (the **pharyngeal part**) (Fig. 1205). At the junction of the two portions, immediately behind the median vallate papilla, is the **foramen cæcum**, which represents the remains of the pharyngeal end of the **thyro-glossal duct**. *Congenital cysts* and *fistulæ* which develop from persistent remains of that duct are always median, and are met with both above and below the hyoid bone.

The mucous membrane of the pharyngeal part of the tongue is much more sensitive than that of the oral part; hence, when a tongue depressor is used, the instrument should, except under special circumstances, rest only upon the oral region; otherwise a reflex arching of the tongue will be set up which prevents the operator from obtaining a satisfactory

FIG. 1203.—CORONAL SECTION THROUGH TONGUE AND SUBMANDIBULAR REGION IN PLANE BEHIND THE MOLAR TEETH.

view of the throat. Scattered over the pharyngeal part are clusters of **lymphoid follicles** (lingual tonsil) which appear on the surface as a number of nodular umbilicated elevations provided with little crypts into which mucous glands open (Fig. 492, p. 575). The lingual tonsil is liable to chronic inflammation and hypertrophy—conditions which are often accompanied by a varicose condition of the veins that lie immediately beneath the mucous membrane that covers the palato-glossus muscle. To obtain a satisfactory view of the lingual tonsil in the living subject, a laryngoscopic mirror is used.

The pair of mucous glands situated in the lower part of the tongue a little behind its tip, and known as the **anterior lingual glands**, are of interest in that they occasionally give rise to mucous cysts similar to those which develop in connexion with the labial glands (Fig. 1204).

The **muscular bundles** of the tongue are separated by a quantity of loose areolar tissue, rich in blood-vessels and lymph-vessels (Fig. 1203); hence acute inflammatory œdema of the tongue may be attended with a degree of swelling sufficient to obstruct the respiratory passage.

The main **blood-vessels** of the tongue run from behind forwards, nearer its lower surface than its upper surface (Fig. 1203); incisions into the substance of the tongue to reduce swelling and tension should therefore be made longitudinally on the dorsum. Bleeding from the lingual artery, divided in the substance of the tongue, is temporarily arrested by the finger passed behind the tongue to hook it well forward and compress the vessel against the lingual surface of the mandible. On account of the very slender anastomosis between the vessels of the two halves of the tongue, scarcely any bleeding occurs when it is split in the median plane.

The collecting **lymph-vessels** which arise from the lymph-networks in the mucous membrane and muscular substance of the tongue may be divided into four

groups:—(1) **Apical trunks,** which open partly into the submental glands and partly into a gland (jugulo-omohyoid) that lies immediately above the tendon of the omo-hyoid muscle. (2) **Marginal trunks,** some of which pass lateral to the sublingual gland and through the mylo-hyoid muscle to join the most anterior of the submandibular lymph-glands, while others pass medial to the sublingual gland, in front of and behind the hyo-glossus muscle, to join the glands in the carotid triangle. The more *anterior* their lingual origin the *lower* is the gland to which they pass. (3) The **basal trunks**, from the posterior third of the tongue, pass from before backwards towards the lower end of the tonsil, where they pierce the superior and middle constrictors of the pharynx, and, after surrounding the lingual artery, open into a gland (jugulo-digastric) placed on the internal jugular vein immediately below the posterior belly of the digastric. (4) The **central trunks**, which descend in the median plane between the genio-glossi, pass deep to the hyo-glossus and mylo-hyoid muscles into the submandibular space, and thence in front of the hyoid bone (having embraced the tendon of the digastric) to join glands in the carotid triangle (Figs. 1180, 1181). Both apical and marginal trunks may cross the median line of the neck to join glands on the opposite side. Thus in malignant lesions of the tongue it is important to examine both sides of the neck for evidence of glandular spread.

Cavity of Mouth.—The groove between the tongue and the gums is crossed in the median plane by the **frenulum linguæ** (Fig. 1204). At each side of the lower part of the frenulum is the **orifice of the submandibular duct**. A little to one side of the frenulum the **profunda vein** is seen through the thin mucous membrane; to the lateral side of the vein are the profunda artery and the lingual nerve, both of which lie deeper in the tongue than the vein and are therefore not visible.

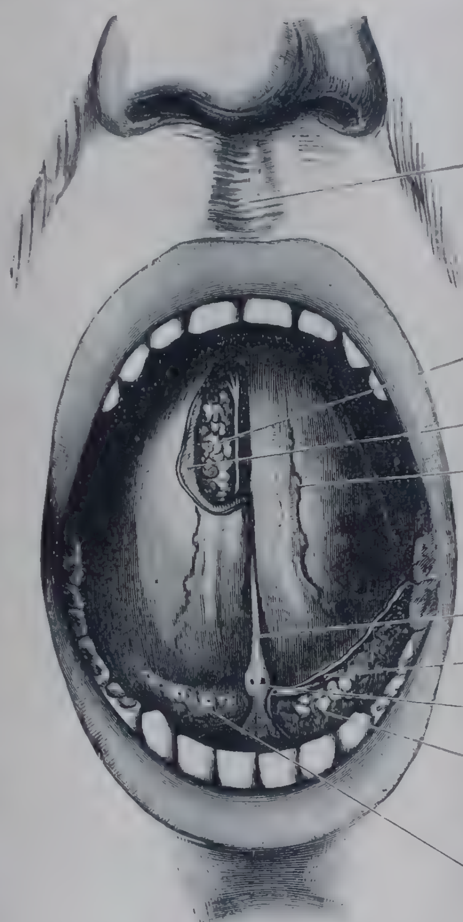

Fig. 1204.—Open Mouth with Tongue raised and Sublingual and Anterior Lingual Glands exposed.

A branch of the lingual nerve is seen running on the medial side of the sublingual gland.

The position of the profunda artery is indicated by the overlying edge-like fold of mucous membrane—the fimbriated fold.

The mucous membrane at the anterior part of the floor of the mouth is thrown into a slight elevation which overlies and is caused by the corresponding **sublingual salivary gland**. The duct of the submandibular gland and the lingual nerve lie below and to the medial side of the sublingual gland.

When a shortened frenulum is divided for "tongue-tie" the deep lingual vessels and the orifices of the submandibular ducts must be avoided. Behind the frenulum linguæ are the anterior borders of the **genio-glossus muscles**, which ascend from the superior genial tubercles. In removing a small salivary calculus from the floor of the mouth, the calculus is fixed against the lingual surface of the mandible before the incision is made over it.

When the teeth are clenched the only communication between the vestibule of the mouth and the oral cavity proper is an opening behind the last molar tooth which can barely admit a medium-sized catheter. Therefore, when the

jaws cannot be separated it is generally necessary to feed the patient through a tube passed along the floor of the nose.

When the mouth is opened widely and a deep inspiration is taken, the soft palate is elevated, and the palato-glossal and palato-pharyngeal arches are made prominent. The **palato-glossal arches** spring from the anterior surface of the soft palate close to the base of the uvula, and they arch downwards and laterally in front of the tonsils to end at the posterior part of the side of the tongue. The **palato-pharyngeal arches** are really the continuation of the free border of the soft palate downwards behind the tonsils to be lost upon the side-

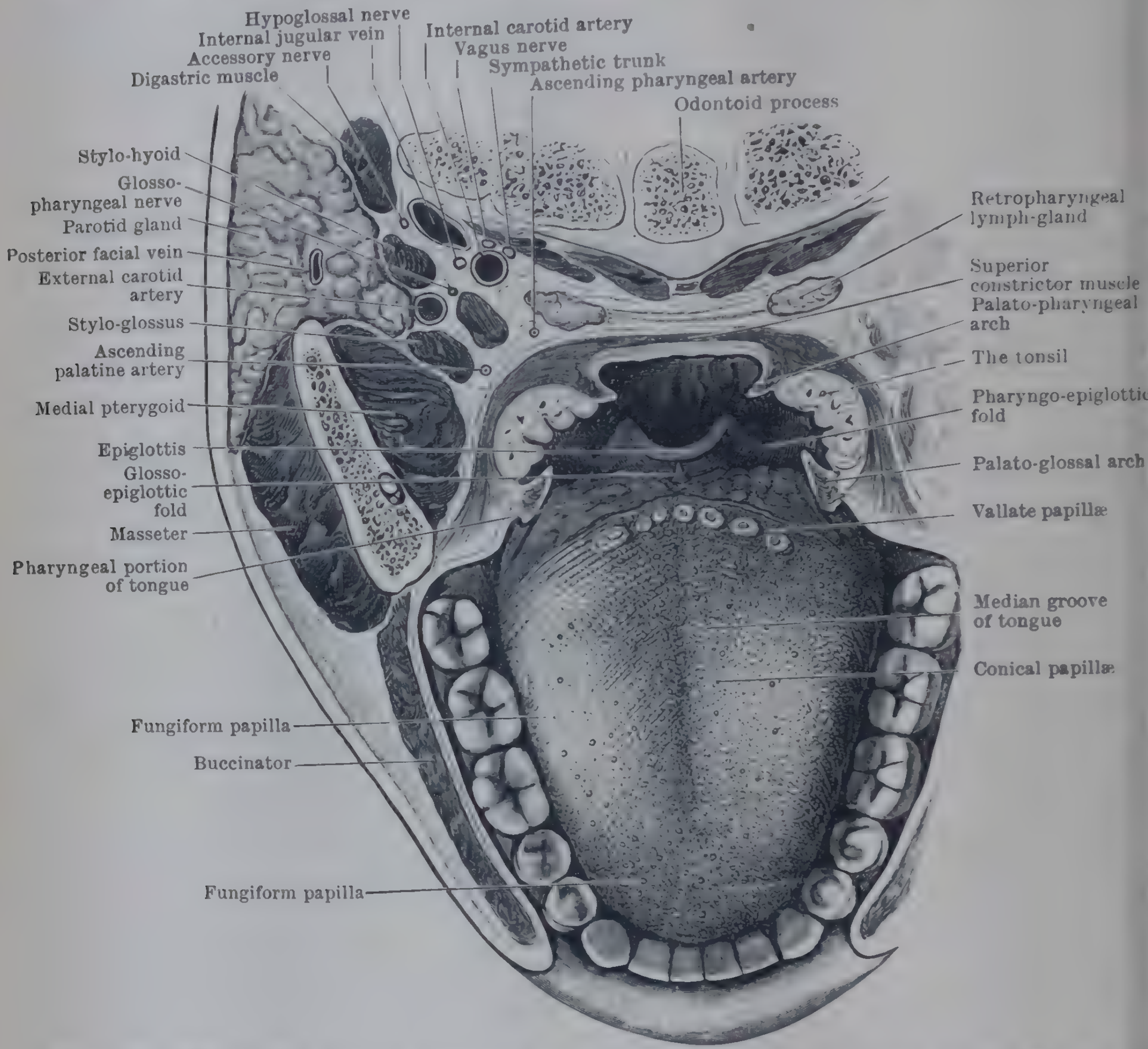

FIG. 1205.—HORIZONTAL SECTION THROUGH MOUTH AND PHARYNX AT THE LEVEL OF THE TONSILS. The stylo-pharyngeus (which is seen on the medial side of the external carotid artery) and the prevertebral muscles are not indicated by reference lines.

wall of the pharynx. Together with the lower edge of the soft palate and the posterior wall of the pharynx, they bound an oblique opening **(pharyngeal isthmus)** through which the mucous membrane of the posterior wall of the nasal portion of the pharynx is visible.

In the *adult* the upper four cervical vertebræ can be explored from the mouth (Pl. XXIX, Fig. 1, p. 342); in the *child* the finger can reach still farther—down to the sixth vertebra and the back of the cricoid cartilage.

Tonsils (Fig. 1205).—The **tonsil** lies in the side-wall of the pharynx between the palatine arches, opposite a point a little above the angle of the mandible. It is covered, on its free surface, with mucous membrane upon which are seen the orifices of the *tonsillar pits* ; the lateral or deep surface is covered with a layer of fibrous tissue which forms an imperfect sheath for the organ and is separated from the superior constrictor by a quantity of loose areolar tissue and fat, and the tonsil can therefore

be grasped with a volsellum and pulled forwards without dragging the muscle with it. The tonsil receives its *blood-supply* mainly from the tonsillar branch of the facial artery; when that branch is larger than usual and adherent to the sheath of the tonsil, the bleeding which attends the operation of removal of the tonsils may be considerable. To arrest the hæmorrhage the bleeding point is pressed outwards against the medial pterygoid and the ramus of the mandible. If the bleeding is from a spurting vessel of larger size, its source is probably the *facial artery*, which has been wounded as it arches upwards deep to the digastric and stylo-hyoid muscles and is separated from the lateral surface of the tonsil only by the superior constrictor muscle. In children and adolescents the tonsils are frequently hypertrophied; the enlargement may be either general, or local; in the latter event the enlargement may be towards the median line, downwards along the pharynx, or upwards behind the soft palate.

The mucous membrane and the periosteum of the **hard palate** are so closely united as to form practically one membrane. The **greater palatine arteries**, after leaving the greater palatine foramina, run forwards in shallow grooves in the bony palate, close to its alveolar margin. In the operation for cleft palate (*staphylorrhaphy*), if lateral incisions are employed, they should be made *lateral* to those vessels in order that nourishment for the muco-periosteal flaps may be ensured. In the operation to close a wide cleft of the soft palate the tension of the **tensor palati muscle** is lessened if the **pterygoid hamulus** is fractured at the posterior end of the lateral relief-incisions.

Nasal Part of Pharynx.—To explore the nasal part of the pharynx the finger is hooked upwards behind the soft palate. *Anteriorly*, the finger readily detects the sharp, posterior border of the vomer, the posterior aperture of the nose, and the posterior ends of the middle and inferior conchæ. The *roof* of the space is formed by the basilar part of the occipital bone, while on the *posterior wall* there is a transverse ridge formed by the anterior arch of the atlas. On each *side-wall* there is the opening of the **pharyngo-tympanic tube** situated 1·3 cm. behind the posterior end of the inferior concha. The orifice, bounded above and behind by a prominent margin, is directed downwards and forwards, and therefore in a direction favourable to the passage of the Eustachian catheter. Behind the posterior margin of the orifice there is the *recess of the pharynx*, in which the point of the catheter is apt to become engaged. On the roof and posterior wall of the pharynx, down to the level of the foramen magnum (Fig. 502, p. 586), and extending laterally as far as the orifices of the tubes, there is a collection of adenoid tissue called the **naso-pharyngeal tonsil**. Hypertrophy of that tissue constitutes the condition known as "*adenoids*", the harmful effects of which are due to their interference with nasal respiration. On the centre of the naso-pharyngeal tonsil there is an orifice leading into a small recess into which numerous mucous glands open. The structures felt in the naso-pharynx may be viewed by means of light reflected on a small mirror placed immediately behind and below the soft palate (*posterior rhinoscopy*). The lower part of the inferior concha is obscured from view by the bulging of the upper surface of the soft palate.

If the posterior wall of the pharynx is observed during the pronunciation of vowels it will be noticed that a transverse ridge appears immediately below the naso-pharyngeal tonsil, opposite the anterior arch of the atlas (Passavant's ridge). It is produced by the contraction of certain fibres of the superior constrictor muscle, and may be regarded as the posterior portion of a naso-pharyngeal valve or sphincter, described by Whillis (1930) as a 'palato-pharyngeal sphincter' (see pp. 441, 445).

When the posterior apertures of the nose have to be plugged it is important to remember that these openings are rather more than 2·5 cm. in height and about 1·3 cm. across. In the child, owing to the small size of the face, the vertical diameter of the naso-pharynx and the height of these apertures are relatively much smaller than in the adult.

The **retropharyngeal lymph-glands** are one or two pairs of glands that lie at the junction of the posterior wall and side walls of the pharynx, opposite the level of the hollow below the auricle. They are embedded in loose areolar tissue and are

afferent lymph-vessels from the mucosa of the nasal cavities and the air-sinuses, the naso-pharynx, the pharyngo-tympanic tubes, and the tympanic cavity. Their efferent lymph-vessels empty into the glands in the upper part of the carotid triangle. After the first year of life they undergo retrogressive changes, but they persist as lymphatic nodes until the tenth or twelfth year. In children, suppuration originating in one of them is the commonest cause of a retropharyngeal abscess.

THE NECK

Compartments.—The processes and partitions which proceed from the deep surface of the general envelope of **deep cervical fascia** divide the neck into compartments which limit and determine the spread of pus (Fig. 380, p. 446).

The most important compartment is the **visceral compartment**, which contains the larynx and trachea, the pharynx and œsophagus, and is bounded *anteriorly* by the pretracheal fascia, *posteriorly* by the prevertebral fascia, and *laterally* by the fascia which encloses the vascular compartment. Inferiorly, the visceral compartment extends into the superior mediastinum ; superiorly, its posterior part extends to the base of the skull, but its anterior part reaches only to the hyoid bone. *Abscesses* in the compartment are either secondary to disease of the lymph-glands or other organs which it contains, or are the result of a primary suppurative cellulitis. A tubercular abscess originating in one of the retropharyngeal lymph-glands (Fig. 1205) lies *in front of* the prevertebral fascia and points into the pharynx ; abscesses secondary to disease of the cervical vertebræ lie *behind* the prevertebral fascia and spread laterally behind the vascular compartment ; they point behind the sterno-mastoid and are evacuated through an incision at the posterior border of the muscle—the surgeon keeping close to the transverse processes in order to avoid the structures in the vascular compartment.

In front of the visceral compartment there is a **small muscular compartment** which contains the infrahyoid muscles ; in front of it again, in the region of the suprasternal notch, is the small **suprasternal compartment**, which contains the anterior jugular veins and their transverse communicating branch (*jugular arch*), a little fat, and one or two lymph-glands.

The **vascular compartment** contains the carotid arteries and the internal jugular vein, and the following nerves: the vagus, part of the hypoglossal nerve, the descendens hypoglossi, and part of the accessory nerve. These structures are enveloped in an ill-defined fascial tube called the *carotid sheath*. The sheath is surrounded by areolar tissue in which a chain of lymph-glands is embedded ; normally, the glands may be readily separated from the sheath of the internal jugular vein, but they become adherent to it when they are inflamed. The sympathetic trunk and the inferior thyroid artery lie in the areolar tissue between the posterior wall of the carotid sheath and the prevertebral fascia ; they can be reached through an incision along the posterior border of the sterno-mastoid muscle—that muscle, along with the carotid sheath and its contents, being pulled well forwards. In the approach to the trunk of the inferior thyroid artery from the front the sterno-mastoid and carotid sheath are displaced laterally and the dissection is continued through the areolar tissue between the carotid sheath and the sheath of the thyroid gland, which is formed by the pretracheal fascia.

A glandular abscess in the vascular compartment usually points on the surface, adhesions being formed, first, between the gland and the fascia, and, subsequently, between the fascia and the cutaneous structures. In diffuse suppurative cellulitis of the compartment the pus burrows towards the root of the neck, and may reach either the mediastinum or the axilla.

Median Line of Neck.—The body of the **hyoid bone** divides the median plane of the neck into **suprahyoid** and **infrahyoid portions**. Above the hyoid bone is the **submental triangle**, with its apex at the symphysis menti and its sides formed by the anterior bellies of the digastric muscles. In the floor of the triangle are the anterior portions of the mylo-hyoid muscles united by the median raphe (Fig. 1207). The most important structures in the triangle are the **submental lymph-glands**, which can usually be felt a little above the body of the hyoid

bone. In children they are a frequent seat of abscess secondary to impetigo of the lower lip and chin. About 2·5 cm. below the hyoid bone is the **laryngeal prominence**—more prominent in men than in women. On each side of the prominence are the laminæ of the thyroid cartilage, while between that cartilage and the hyoid bone there are the **thyro-hyoid membrane** and **ligaments**.

The wound in suicidal *cut-throat* is generally at the level of the thyro-hyoid interval. The more important structures usually divided are: (1) more or less of the left sterno-mastoid muscle, (2) the superior thyroid vessels, (3) the thyro-hyoid membrane, (4) the stem of the epiglottis, and, less frequently, (5) the carotid vessels, the internal jugular vein, and the internal laryngeal nerve. When the wound is above the hyoid bone, the lingual and facial vessels and the muscles of the tongue are the more important structures injured.

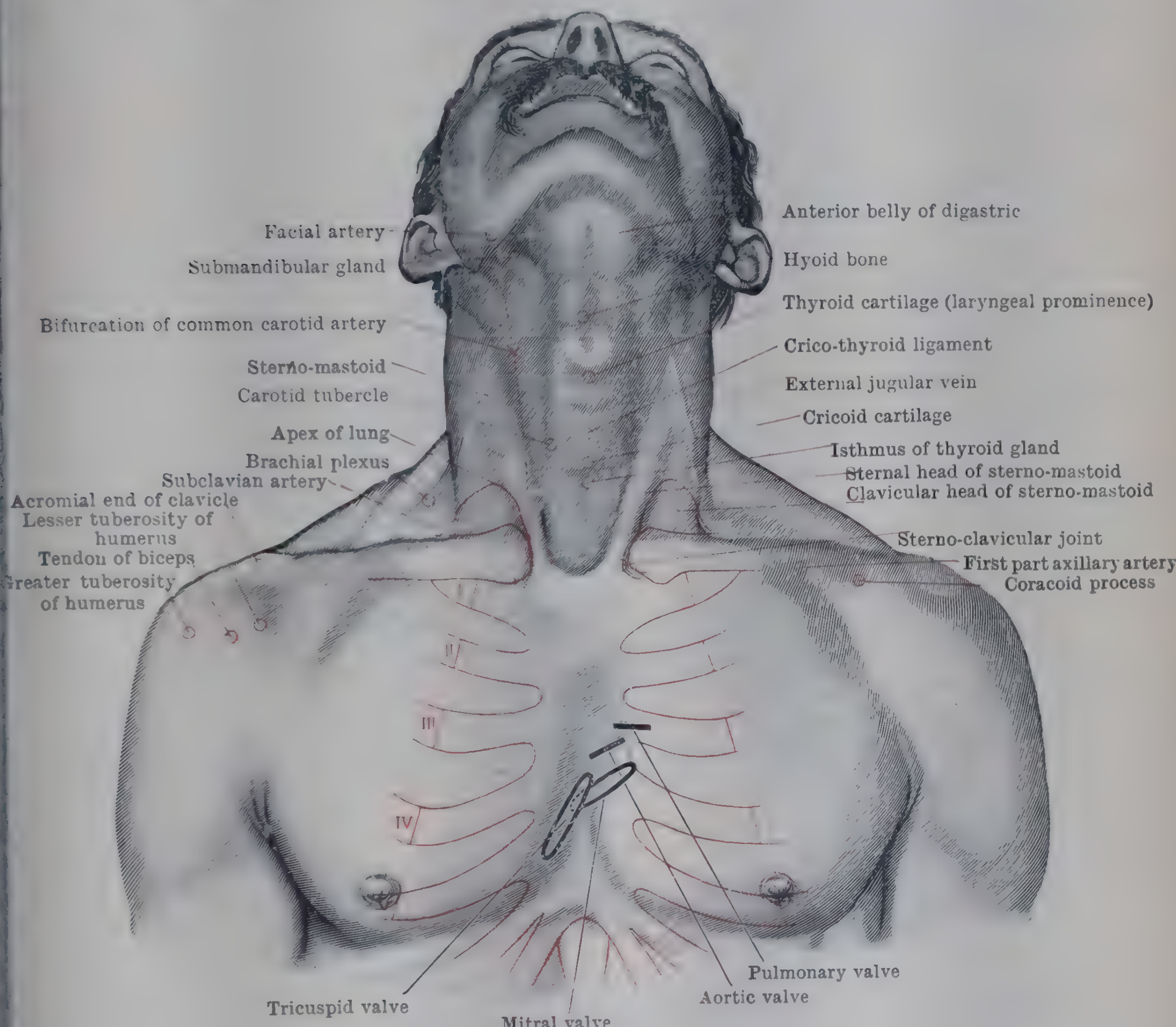

Fig. 1206.—Front of Neck and Shoulders.

The **rima glottidis** is opposite the middle of the anterior border of the thyroid cartilage.

In the operation of thyrotomy, care is taken to divide the thyroid cartilage exactly in the median plane in order that injury to the vocal folds may be avoided.

A little more than 2·5 cm. below the laryngeal prominence is the arch of the **cricoid cartilage**, which may be readily felt, and, when the neck is extended, often seen. Above the cricoid is the **crico-thyroid ligament**; in the operation of laryngotomy only the median portion of the ligament is divided, lest the crico-thyroid muscles be injured. The crico-thyroid branch of the superior thyroid artery lies close to the lower border of the thyroid cartilage.

Below the cricoid cartilage is the **trachea**, which recedes as it descends, so that it lies 4 cm. from the surface at the level of the upper border of the sternum. The **isthmus** of the **thyroid gland** usually lies in front of the second, third, and fourth

rings of the trachea (Fig. 1207), but may reach up to the cricoid. Immediately in front of the trachea, below the isthmus of the thyroid, is the pretracheal fat, containing one or two **lymph-glands** and the **inferior thyroid veins**, each represented by one or more branches which converge as they descend. The pretracheal lymph-glands receive afferent vessels from the larynx and thyroid gland, and their efferent vessels open into the glands along the lower part of the carotid sheath. In the adult the **innominate artery** crosses the front of the trachea at the level of the upper border of the sternum; in the child, however, it often crosses 1·3 cm. higher —a relation which must be remembered in the operation of low tracheotomy.

In the operation of **high tracheotomy** the upper three rings of the trachea are divided by a median incision. The incision divides the skin, the superficial fascia and the tributaries of the anterior jugular veins, the general envelope of deep cervical fascia, and (after

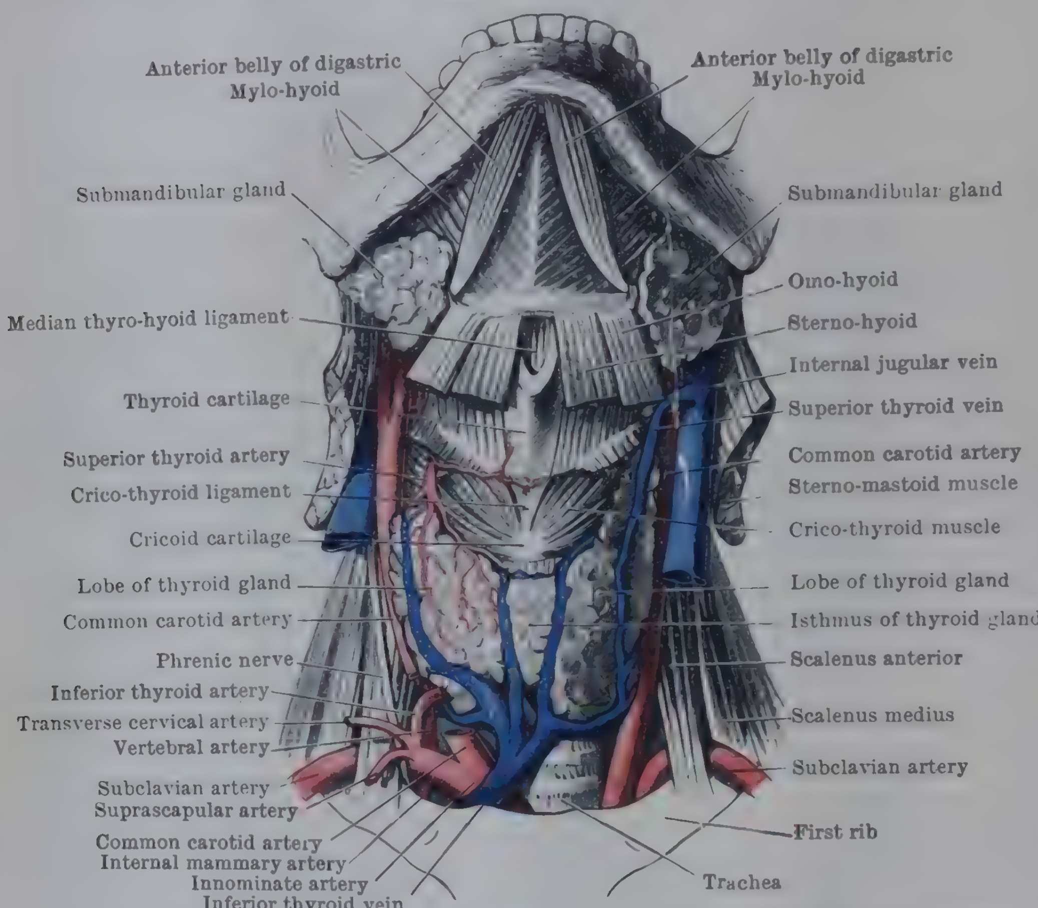

FIG. 1207.—DISSECTION OF FRONT OF NECK. The lower portions of the sterno-mastoid muscles and right common carotid artery have been removed to show the deeper parts.

passing between the right and left infrahyoid muscles) the pretracheal fascia, which descends from the cricoid to enclose the isthmus of the thyroid gland. If this fascia is divided transversely below the cricoid, the isthmus may be pulled downwards and the upper rings of the trachea exposed. In opening the uppermost part of the trachea, the operator keeps the edge of the knife directed upwards to avoid injuring the vessels at the upper border of the isthmus. The anterior jugular veins are in danger of being wounded if the skin incision is not strictly median.

In **low tracheotomy** the trachea below the isthmus is opened; it is a more troublesome operation, on account of the depth of the trachea and the presence in front of it of the inferior thyroid veins and of the anastomosis between the anterior jugular veins. In children the difficulty is increased by the higher position of the innominate artery and left innominate vein, by the presence of the thymus, and by the shortness of the neck.

Thyroid and Parathyroid Glands.—The **thyroid gland** is moulded on and adherent to the front and sides of the upper part of the trachea and the lower and posterior portions of the sides of the larynx, and is covered by the infrahyoid muscles and overlapped by the sterno-mastoid. The posterior borders of its lobes come in contact with the œsophagus and lower part of the pharynx, and overlap the carotid sheath.

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The thyroid gland, like the prostate, has its own proper capsule and also a sheath derived from the fascia. The capsule, like that of the liver, is inseparably connected with the gland. The sheath is derived from the pretracheal fascia, which splits to enclose the gland; and it is separated from the capsule by an interval which is filled with areolar tissue and is crossed by branches of the thyroid arteries and veins on their way to and from the gland. The veins anastomose very freely, making conspicuous networks between the capsule and the sheath.

The surgeon reaches the gland in the median plane through the interval between the infrahyoid muscles. If, in order to obtain more room, he has to divide the infrahyoid muscles on one or both sides, that should be done towards their upper attachments, as their nerves of supply, derived from the ansa hypoglossi, enter the muscles near their lower attachments. By freely dividing the pretracheal fascia where it forms the anterior portion of the sheath of the thyroid,

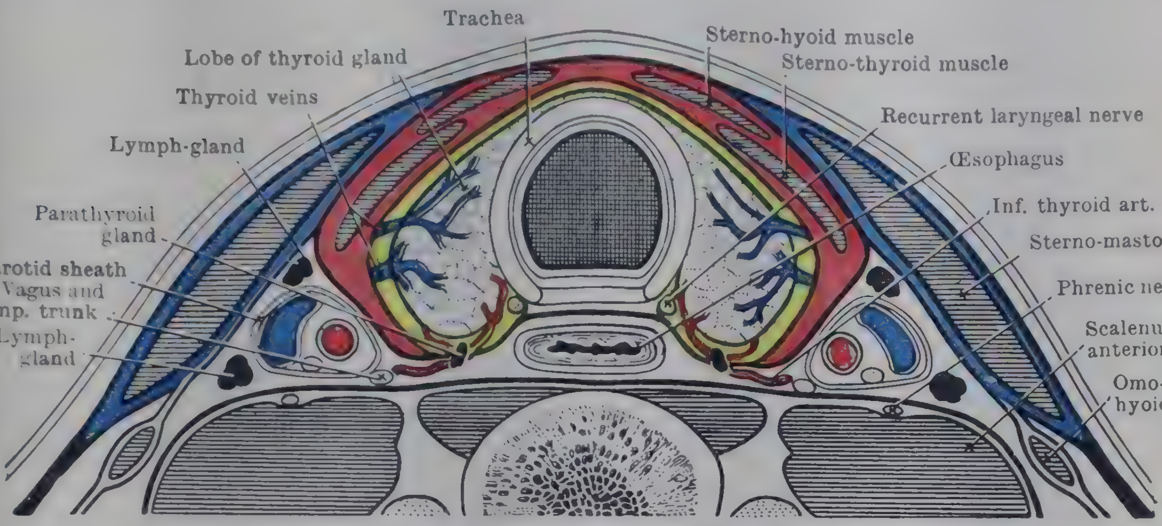

FIG. 1208.—DIAGRAM OF RELATION OF CERVICAL FASCIA TO THYROID GLAND.
Blue = deep cervical fascia (sterno-mastoid layer). Red = sheath of thyroid gland (pretracheal fascia). Yellow = capsule of the thyroid gland. (Modified from De Quervain, 1924.)

the surgeon can deliver the gland out of the wound so that the main vessels may be brought into view and ligatured.

To expose the superior thyroid vessels, the upper pole of the lobe is freed and drawn downwards and forwards. The inferior thyroid trunk may be secured as it lies between the carotid sheath and the prevertebral fascia, or its branches may be ligatured one by one as they enter the gland. In the operation of subtotal thyroidectomy, the postero-medial part of the capsule and a layer of thyroid tissue are preserved, in order to protect the parathyroids and the recurrent laryngeal nerve; the relation of the latter to the inferior thyroid artery is variable.

The **parathyroid glands** can generally be distinguished from the thyroid tissue itself, and from the lymph-glands, by their greyish-yellow colour and by their smooth and shining surfaces. Each superior parathyroid is embedded in the posterior border of the lobe opposite the cricoid cartilage. It is in close relation to the pharyngo-œsophageal junction, from which it is separated by the posterior part of the sheath of the thyroid gland. The inferior parathyroid, on each side, is supplied by a small vessel from one of the branches of the inferior thyroid artery; it also lies within the sheath and is on the back of the lower pole of the gland, a little lateral to the inferior thyroid artery and the recurrent laryngeal nerve. When the inferior thyroid artery has been ligatured, the medial glandular branch of the superior thyroid artery furnishes a sufficient blood-supply to the inferior parathyroid (see also p. 817). The positions of the parathyroid glands are variable.

Triangles of Neck.—The side of the neck is divided into an **anterior** and a **posterior triangle** by the sterno-mastoid muscle; the anterior triangle is further subdivided into *digastric, carotid,* and *muscular triangles* by the digastric and omo-hyoid muscles.

The **sterno-mastoid muscle** is one of the most important superficial landmarks of the neck. The anterior border of the muscle, the more distinct of the two, may be felt along its whole extent. Between the prominent sternal origin

and the broad, ribbon-like clavicular origin there is a slight triangular depression which overlies the lowest part of the internal jugular vein.

By dividing the cervical fascia along the anterior and posterior borders of the muscle the surgeon is able to displace the muscle backwards and forwards and so obtain free access to the structures deep to it. If the posterior fibres of the muscle are divided at their clavicular and cranial attachments the muscle is made still more freely movable. As the fascia along its posterior border is cut, the cutaneous branches of the cervical plexus are usually divided, but care is taken to preserve the accessory nerve. Should it be necessary to remove the upper third or more of the muscle, the divided end is stitched to the levator scapulæ or to the scalenus medius, according to the amount resected. When the muscle is completely cut across at the lower part of the neck, as is done, for example, in congenital wry-neck, the close relation of the anterior and external jugular veins to its two borders must be kept in mind. After division of the muscle, the lower part of the superior belly of the omo-hyoid is seen, lying on that part of the carotid sheath which overlies the internal jugular vein. In block dissection of the neck for malignant glands, the whole muscle is removed with the internal jugular vein and its related **lymph-glands.**

Digastric Triangle.—The chief structure in this triangle is the **submandibular gland**, which is overlapped by the body of the mandible and reaches down to the greater horn of the hyoid bone. The **anterior facial vein** passes downwards and backwards, superficial to the gland, while the **facial artery**, embedded in its deep surface, arches upwards under cover of the angle of the mandible, where it approaches the tonsil, being separated from it, however, by the superior constrictor of the pharynx. The *floor* of the digastric triangle is formed, from before backwards, by the mylo-hyoid, hyo-glossus, and superior constrictor of the pharynx. The **lymph-glands** of the space receive their lymph from the face, lips, teeth and gums, tongue, and floor of the mouth ; hence the frequency with which they become the seat of abscess formation and malignant enlargement. To palpate them the surgeon stands behind the patient and feels the glands between a finger of one hand in the floor of the mouth, and a finger of the other hand thrust well up medial to the mandible, the chin of the patient being depressed to relax the cervical fascia.

Carotid Triangle.—The central landmark of the carotid triangle is the **greater horn of the hyoid bone**, the tip of which, when the fascia is relaxed, may be felt, at the anterior border of the sterno-mastoid, about 2·5 cm. below the angle of the mandible. The deep cervical fascia holds the upper part of the sterno-mastoid forwards towards the angle of the mandible, so that, with the fascia undivided, the anterior border of the sterno-mastoid overlaps the internal jugular vein and the bifurcation of the common carotid artery.

The **course of the carotid vessels** is indicated, on the surface, by a line extending from the sterno-clavicular joint to the lobule of the auricle ; a point on that line, at the level of the upper border of the thyroid cartilage, is opposite the **bifurcation of the common carotid**. The **superior belly** of the **omo-hyoid** crosses the common carotid very obliquely at the level of the lower border of the larynx. The pulsations of the carotid vessels may be felt in the hollow between the larynx and the sterno-mastoid. In the carotid triangle the **external carotid** lies medial and anterior to the internal carotid. Ligation of the external carotid is performed between its superior thyroid and lingual branches (which are also secured) immediately below the tip of the greater horn of the hyoid bone ; the difficulty in the operation is due to the plexus of veins (formed by the common facial, lingual, and superior thyroid veins) which overlies the artery. The lingual and facial arteries sometimes arise from a common trunk which must not be mistaken for the external carotid. The **superior thyroid artery** arises opposite the upper horn of the thyroid cartilage, which may be felt 2·5 cm. or less below the tip of the greater horn of the hyoid bone. The vessel is the common source of arterial hæmorrhage in cut-throat.

From a surgical point of view the **internal jugular vein** is the most important structure in the whole anterior triangle. In the carotid triangle it overlaps the carotid vessels, and its sheath is under cover of the general envelope of deep cervical fascia, from which it is separated by loose areolar tissue. About the level of the hyoid bone it receives the common facial vein, which is a large vessel ; at a lower level it receives the superior and middle thyroid veins, which are often

greatly enlarged in goitre—the superior vein entering it opposite the upper part of the larynx and the middle vein at the lower pole of the thyroid gland.

The term **deep cervical glands** includes a broad chain of lymph-glands which is closely related to the internal jugular vein and stretches from the transverse process of the atlas to the root of the neck (Figs. 1175-1177).

The chain is divided into medial and lateral parts by the internal jugular vein. The medial division extends from the level of the posterior belly of the digastric muscle and the stylo-mandibular ligament to the lower border of the superior belly of the omo-hyoid muscle—the main group, which includes the jugulo-digastric gland (p. 1433), occupying a triangle bounded above by the posterior

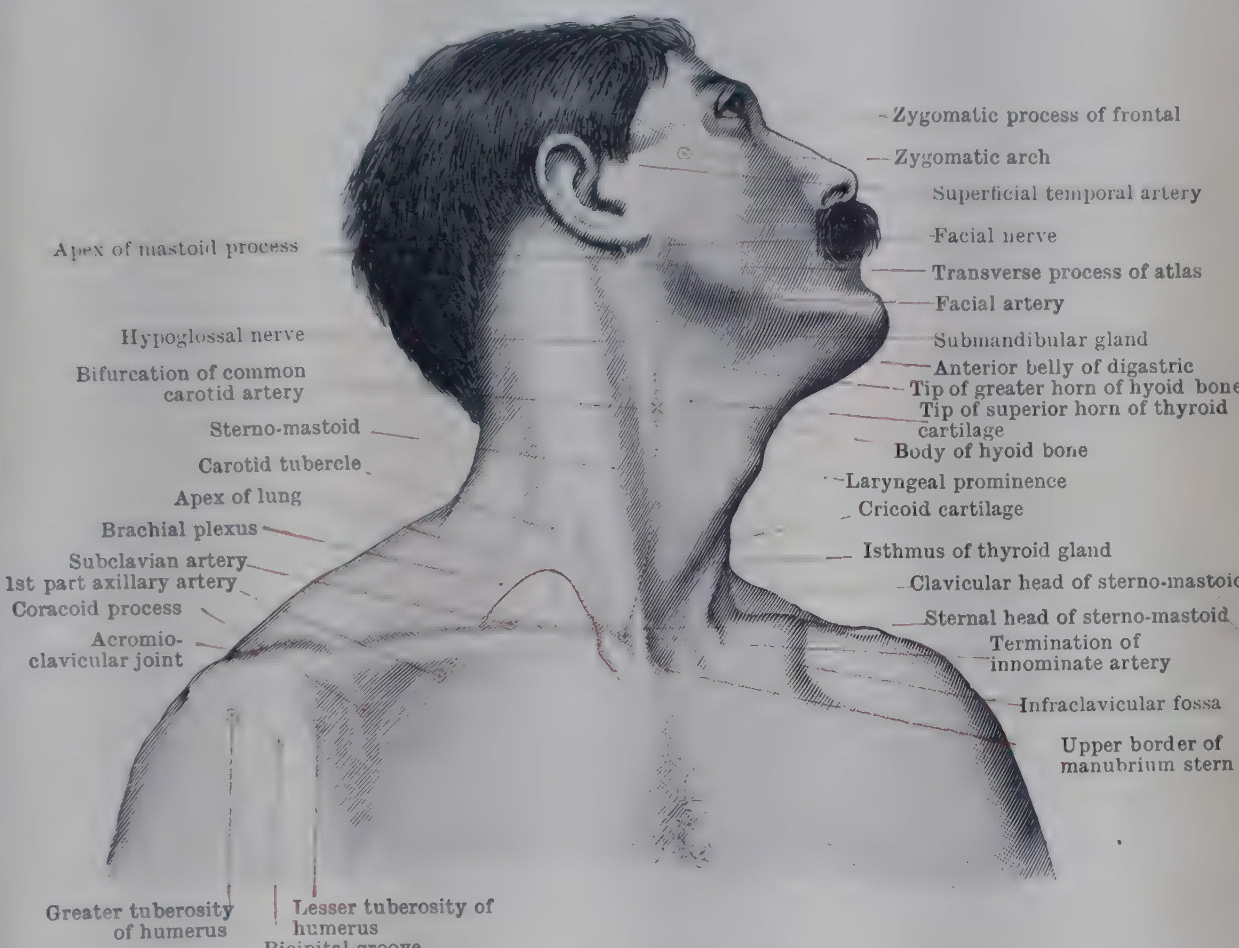

FIG. 1209.—SIDE OF THE NECK.

belly of the digastric muscle, in front by the common facial vein, and posteriorly by the internal jugular vein.

Lymph from the tonsil passes to this group, and, as the tonsil is one of the principal portals of entry of tuberculous infection, the jugulo-digastric glands are those most commonly affected by the disease. These glands receive lymph from the back of the tongue also, and they are therefore affected secondary to malignant disease of that organ (p. 1469).

The lateral chain lies postero-lateral to the internal jugular on the attachments of the scalenus medius and levator scapulæ muscles. These glands are smaller than those of the medial group, but when enlarged they may form a swelling which projects across the posterior triangle as far as the trapezius. They are embedded in a quantity of fibro-fatty tissue which encloses the branches of the cervical plexus including those to the trapezius; and, when the mass is greatly swollen, the accessory nerve may be embedded in it near the sterno-mastoid. They receive lymph from the posterior and lateral walls of the pharynx and the posterior portion of the tongue.

The lowest glands of the group (inferior deep cervical glands) are supra-clavicular in position, and they are divided into a superficial and a deep cluster by

the omo-hyoid muscle and the second layer of deep cervical fascia. The deeper ones receive afferent vessels from the apical (infraclavicular) group of axillary glands.

The **hypoglossal nerve**, in the carotid triangle, is overlapped by the lower border of the posterior belly of the digastric muscle. It runs forwards, superficial to the internal and external carotid and lingual arteries, immediately below the origin of the inferior sterno-mastoid branch of the occipital artery. The **vagus nerve** descends vertically, within the carotid sheath, behind and between the carotid vessels and the internal jugular vein; care must be taken not to include it when ligaturing the common carotid artery or the internal jugular vein. Surgically, the **accessory** is the most important nerve in the anterior triangle; it enters the substance of the sterno-mastoid muscle opposite the angle of the mandible; it is always exposed in the removal of the lateral group of deep cervical glands. The course of the nerve in the carotid and posterior triangles may be mapped out by a line drawn from a point midway between the tip of the mastoid process and the angle of the mandible to a point a little above the middle of the posterior border of the sterno-mastoid, and thence across the posterior triangle to the anterior border of the trapezius about 5 cm. above the clavicle. The deeper guides to the nerve are the posterior belly of the digastric, which is superficial to it, and the internal jugular vein, which it crosses very obliquely, from above downwards and backwards, below and in front of the **transverse process of the atlas** (felt as a distinct bony resistance midway between the tip of the mastoid process and the angle of the mandible). The superior sterno-mastoid branch of the occipital artery lies in close relation to the nerve, and often serves as a guide to the nerve when it is obscured by diseased tissues.

In paralysis of the trapezius muscle from injury to the accessory nerve the shoulder droops and is pulled forwards and medially by the pectoralis major and minor muscles. If the paralysis occurs during childhood the chest on the same side becomes flattened in front, owing to the adaptive shortening of the pectorals and to their diminished pull on the ribs. Unless that mechanism is appreciated the infraclavicular flattening of the chest is very liable to be erroneously attributed to pulmonary tuberculosis. The upper part of the accessory nerve is surrounded by the upper lateral group of deep cervical glands; it is in that situation, and again when it emerges from under cover of the posterior border of the sterno-mastoid muscle, that it is liable to be injured in operations for the removal of tuberculous glands.

The **cervical part of the sympathetic trunk** lies in the posterior wall of the vascular compartment of the neck, and may be reached by an incision along the posterior border of the sterno-mastoid: the anterior surfaces of the roots of the transverse processes of the vertebræ are the deep guides to the trunk.

The **cervical plexus** lies deep to the upper half of the sterno-mastoid on the levator scapulæ and scalenus medius muscles, and it may be exposed through an incision along the posterior border of the upper half of the sterno-mastoid muscle. The **phrenic nerve**—the most important branch of the cervical plexus—arises 2·5 cm. above the carotid tubercle and descends almost vertically towards the medial part of the clavicle; it is overlapped by the lateral margin of the internal jugular vein. Although the surgeon frequently exposes the phrenic nerve in removing the lower medial group of deep cervical glands, it is protected from injury by the fascia which binds it down to the scalenus anterior. In the operation of **phrenic avulsion**, practised in certain cases of pulmonary tuberculosis, the nerve is exposed through an incision parallel to and one finger's breadth above the upper border of the clavicle.

Muscular Triangle.—This is an important triangular intermuscular space bounded by the sterno-mastoid, the superior belly of the omo-hyoid, and the median line of the neck. Behind that space, there is a deeper space which is bounded by the longus cervicis and scalenus anterior muscles, and whose apex is the anterior tubercle of the transverse process of the sixth cervical vertebra. By making an incision along the anterior border of the left sterno-mastoid muscle, and passing through the muscular triangle into the deeper space, the surgeon reaches the internal jugular vein, the common carotid artery, the vagus, the thoracic duct, the middle cervical ganglion of the sympathetic, the inferior thyroid artery, the

vertebral vessels, the recurrent laryngeal nerve, and the œsophagus. The most important bony landmark in the deeper space is the anterior tubercle of the transverse process of the sixth cervical vertebra. The common carotid artery may be compressed against that tubercle, which is therefore termed the "*carotid tubercle*". It is the most important guide to the vertebral artery, for the artery enters the foramen in the transverse process of the sixth cervical vertebra.

The **cervical portion of the œsophagus** begins at the level of the cricoid cartilage and descends behind the trachea, protruding a little beyond its left margin. To expose it the muscular triangle is entered by an incision along the lower two-thirds of the anterior border of the left sterno-mastoid muscle; the pretracheal fascia is divided and the dissection carried between the trachea and the carotid sheath down to the longus cervicis muscle medial to the inferior thyroid artery and vertebral vessels. The lower pole of the lobe of the thyroid gland is pulled medially along with the trachea. The œsophagus lies in the loose areolar tissue in front of the prevertebral fascia, and is therefore sufficiently movable to be brought to the surface. If the œsophagus has to be opened care must be taken not to injure the **recurrent laryngeal nerve**, which ascends in the groove between it and the trachea; and also the loose submucous coat must not be mistaken for the lumen of the tube. The so-called "pulsion-diverticulum of the œsophagus" does not take origin from the upper part of the gullet; it begins as a hernia-like protrusion of the posterior wall of the pharynx, between the oblique and the transverse fibres of the inferior constrictor muscle. During the act of swallowing, the transverse fibres act as a sphincter, while the oblique fibres elevate the larynx. If the sphincter should fail to relax during the detrusor action of the pharynx it is not difficult to understand how a diverticulum might arise, and, when once produced, why it should undergo progressive enlargement.

The **thoracic duct,** after entering the left side of the root of the neck between the œsophagus and the pleura, ascends to about 2·5 cm. above the clavicle. At that level it arches laterally behind the carotid sheath but in front of the vertebral vessels. Great care must therefore be taken not to injure the duct during removal of the lymph-glands which lie in the loose areolar tissue behind the lower part of the internal jugular vein, between it and the vertebral vein, at the medial border of the scalenus anterior. A few small lymph-glands lie along the sides of the cervical portions of the trachea and œsophagus; they receive their afferent vessels from the larynx, trachea, œsophagus, and thyroid gland.

Posterior Triangle.—The posterior triangle is bounded in front by the sterno-mastoid muscle, and behind by the anterior border of the trapezius muscle; its apex is at the meeting-point of these two muscles on the superior nuchal line; and its base corresponds to the middle third of the clavicle. The inferior belly of the omo-hyoid muscle cuts off the lower portion of the large triangle as a small supraclavicular triangle.

The roof of the triangle is the general envelope of deep cervical fascia; the fascia which covers the muscles of its floor, as well as that which covers the brachial nerve-trunks and the subclavian artery, is a lateral continuation of the prevertebral fascia. Numerous lymph-glands are embedded in the areolar tissue between these two layers of fascia. During removal of these glands, every endeavour should be made to preserve the motor nerves.

The **accessory nerve,** after entering the posterior triangle a little above the middle of the posterior border of the sterno-mastoid, crosses the triangle parallel to the fibres of the levator scapulæ muscle. It leaves the triangle by passing under cover of the anterior border of the trapezius about 5 cm. above the clavicle. The **lesser occipital nerve** curves round the accessory from below upwards, superficially, at the posterior border of the sterno-mastoid; it furnishes, therefore, a useful guide to the position of that important motor nerve.

The **nerve to the rhomboids** crosses the triangle below the accessory, and enters the fascial septum between the levator scapulæ and scalenus medius muscles. The **nerve to the serratus anterior** arises from the fifth, sixth, and seventh cervical nerves. The roots from the fifth and sixth pierce the scalenus medius and join the root from the seventh (which runs superficial to the muscle) in the axilla.

The **suprascapular nerve** is seen arising from the lateral edge of the upper trunk of the brachial plexus a little above the inferior belly of the omo-hyoid muscle.

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TABLE I.—SEGMENTAL INNERVATION OF MUSCLES OF UPPER LIMB.

The loops of the **cervical plexus** lie under cover of the upper part of the sterno-mastoid muscle, between it and the origins of the levator scapulæ and the upper part of the scalenus medius muscles, and they are overlapped by the internal jugular vein.

The **inferior belly of the omo-hyoid** passes deep to the posterior border of the sterno-mastoid at a point about 2·5 cm. above the clavicle. The **external jugular vein**—usually visible through the skin—runs in a line from the angle of the jaw to the junction of the medial and middle thirds of the clavicle. It pierces the deep fascia at the posterior border of the sterno-mastoid about 2·5 cm. above the clavicle, and, as its walls are adherent to the margins of the aperture, its lumen is kept open at that point; hence a wound of the vein in that situation is liable to be followed by the suction of air into the blood-stream during inspiration.

The **third part** of the **subclavian artery** can be compressed against the first rib by pressure directed downwards and backwards, immediately above the clavicle, a little behind the posterior border of the sterno-mastoid muscle. To map out the *course* of the subclavian artery in the neck, a line is drawn, convex upwards, from the upper border of the sterno-clavicular joint to the middle of the clavicle, the highest part of the arch to reach from 1·3 to 2·5 cm. above the bone.

To *ligature the vessel* in the third part of its course, an incision is made parallel to, and one finger's breadth above, the medial two-thirds of the clavicle. It may be necessary to divide the clavicular head of the sterno-mastoid muscle. The most important guides to the vessel are the inferior belly of the omo-hyoid, the lateral border of the scalenus anterior, and the scalene tubercle of the first rib. The close relation of the vessel to the lowest trunk of the brachial plexus and to the cervical pleura must be kept in mind. In the rare instances in which a cervical rib is present the subclavian artery lies either in front of it, or arches above it, according to the degree of development of the rib. The **subclavian vein** lies below and in front of the artery, separated from it by the scalenus anterior, and altogether under cover of the clavicle.

Brachial Plexus.—Entering the posterior triangle, from behind the lateral border of the scalenus anterior, are the roots of the **brachial plexus**. They unite to form the three trunks of the plexus, which lie on the scalenus medius—the lower trunk behind the third part of the subclavian artery, the other two above the artery. The upper part of the plexus can be felt through the skin.

The segmental innervation of the muscles of the upper limb is shown in Table I. For the cutaneous distribution of the nerves of the brachial plexus, see Fig. 928, p. 1074, and for the dermatomes of the upper limb, Fig. 929, p. 1075.

When the first thoracic nerve is ruptured within, or close to, the vertebral canal, the sympathetic fibres which run in it on their way to join the inferior cervical ganglion are torn across. The result is that, among other signs, there will be: (1) contraction of the pupil, due to paralysis of the dilatator pupillæ; and (2) narrowing of the palpebral fissure, due to paralysis of the involuntary fibres of the upper eyelid. This combination is known as *Horner's Syndrome.*

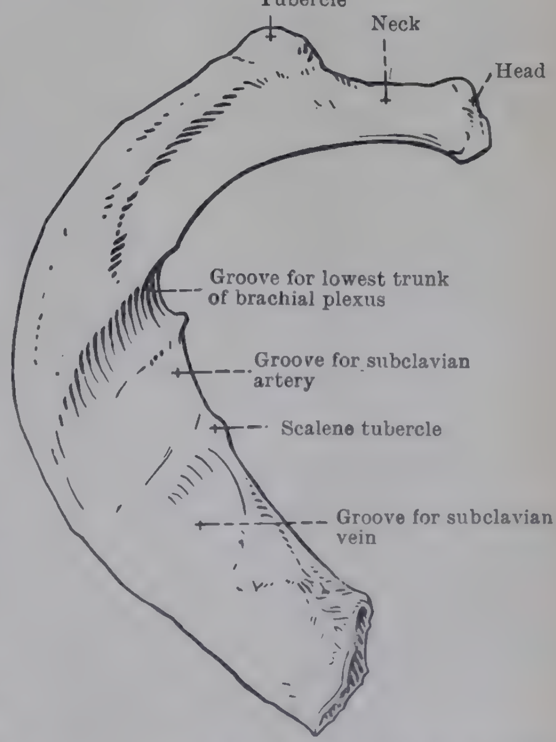

Fig. 1210.—Right First Rib, seen from above.

As regards the cutaneous distribution in the upper limb, the sensory fibres from the lateral (pre-axial) border of the upper arm enter the fifth nerve, while those from the lateral half of the forearm and hand enter the sixth nerve. The fibres from the centre of the surface of the hand on both palmar and dorsal surfaces and adjacent sides of middle and ring fingers enter the seventh nerve. The fibres from the medial (post-axial) part of the hand enter the eighth cervical nerve; those from the medial border of the forearm enter the first thoracic; and those from the medial side of the upper arm run in the second thoracic nerve (Fig. 929, p. 1075).

The carotid tubercle lies between the anterior primary rami of the sixth and

seventh cervical nerves. The fifth and sixth cervical nerves are those which suffer most when the plexus is injured by forcible depression of the shoulder while the head is bent to the opposite side, such as occurs, for instance, in "obstetrical paralysis". The lowest trunk of the plexus is the one most liable to be overstretched when traction is applied either to the upper limb or to the rest of the body when the limb is elevated above the shoulder; the result is a paralysis of the small muscles of the hand.

The trunks of the brachial plexus may be exposed through an incision from the junction of the middle and lower thirds of the posterior border of the sterno-mastoid downwards and laterally to the junction of the lateral and middle thirds of the clavicle.

As the neuro-vascular bundle for the upper limb leaves the thoracic outlet, it may be subjected to pressure to which the following may contribute: an unusually high first rib, an abnormal first rib, or a cervical rib; adjacent parts of the scalenus anterior, scalenus medius or scalenus pleuralis muscles; the first rib and the clavicle. As a result, there may be signs of vascular insufficiency, with or without signs of impaired function of the brachial plexus, usually in the territory of the first thoracic nerve.

Back of Neck.—In the posterior median line of the neck is the **nuchal furrow** at the bottom of which are the cervical spines and the ligamentum nuchæ. At the upper part of the furrow, about 5 cm. below the external occipital protuberance, is the **spine of the axis vertebra**, which is large and can be distinctly felt; a line drawn from it to the transverse process of the atlas corresponds to the position of the inferior oblique muscle and, therefore, to the inferior margin of the **suboccipital triangle**. The course of the deep part of the **greater occipital nerve** may be mapped out by a line from the middle of the above-mentioned line to a point 2·5 cm. lateral to the external occipital protuberance. In the floor of the suboccipital triangle is the posterior arch of the atlas, upon which the third part of the **vertebral artery** lies.

THORAX

WALLS OF THORAX

In the male the **nipple** is placed usually over the fourth interspace, or the fifth rib, 10 cm. from the median plane. In the child the nipple may be as high as the lower border of the third rib. In the female the position of the nipple is so variable that it is of no topographical value.

In muscular subjects there is a well-marked median furrow between the sternal origins of the right and left **pectoralis major muscles**. The medial part of the lower border of each of these muscles forms a curved prominence which lies over the fifth rib. Below that prominence there is a more or less flat surface that corresponds to the upper part of the rectus abdominis muscle. In the axillary and infra-axillary regions there are the prominences caused by the digitations of origin of the **serratus anterior**, the first to appear below the pectoralis major being that which springs from the fifth rib.

The **upper border** of the **sternum** lies in the same horizontal plane as the lower border of the body of the second thoracic vertebra, the distance between the two being about 5 cm. The manubrium and the body of the sternum form a slight angle at their junction, known as the *sternal angle*. At the angle there is a horizontal ridge which, although not always visible, can always be felt. The angle is in the same plane as the upper border of the body of the fifth thoracic vertebra.

The **xiphi-sternal joint** is opposite the ninth thoracic vertebra, and is felt as a short, transverse ridge between the seventh pair of costal cartilages, immediately above a shallow depression called the **epigastric fossa**, in whose floor the xiphoid process can be felt.

The xiphoid process lies in the wall of the abdomen in front of the liver, for the xiphi-sternal joint marks the junction between the thorax and abdomen in

the median plane, and in that situation it is the guide to the diaphragm, the lower border of the heart, and the upper surface of the liver.

Fracture of the sternum is rare, and generally occurs at or close to the junction of the manubrium and the body; it may occur either from direct violence, or indirectly along with fracture of the vertebral column. The periosteum of the sternum, unlike that of the ribs, is firmly adherent to the bone.

The **ribs**, which in well-nourished subjects cause no surface prominences, are visible in thin persons; in the obese it is very difficult even to feel them. When the ribs are counted from the front, the *second* may always be identified by its relation to the sternal angle. The *first rib* is to a large extent under cover of the clavicle. The lower border of the pectoralis major and the first visible digitation of the serratus anterior afford reliable guides to the *fifth rib*. The *seventh costal cartilage* is the one felt on the costal margin nearest the sternum (though occasionally the eighth cartilage, and not the seventh, is the lowest to reach the sternum). The second and third costal cartilages are almost horizontal; below that the cartilages ascend with increasing obliquity, that of the sixth being the first to present a distinct angle. The anterior end of the second intercostal space is the widest, while those of the fifth and sixth are very narrow.

The **costo-chondral junctions** may be indicated, on the surface, by a line drawn from the sterno-clavicular joint to a point a finger's breadth behind the angle of the tenth costal cartilage; the first junction, however, is lateral to that line.

The **internal mammary artery** descends behind the medial ends of the upper five intercostal spaces about 1·3 cm. from the edge of the sternum. The vessel is accompanied by two veins which unite opposite the third interspace to form a single vein which ends in the innominate vein at the inlet of the thorax.

This artery is occasionally injured in punctured wounds of the chest. At the second or third intercostal space it is easily ligatured through a transverse incision, but at a lower level it is generally necessary to resect a portion of one of the costal cartilages.

Operations on Thorax.—The operation of **thoracoplasty** is practised in certain cases of chronic unilateral phthisis. It implies removal of segments of the ribs; it may be total or partial, depending upon the number of rib-portions removed. Its purpose is to permit a "falling-in" of the thoracic cage so that the collapse of the underlying lung is encouraged.

The incision extends from the root of the neck parallel to the vertebral column midway between the median line and the medial border of the scapula. At the level of the lowest rib-resection, the incision curves forward along the line of the rib.

LUNGS, PLEURÆ, AND TRACHEA

Lungs.—The **apex of the lung** and the cervical pleura extend upwards into the root of the neck for a distance of about 2·5 cm. above the sternal third of the clavicle and are intimately related to the subclavian artery anteriorly; they are mapped out by a curved line drawn from the upper border of the sterno-clavicular joint across the sterno-mastoid to the junction of the medial and middle thirds of the clavicle, the highest part of the curve reaching from 1·3 to 3·8 cm. above the clavicle.

Both the **cervical pleura** and the **subclavian artery** may be injured by one of the fragments in a fracture of the clavicle; the scalene muscles, however, afford considerable protection to the pleura. When the third part of the subclavian artery is ligatured, care must be taken not to injure the cervical pleura.

To mark in the **anterior border** of the **right lung**, a line is drawn from the upper border of the sterno-clavicular joint to the centre of the manubrium sterni, and from there vertically downwards, in or slightly to the left of the median plane, to the xiphi-sternal joint (Figs. 1211, 1220).

The **anterior border** of the **left lung** is mapped out by a corresponding line as far as the fourth costal cartilage; thence, it is directed along the lower border of the fourth costal cartilage for 3·8 to 5 cm. and then curved downwards and medially to a point a little below and to the left of the xiphisternal joint. The lower part of the front of the right ventricle is therefore uncovered by lung and gives a completely dull note on percussion; that area is spoken of as the area of "*complete cardiac dullness*".

The level of the **lower border** of the lung is practically the same on both sides; it is mapped out by a line that begins at or near the xiphi-sternal joint and is drawn in a slightly curved direction, with the convexity downwards, across the side of the chest towards the tenth thoracic spine. The line crosses

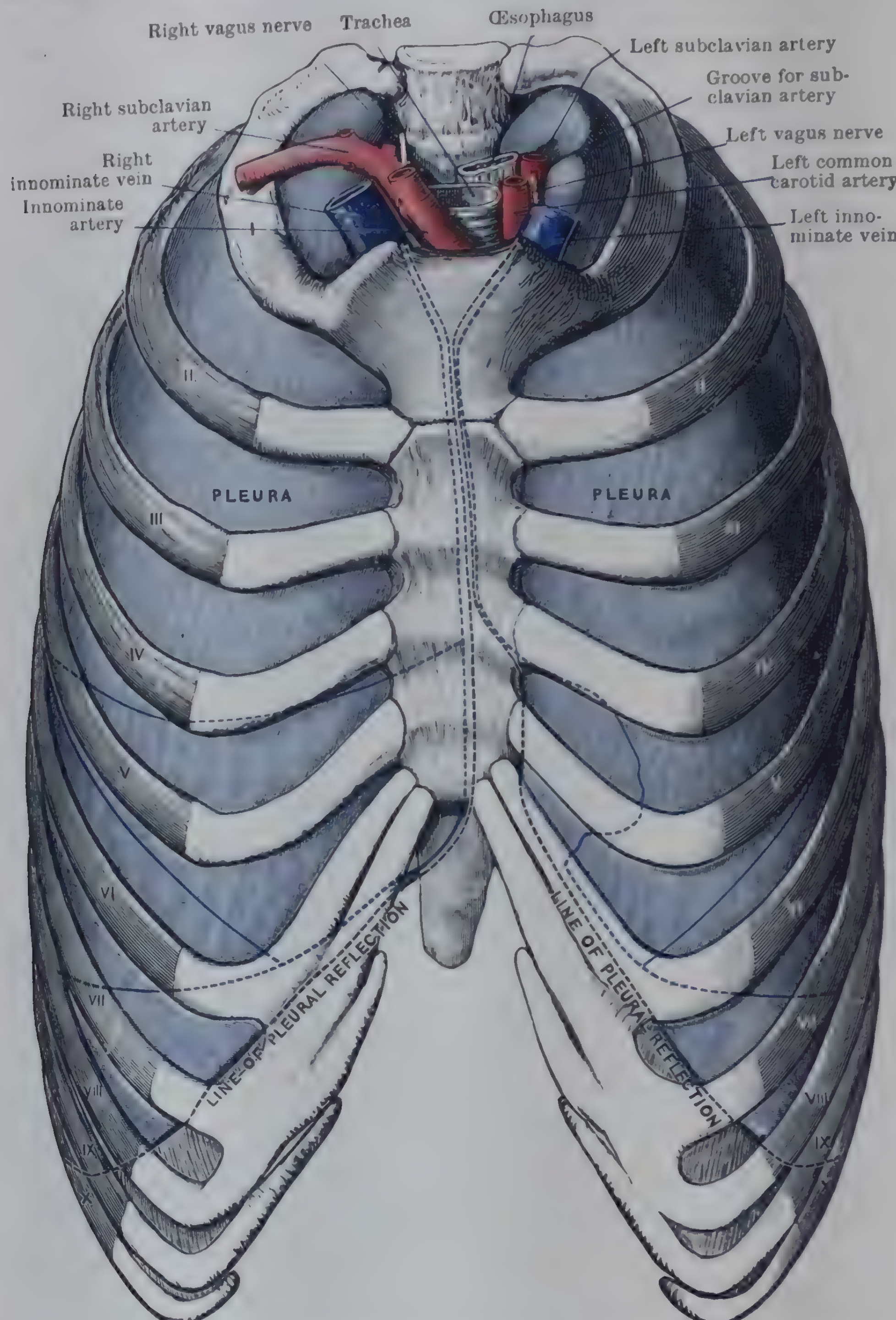

Fig. 1211.—Dissection of Subject hardened by Formalin Injection, to show the Pleural Sacs from the Front. The anterior and diaphragmatic lines of pleural reflexion are indicated by black dotted lines, and the outlines of the lungs and their fissures by the blue lines.

the eighth rib in the mid-axillary line about a hand's breadth above the costal margin (Figs. 1211-1213, 1230).

The position of the **oblique fissure** is indicated by a line drawn from the second thoracic spine to the root of the spine of the scapula, and thence downwards, laterally and forwards to end at the sixth or seventh costal cartilage about three finger-breadths from the median plane. When the arm is raised above the level of the shoulder, and the hand placed on the back of the head, the inferior angle of the scapula is rotated upwards and forwards so that the medial margin practically corresponds with the line of the oblique fissure.

The **horizontal fissure** of the right lung is mapped out by a line drawn from

the median line of the sternum, at the level of the fourth costal cartilage, towards the right and slightly upwards to the mid-axillary line.

Pleuræ.—The **line of reflexion** of the **right pleura** from the back of the sternum may be said to correspond to the anterior border of the right lung.

On the **left side**, the pleural reflexion corresponds to the anterior border of the left lung as far as the lower edge of the fourth chondro-sternal junction, at which point it leaves the lung and descends behind the left border of the sternum to the xiphi-sternal joint (Figs. 1211, 1220).

The **costo-diaphragmatic reflexion** or lower border of the pleura (see Figs. 1212 and 1219) is indicated on the surface by a line drawn from the xiphi-sternal joint towards the twelfth thoracic spine. The line is markedly convex downwards and crosses the tenth rib on the mid-axillary line about two finger-breadths above the costal margin.

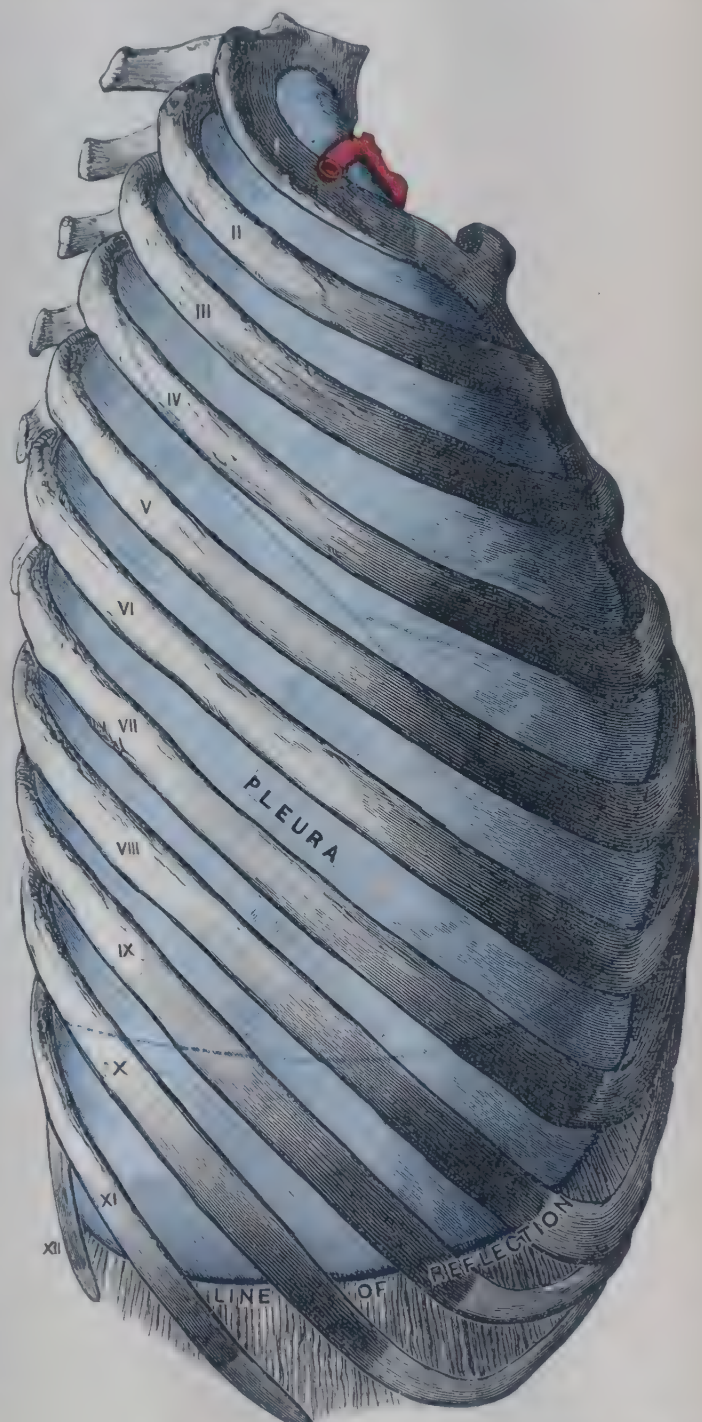

Fig. 1212.—Lateral View of Right Pleural Sac in Subject hardened by Formalin Injection. The blue lines indicate the outline of the right lung, and also the position of its fissures.

The **relations** of the **pleura** to the **twelfth rib** are of importance to the surgeon, especially in connection with operations on the kidney (Figs. 1213, 1214, 1230). When the rib is not abnormally short, the pleural reflexion crosses it opposite the lateral border of the sacro-spinalis muscle; hence an incision may be carried deeply as far as the apex of the angle between the twelfth rib and the lateral border of the sacro-spinalis without risk to the pleura. When, however, the twelfth rib does not reach the lateral border of the sacro-spinalis, the rib felt there is the eleventh; an incision carried upwards to that level is certain to wound the pleura.

Medial to the lateral edge of the sacro-spinalis the pleural reflexion is below the level of the twelfth rib, and not infrequently descends as far as the transverse process of the first lumbar vertebra. This must be borne in mind by the surgeon when he is carrying out a dissection to expose the kidney from the back.

On the *right side* of the posterior mediastinum, the **mediastinal pleura**, as it passes backwards from the pericardium to the vertebral column, sweeps over the right side of the œsophagus; malignant ulcers of the œsophagus are therefore more likely to invade the right pleura than the left. On the *left side* it passes from the bodies of the vertebræ on to the left side of the aorta. Hence, in the operation to evacuate pus from the posterior mediastinum, there is less risk of opening the pleura if the space is entered from the left side of the vertebral column.

Paracentesis or *tapping* of the pleura is used to confirm the presence of pus or other fluid in the pleural cavity. It is most often required for postero-inferior collections; the site of puncture is then the ninth intercostal space in the line of the angles of the

ribs. The needle is kept close to the upper border of the lower rib, to avoid intercostal vessels. Drainage of a collection of pus (*empyema*) is performed by resecting a portion of the ninth rib at its angle, after stripping its periosteum.

Trachea.—Anteriorly, the **bifurcation** of the **trachea** is opposite the *sternal angle*, while posteriorly it is a little below the level of the root of the spine of the scapula,

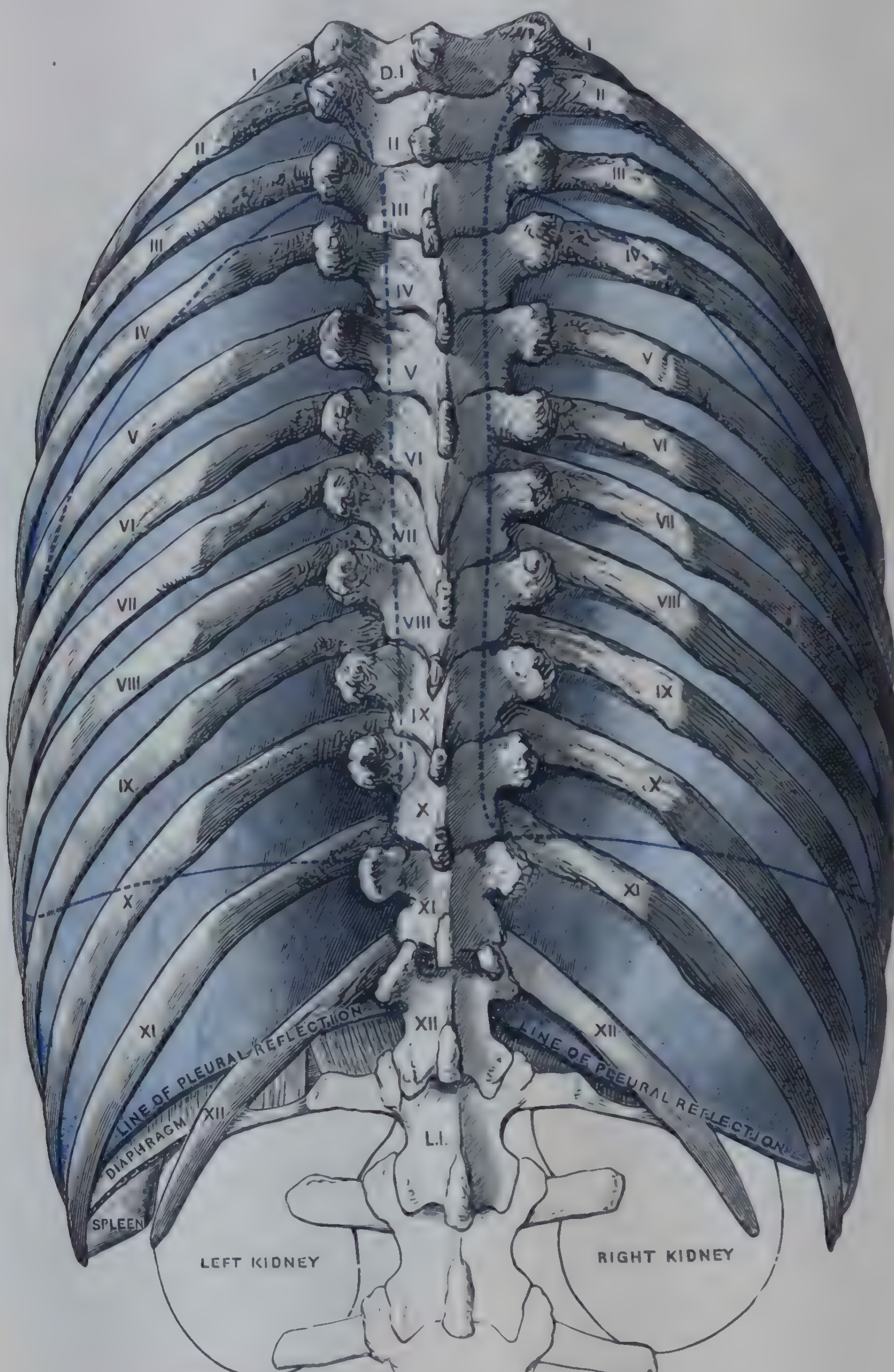

FIG. 1213.—DISSECTION OF PLEURAL SACS FROM BEHIND.
The blue lines indicate the outlines and the fissures of the lungs.

opposite the fourth thoracic spine (Fig. 1230). The bifurcation takes place one vertebra higher in the infant than in the adult (Symington, 1887), and its level varies in the same individual with phases of respiration and changes in position (p. 701).

The septum between the right and the left bronchus is a little to the left of the middle of the trachea, and the right bronchus is wider and more nearly in a line with the trachea than the left bronchus; hence the greater tendency of foreign bodies to enter the right bronchus.

Bronchial Tree and Broncho-Pulmonary Segments.—The branches of the bronchi and their relation to the *broncho-pulmonary segments* (Jackson & Huber,

1943; Brock, 1946) are fully described with the Respiratory System (p. 717). In Fig. 1215 they are represented from the point of view of bronchoscopy and the removal of a foreign body from a bronchus.

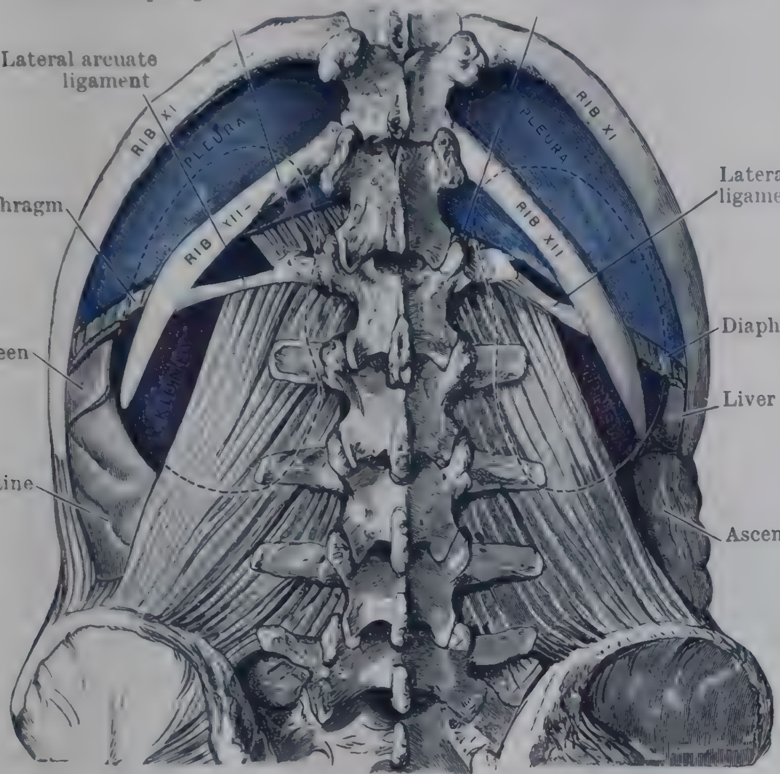

FIG. 1214.—DISSECTION FROM BEHIND TO SHOW RELATION OF PLEURAL SACS TO KIDNEYS.
The outline of the concealed portions of the kidneys (which are more alike in level than usual) is indicated by dotted lines.

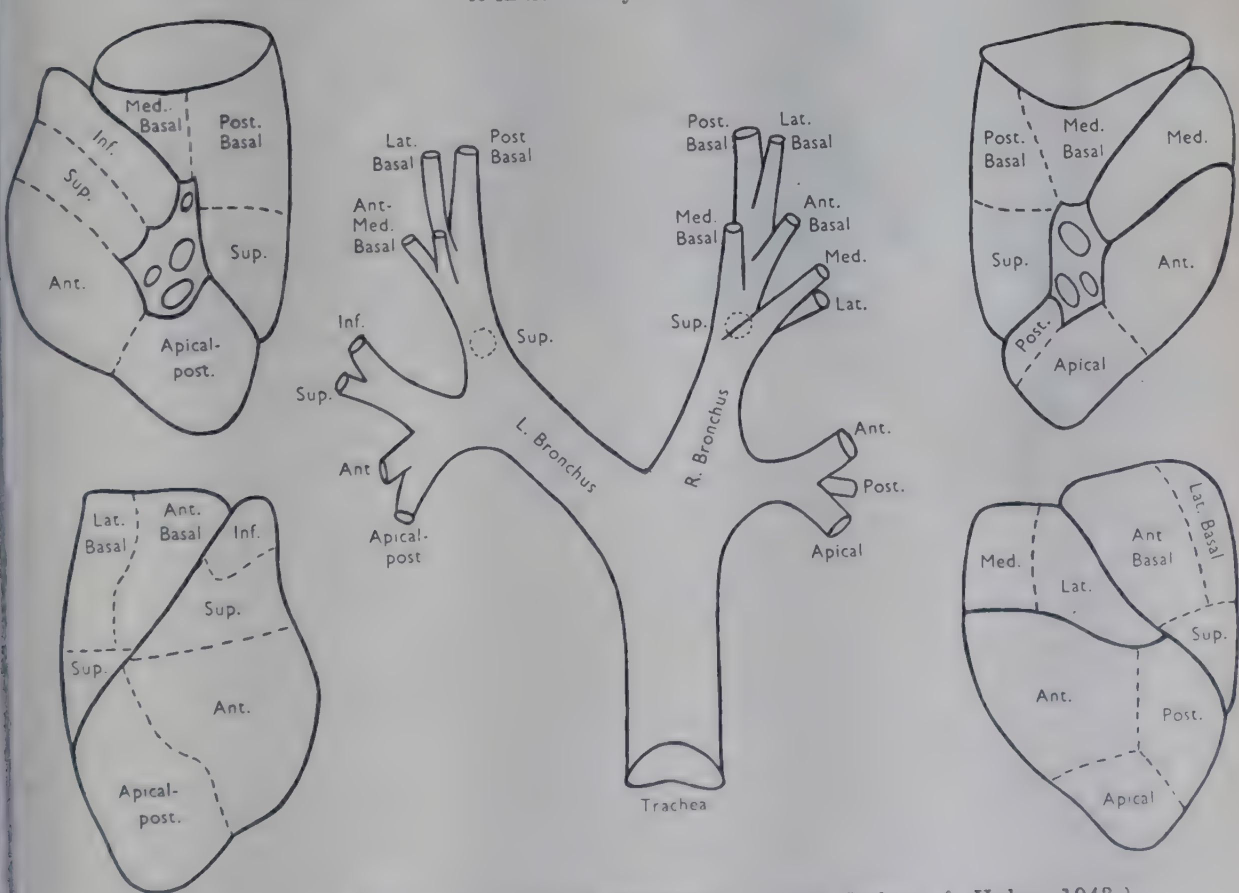

FIG. 1215.—THE BRONCHO-PULMONARY SEGMENTS. (After Jackson & Huber, 1943.)
Each bronchial branch is designated by the name of the subdivision of the lung supplied by it.

The **root** of the **lung** is opposite the fourth, fifth, and sixth thoracic spines midway between them and the medial margin of the scapula

The lower end of the trachea, the bronchi, the vagi, and the left recurrent laryngeal nerve, are all more or less surrounded by lymph-glands which, when enlarged, may exert injurious pressure on them.

Operations on Lungs.—**Lobectomy** is the removal of one or more lobes of the lung on account of tumour-development or of bronchiectasis. An incision is made along the line of the sixth interspace, and portions of the sixth and seventh ribs are resected as close to the vertebral attachment as possible, this permitting of wide retraction of the thoracic wound. The pedicle of the segment of lung to be removed is clamped in a special tourniquet: and after removal the stump is closed by sutures.

HEART, PERICARDIUM, AND GREAT VESSELS

Heart and Pericardium.—On the front, the **outline** of the **heart** is marked out as follows (Figs. 1216, 1220):

The *right border*, formed by the right atrium, is indicated by a line drawn about 2·5 cm. from the median plane from the upper border of the third costal cartilage to the sixth; the line should be slightly convex laterally—attaining its maximum opposite the fourth intercostal space.

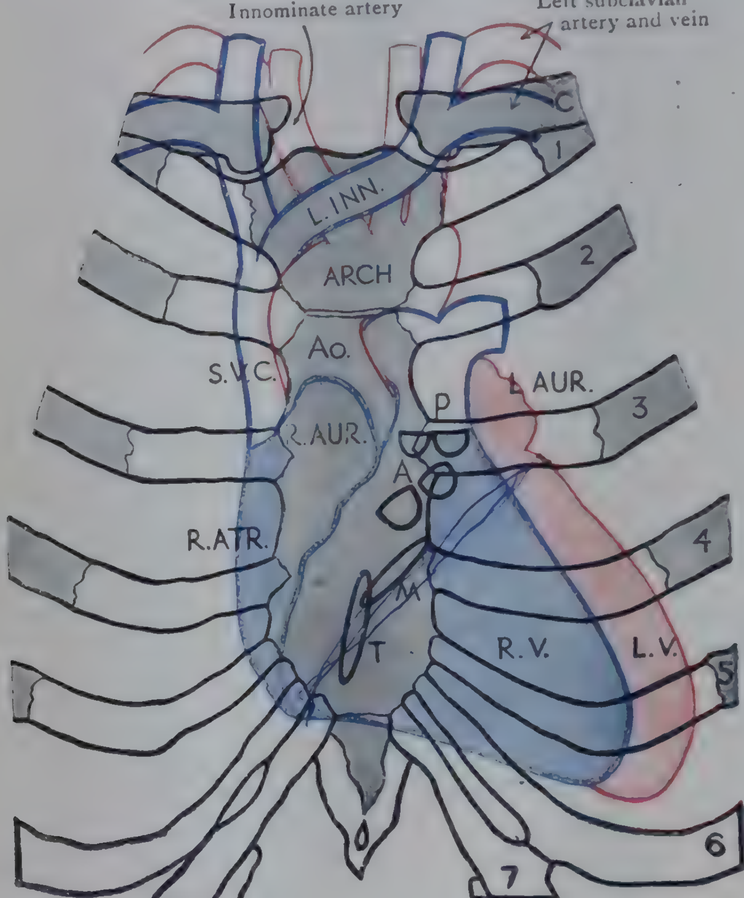

FIG. 1216.—RELATION OF HEART AND GREAT VESSELS TO ANTERIOR WALL OF THORAX.

1 to 7. Ribs and costal cartilages.
A. Aortic orifice.
Ao. Ascending aorta.
C. Clavicle.
L.V. Left ventricle
M. Mitral orifice.
P. Pulmonary orifice.
R.V. Right ventricle.
S.V.C. Superior vena cava.
T. Tricuspid orifice.

The *lower border*, formed by the right ventricle and, to a very slight extent, by the apical portion of the left ventricle, is almost horizontal, and corresponds to a line drawn from the sixth right costal cartilage to the point opposite the apex of the heart, which lies behind the fifth left intercostal space, about 4 cm. from the median plane. The line is opposite the xiphi-sternal joint.

The *left border*, formed almost wholly by the left ventricle, is indicated by a slightly curved line extending from the point opposite the apex of the heart to the second left costal cartilage 3·8 cm. from the median line, the convexity of the curve being directed laterally and slightly upwards.

The upper border is opposite a line drawn from the second left cartilage to the third right (between the ends of the lines for the right and left borders).

The lines indicating the outline of the pericardium are similar, except that the line for the upper border passes from the second left cartilage to the second right.

The situation of the anterior part of the **atrio-ventricular sulcus** is mapped out by a line drawn from the lower border of the third left costal cartilage to the sixth right chondro-sternal junction; the line should be slightly convex upwards and to the right. The **auricle** of the **right** atrium lies in the median plane, or a little to the right of it, at the level of the second intercostal space and the upper border of the third costal cartilage. The **auricle** of the **left** atrium lies behind the second left intercostal space, close to the edge of the sternum.

The *base* or *posterior surface* of the heart is formed mainly by the **left atrium**, which is moulded posteriorly on the œsophagus, the aorta, the bronchi, and the bronchial glands—the pericardium intervening. The left atrium extends behind the right atrium for a considerable distance to the right of the median plane.

In radiographic examination in cases of general visceroptosis, the diaphragm, which should rise and fall opposite the xiphi-sternal junction, will be seen to be 2·5 cm. or more lower down, while the long axis of the heart assumes an almost vertical direction (cardioptosis).

Orifices of Heart.—The *cardiac orifices* and *their valves* are situated below and to the left of the anterior part of the atrio-ventricular sulcus, and lie in the following order from above downwards and from left to right, viz., pulmonary, aortic, mitral, and tricuspid.

The **pulmonary orifice**, directed upwards and backwards, is opposite the third left costal cartilage. The **aortic orifice**, directed upwards, forwards, and to the right, is farther from the surface, behind the left margin of the sternum, opposite the lower border of the third intercostal space. The **mitral orifice** is at a lower level, behind the left half of the sternum, at the level of the fourth costal cartilage; it is directed downwards, forwards, and to the left. The **tricuspid orifice** is nearer the anterior wall of the chest than the mitral, and is opposite the middle of the sternum at the level of the fourth and fifth cartilages and intervening space.

Heart-Sounds.—Although the first and second sounds are heard all over the cardiac area, the sounds produced by the individual valves are heard most distinctly, not directly over their anatomical situation, but over the area where the cavity in which the valve lies is nearest the surface. Hence the **mitral sound** is best heard over the apex (mitral area), the **tricuspid** over the lower left part of the body of the sternum (tricuspid area), the **aortic** over the second right costal cartilage (aortic area), and the **pulmonary** over the third left costal cartilage (pulmonary area).

Operations on Pericardium and Heart.—In *paracentesis* of the pericardium, the needle is entered at the angle between the xiphoid process and the seventh left costal cartilage, and directed upwards and backwards. To drain the pericardium, a portion of that costal cartilage is excised, the diaphragm is displaced downwards, and the pericardial sac is opened at its most dependent point.

Extrapleural exposure of the heart requires resection of the fourth, fifth and sixth costal cartilages on the left side, after a flap of skin and pectoralis major muscle has been turned outwards and upwards. The corresponding intercostal vessels, and the internal mammary vessels, must be ligatured.

Great Vessels.—The **ascending aorta** lies behind the first piece of the body of the sternum, and, unless dilated, does not project beyond its right border. The upper border of the **aortic arch** lies at or a little above the centre of the manubrium sterni, but in the child it may reach as high as the upper border of the manubrium.

The **innominate** and **left common carotid arteries** diverge from the sides of the median plane between the upper part of the manubrium sterni and the front of the trachea and pass towards the sterno-clavicular joints.

The **pulmonary trunk** lies behind the sternal end of the left second interspace and the second costal cartilage.

The **left innominate vein** lies behind the medial part of the left clavicle and the upper part of the manubrium sterni, the **right** behind the medial part of the right clavicle and first costal cartilage. The **superior vena cava** lies immediately to the right of the margin of the sternum, opposite the first and second interspaces and the second cartilage; its opening into the right atrium, behind the third chondro-sternal joint, is opposite the centre of the root of the right lung.

Radiographic Examination.—For the radiographic examination of the thoracic organs, see pp. 721 and 1240. The functional variations in the position of these organs, as determined by radiography, are discussed by Mainland & Gordon (1941) and Lachman (1946).

ŒSOPHAGUS

The average length of the **œsophagus** in the adult is 25 cm. The distance from the incisor teeth to its commencement is 15 cm.; to the point or level where it is crossed by the left bronchus, 22·5 cm.; to the œsophageal opening of the diaphragm,

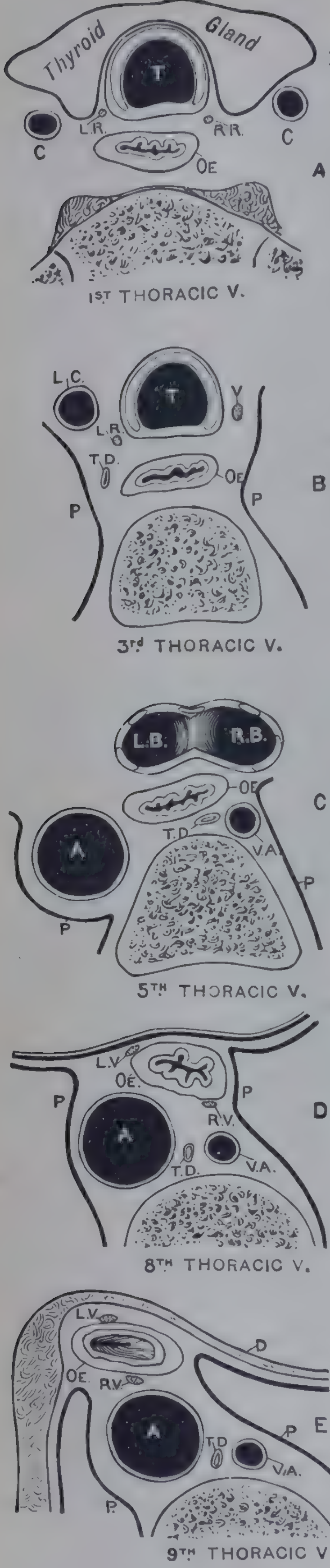

Fig. A is at the level of the superior part of the 1st thoracic vertebra, and shows the chief relations of the œsophagus in the neck and also its divergence to the left.

Fig. B, at the 3rd thoracic vertebra, shows the thoracic duct lying on the left side of the œsophagus. V, Right vagus nerve.

In Fig. C, at the level of the 5th thoracic vertebra, the left bronchus is seen in relation to the anterior surface of the œsophagus.

Fig. D is at the level of the 8th thoracic vertebra, and shows the œsophagus passing behind the pericardium.

Fig. E, at the 9th thoracic vertebra, shows the œsophagus inclining to the left just before piercing the diaphragm.

Fig. 1217.—Relations of Œsophagus at different Levels. A, in Neck; B, in Superior Mediastinum; C, D, E, in Posterior Mediastinum. See also Fig. 593, p. 701.

A, Aorta; C, Common carotid artery; D, Diaphragm; L.B, Left bronchus; L.C, Left subclavian artery; L.R, Left recurrent laryngeal nerve; L.V, Left vagus; Oe, Œsophagus; P, Pleura; Pc, Pericardium; R.B, Right bronchus; R.R, Right recurrent laryngeal nerve; R.V, Right vagus; T, Trachea; T.D, Thoracic duct; V.A, Vena azygos.

35 cm.; to the cardiac orifice of the stomach, 40 cm. These measurements, which are of great importance in the diagnosis of the seat of œsophageal obstructions, should be marked off from below upwards upon all œsophageal bougies. Posteriorly, the œsophagus extends from the level of the sixth cervical spine to that of the ninth thoracic, a little to the left of which is the situation at which the stethoscope is placed in order that the sound produced by the passage of fluid into the stomach may be heard (Fig. 1217 and Pl. L, p. 593).

There are three points in the lumen of the œsophagus at which foreign bodies are apt to become impacted, and in which neoplasms commonly occur. They are at the pharyngo-œsophageal junction (15 cm. from the teeth), the level of the crossing of the left bronchus (opposite the body of the fifth thoracic vertebra), and at the passage through the diaphragm (35 cm. from the teeth).

Clinically it is important to bear in mind the relation of the œsophagus to the trachea and left bronchus, to the left recurrent laryngeal nerve, to the bronchial and posterior mediastinal glands, to the descending thoracic aorta, and to the right pleura in the posterior mediastinum. Ulcers of the œsophagus are apt to open into either the trachea, the left bronchus, or the right pleura.

The *veins* of the lower end of the œsophagus open partly into the systemic veins and partly into the portal system; like those at the lower end of the rectum they are liable to become varicose in conditions which give rise to obstruction of the portal circulation.

The *lymph-vessels* of the upper part of the œsophagus open into the glands in the root of the neck, the remainder into the posterior mediastinal glands.

By means of X-ray cinematography the relatively quick movements of the œsophagus have been studied. Three phases may be distinguished in the process of swallowing—the pharyngeal, the œsophageal, and the cardiac. The upper end of the œsophagus opens secondary to contraction of the pharynx; a series of rapid peristaltic waves then appear in the œsophagus—each contraction lasting four to six seconds—and after a perceptible interval, dependent upon the type of food, the cardiac orifice of the stomach opens.

The clinical investigation of the œsophagus is carried out by radiographic examinaton during the swallowing of a thick barium-paste (p. 1555) and by œsophagoscopy. In the latter method, a metal tube carrying a small electric lamp is introduced, and the interior of the œsophagus is brought under direct vision.

Operations on Œsophagus.—The operation to expose the cervical portion of the œsophagus has been described (p. 1479). The thoracic portion of the oesophagus (usually its lower half) is exposed by a long incision in the line of the eighth or ninth intercostal space. Segments of the posterior ends of the ribs bounding the space are resected, to allow

f wide retraction of the edges of the incision. Access to the upper part of the abdominal avity (for example, to the cardia) is secured by a radial incision in the diaphragm, after it as been temporarily paralysed by picking up and crushing the phrenic nerve as it courses over the pericardium.

ABDOMEN

ANTERIOR WALL OF ABDOMEN

Landmarks.—The configuration of the abdomen varies with the age, sex, obesity, and muscular development of the individual. In the child it is wider above than below, while the reverse is the case in the female adult. It is most prominent in the region of the **umbilicus**, which, in the recumbent posture, is situated below the mid-point between the xiphi-sternal joint and the pubic symphysis, usually a little above the level of the highest part of the iliac crest, and opposite the disc between the third and fourth lumbar vertebræ; but in a person standing upright it sinks to a lower level and is opposite the middle of the body of the fourth lumbar vertebra. In the obese, and especially when the abdominal muscles have lost their tone, the umbilical region becomes prominent and more or less pendulous, so that the umbilicus may come to lie considerably below the normal level. In the child it is relatively lower than in the adult, in consequence of the undeveloped state of the pelvis.

In spare subjects the lower end of the body of the sternum, the xiphoid process, and the costal margin can readily be traced. Below the xiphi-sternal joint and bounded on each side by the seventh, eighth, and ninth costal cartilages, is the **infrasternal angle**, which varies considerably according to the shape of the chest; it is relatively wider in the child than in the adult. The lower border of the curve of the **tenth costal cartilage** is easily recognizable, and is usually the lowest point seen or felt on the costal margin when the body is examined from the front; it also marks the level of the subcostal plane.

The anterior wall is limited below by the groove of the groin and the pubic crest. In a spare muscular subject the recti muscles, the furrows corresponding to the tendinous intersections and the supra-umbilical portion of the **linea alba** can be readily made out. When the outline of the rectus is not visible, the lateral border may be indicated by a line drawn from the tip of the ninth costal cartilage to the mid-point of a line between the umbilicus and the anterior superior iliac spine, and from there to the pubic tubercle. In the angle between the lateral border of the rectus and the ninth costal cartilage there is a slight triangular depression which, on the right side, overlies the fundus of the **gall-bladder**. Between the lower part of the lateral border of the rectus and the bulging above the anterior part of the iliac crest caused by the lower muscular fibres of the external oblique, there is another slight triangular depression which corresponds to the inferior and narrow part of the aponeurosis of the external oblique muscle.

Inferior Epigastric Artery.—This artery may be mapped out by a line drawn from the mid-inguinal point towards the umbilicus. The vessel, together with the medial third of the inguinal ligament and the lower part of the lateral border of the rectus, bounds a triangle known as the **inguinal triangle.** As the inferior epigastric artery passes upwards and medially to disappear behind the conjoint tendon and the lateral border of the rectus, it lies behind the spermatic cord immediately medial to, and below, the deep inguinal ring. The floor of the inguinal triangle is formed throughout by the fascia transversalis, superficial to which, over the medial half or so of the triangle, is the conjoint tendon.

Inguinal Canal and Hernia.—Close above, and almost parallel to, the medial half of the inguinal ligament is the **inguinal canal**, which is traversed by the **spermatic cord** (Fig. 1218); the cord can be felt to emerge at the superficial inguinal ring immediately above the pubic tubercle. The **inguinal rings** are fully described in the section on Muscles. The **superficial inguinal ring** is triangular in shape, with its apex directed upwards and laterally, and its base at the pubic crest. It is to be

noted that the neck of an *inguinal hernia* lies above the pubic tubercle, whereas the neck of a *femoral hernia* emerges below the medial part of the inguinal ligament, lateral to the pubic tubercle. The **deep inguinal ring** is nearly 1·3 cm. above the *mid-inguinal point*—that is, a point on the inguinal ligament midway between the pubic symphysis and the anterior superior iliac spine.

An **oblique inguinal hernia** leaves the abdomen at the deep inguinal ring and traverses the whole length of the inguinal canal; its coverings are therefore the same as those of the spermatic cord, and the neck of the sac lies lateral to the inferior epigastric artery. A **direct inguinal hernia**, on the other hand, instead of traversing the whole length of the inguinal canal, pushes before it that part of its posterior wall which is formed by the floor of the inguinal triangle. The neck of the sac therefore is medial to the inferior epigastric artery. If a direct hernia makes its way through the medial part of the inguinal triangle, it derives a covering from the conjoint tendon as well as from the fascia transversalis; if through the

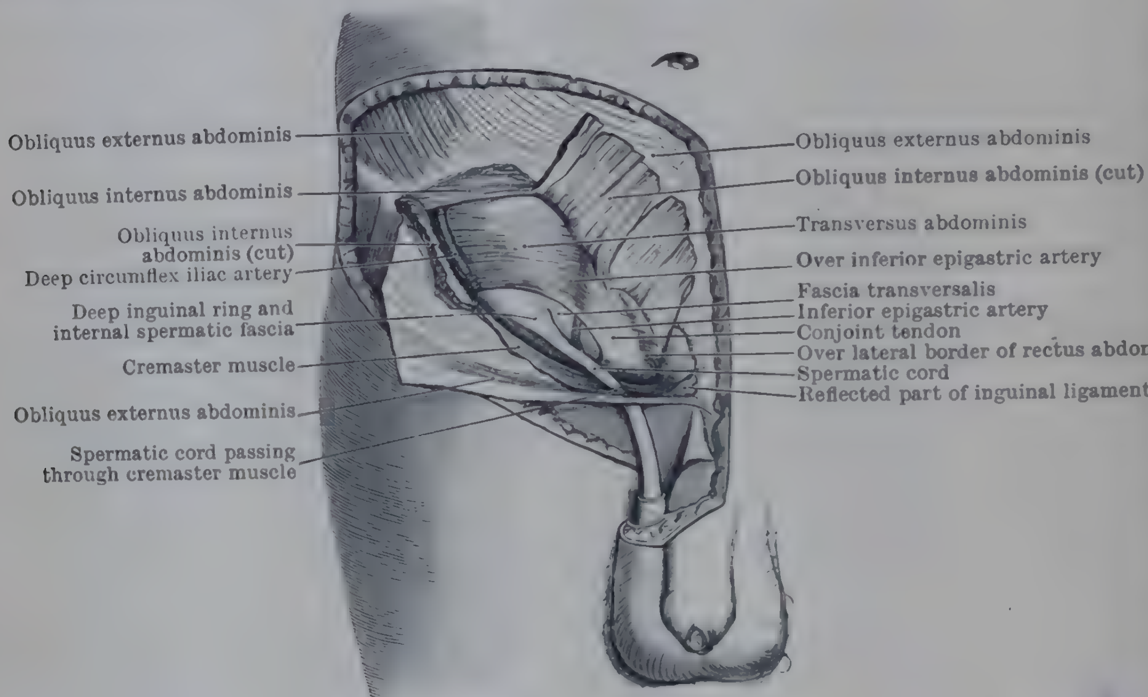

FIG. 1218.—DISSECTION OF GROIN TO SHOW STRUCTURES RELATED TO INGUINAL HERNIA.

lateral part of the triangle, the lateral edge of the conjoint tendon curves round the medial side of the neck of the sac. To relieve the constriction at the neck of the sac, in the case of an *oblique inguinal hernia*, the edge of the knife is directed upwards and laterally to avoid the inferior epigastric artery; in a *direct hernia* the constriction is divided in an upward and medial direction in order to avoid damaging the artery. In an oblique inguinal hernia there are three coverings or fasciæ: the external spermatic derived from the external oblique aponeurosis; the cremasteric from the internal oblique muscle; and the internal spermatic from the transversalis fascia. The sac of the hernia lies within the last-mentioned covering. In a direct inguinal hernia the coverings are less well defined; it may be impossible to distinguish individual layers, but the tunica propria of the hernia is derived from the fascia transversalis. The extraperitoneal fat which covers the outer surface of the hernial sac is sometimes hypertrophied to such an extent as to amount to a fatty tumour.

In a large number of children, at birth, the **vaginal process** of peritoneum which connects the tunica vaginalis testis with the abdominal peritoneum, is still patent, especially on the right side. Should the bowel force its way along the patent process, a **congenital inguinal hernia** arises. In the majority of the cases of congenital inguinal hernia it will be found that the tunica vaginalis testis has been shut off by closure of the lower part of the vaginal process, only the upper part remaining patent and forming the sac of the hernia.

In the child the persistence of a patent vaginal process can almost invariably be detected if the spermatic cord is rolled between the finger and thumb; for after the va

deferens and spermatic vessels have slipped away from one's grasp, the edge of the sac can be felt to follow them. In regard to the operation for the cure of inguinal hernia, it should be borne in mind that in the acquired form the *hernia produces the sac*, whereas in the congenital variety the *sac is the cause of the hernia*; it follows, therefore, that in the operation for *acquired* hernia the closure of the canal is as important as the removal or obliteration of the sac, while in a *congenital* hernia the most essential part of the operation is the closure of the neck of the sac, and, as the muscular and fascial layers of the walls of the canal are often well developed (especially in children), they should be interfered with as little as possible. A patent vaginal process may persist during adult life without any bowel descending into it; on the other hand, years after birth, bowel may suddenly enter it. In practically all oblique inguinal herniæ which develop suddenly in children as well as in adolescents and young adults, the *sac* is congenital.

Hydrocele.—In the ordinary form of hydrocele the fluid is confined to the tunica vaginalis testis; but, when the upper portion of the processus vaginalis remains patent, the hydrocele may extend upwards into the inguinal canal, and it may or may not communicate with the general peritoneal cavity (*infantile hydrocele*). In the condition known as *encysted hydrocele of the cord* the patent vaginal process is shut off both from the tunica vaginalis testis and from the peritoneal cavity.

Distribution of Sensory Nerves.—A knowledge of the segmental distribution of the sensory fibres of the lower intercostal nerves to the anterior abdominal wall enables us to appreciate the significance of the so-called girdle-pain often associated with lesions of the spinal cord and the nerve-roots. In tuberculous disease of the vertebral column, for example, the girdle-pain may be an early symptom, and when present it affords a valuable guide to the situation of the disease in the vertebral column. The seventh thoracic nerve supplies the skin at the level of the epigastric fossa, the eighth and ninth that between it and the umbilicus, the tenth that at the level of the umbilicus, the eleventh and twelfth and the ilio-hypogastric (from first lumbar) that between the umbilicus and groin (Fig. 918, p. 1059).

ABDOMINAL INCISIONS

Before the abdominal cavity is dealt with reference must be made to some anatomical points connected with the more typical incisions employed when the abdomen is opened.

Incisions in Median Plane.—Median incisions through the linea alba have the advantage of being comparatively bloodless and rapid of execution, of dividing no motor nerves, and of enabling the surgeon to expose a wide area of the abdomen. Unless special precautions are taken, however, they are more liable to be followed by a ventral hernia.

Above the umbilicus the linea alba is comparatively broad, so that the edges of the recti are separated by a distinct interval, which may be of considerable width in obese subjects and multiparous women. Deep to the linea alba is the transversalis fascia, which is so thin and adherent that the two structures form practically a single layer. The extraperitoneal fat, which forms a comparatively thick stratum, must not be mistaken for omentum. The peritoneum presents itself as a thin, bluish, semi-transparent membrane. If it is necessary to prolong the incision downwards below the level of the umbilicus, in order to avoid the round ligament of the liver, it should pass to the left of the umbilicus. If, in closing a median supra-umbilical incision, the surgeon merely sutures the edges of the stretched linea alba without opening into the rectal sheaths, a hernia may result. To ensure against it, the medial borders of the recti are exposed by opening into their sheaths along each edge of the wound. In closing the wound, the deepest suture includes on each side the posterior wall of the rectal sheath along with the split linea alba, the transversalis fascia, and the peritoneum. That gives a substantial "first line of defence". The next suture takes up some of the fibres of the medial edges of the recti, along with the anterior wall of their sheaths. The skin is sutured separately. By this procedure the edges of the recti are brought into actual contact and a double-layered linea alba is fashioned—one layer behind the margins of the recti and the other in front of them.

Below the umbilicus the medial edges of the recti are practically in contact, and an incision between them therefore opens into the rectal sheath on both sides.

Infra-umbilical median incisions, if carried as low as the pubic symphysis, may damage the anterior wall of the bladder unless special precautions are taken; this applies more especially in children, for in them the bladder extends up out of the pelvis. The bladder should therefore be emptied before the abdomen is opened by a low median incision; in suprapubic cystotomy, on the other hand, the bladder is intentionally filled so as to elevate the peritoneum well above the symphysis. Below the peritoneal layer is the **retropubic space**, occupied by a pad of extra

peritoneal fat which must be separated by blunt dissection before the bladder-wall is actually exposed. In opening the bladder, the veins which ramify on its surface are avoided. Above the pubes the fascia transversalis recedes a little from the recti, leaving an interval, filled with areolar tissue, which must not be mistaken for the retropubic space.

Incisions through Recti.—In **longitudinal incisions through the rectus** the superior epigastric artery will be encountered above the umbilicus, and the inferior epigastric below it. Incisions must be kept close to the medial margin of the muscle, to preserve its nerve supply. **Above the level of the umbilicus** the posterior wall of the rectus-sheath is well developed; and when the wound is closed this wall is included in the same suture as the transversalis fascia and the peritoneum, the three together forming a most efficient line of closure. The higher and more lateral the incision through the rectus is made, the more will the posterior wall of the sheath be found to be made up of muscular fibres of the transversus abdominis muscle. **Below the level of the umbilicus** the posterior wall of the sheath is much thinner and ceases to be a definite layer, usually appearing to end in a slightly thickened arched band, called the *arcuate line*, about midway between the umbilicus and the pubes. Below that level, therefore, the "deep closure" of a laparotomy wound through the rectus is less secure than it is at a higher level. It is all the more important, therefore, to see that the edges of the anterior wall of the sheath are accurately sutured.

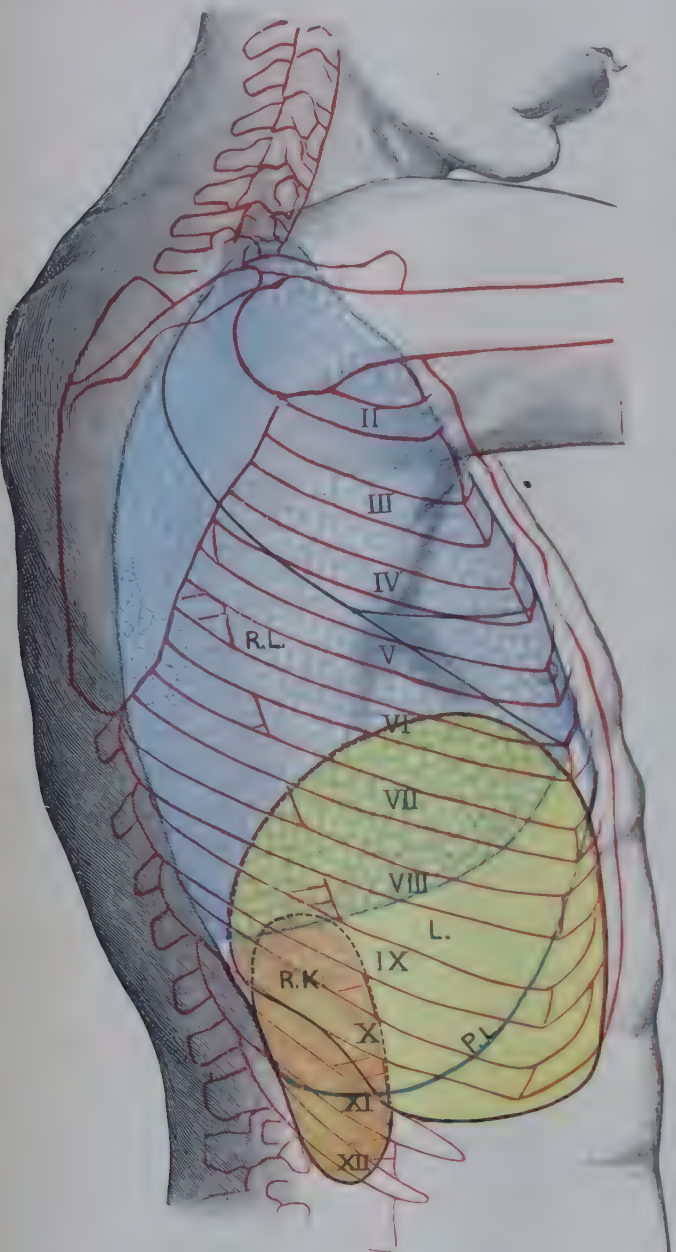

FIG. 1219.—RIGHT LATERAL ASPECT OF TRUNK, SHOWING SURFACE TOPOGRAPHY OF VISCERA.

R.L. Right lung. R.K. Right kidney.
L. Liver. P.L. Pleura.

Incisions which imply Retraction of Rectus.—A vertical incision to one or other side of the median line opens the rectus-sheath, the muscle is separated and retracted laterally, and the posterior wall of the sheath and peritoneum are opened in the line of the skin incision. When the incision is closed, the tier of sutures in the peritoneum and posterior layer of rectus sheath is separated from that in the anterior layer by a "shutter" of muscle. This is the most generally used form of abdominal incision.

Transverse Incisions.—Incisions which divide the upper segments of the rectus muscles transversely give good access, and since they are parallel to the nerves, are not followed by muscular weakness.

Subcostal Incisions.—Incisions from the midline to the ninth costal cartilage, about 4 cm. below and parallel to the costal margin, give good access on the right side to the biliary apparatus, and on the left side to the spleen.

Incisions in Iliac Region.—To reach the cæcum and vermiform appendix on the right side and the pelvic colon on the left side (colostomy), it is customary, by using what is known as the "gridiron incision", to split the three abdominal muscles in the direction of their fibres. The external oblique is split in the direction of the skin-incision, which is made obliquely from above downwards and medially. After retracting the edges of that muscle the fibres of the internal oblique and transversus muscles are split horizontally. The abdomen is then opened by division of the transversalis fascia and peritoneum. If a comparatively large opening is required, the ascending branch of the deep circumflex iliac artery, which runs upwards between the internal oblique and transversus muscles a little medial to the anterior superior iliac spine, is divided and ligatured, while the ilio-hypogastric and ilio-inguinal nerves are to be avoided. If it is necessary to extend the incision in a medial direction, the lateral part of the anterior wall of the sheath of the rectus is opened and the rectus pulled medially; the inferior epigastric artery, now exposed, is pushed aside or ligatured before the opening in the fascia transversalis and peritoneum is enlarged.

If they are made parallel to the nerves of the abdominal wall, long oblique incisions, partly muscle-splitting and partly muscle-cutting, give wide access to structures in the flanks.

ABDOMINAL CAVITY

Divisions of Abdominal Cavity.—The cavity of the abdomen is divided into three zones by two imaginary planes:—

(1) The *subcostal plane*, which passes through the lowest point on the rib margins seen from the front (usually the lower edge of the tenth costal cartilage) and corresponds to the level of the upper border of the third lumbar vertebra.

(2) The *intertubercular plane*, which passes through the tubercles of the iliac crests (the highest part of the crests seen from the front) at the level of the centre of the fifth lumbar vertebra.

Each zone is divided into three regions by a pair of vertical planes, each of which passes through the mid-inguinal point and the ninth costal cartilage near its tip. The upper zone is thus divided into a *right* and *left hypochondrium* and an *epigastrium*, the middle zone into *lumbar* and *umbilical* regions, and the lowest zone into *iliac* and *suprapubic* regions.

A useful line of reference is that which corresponds to the *transpyloric plane* (Addison). This plane is midway between the upper margin of the sternum and the upper margin of the pubic symphysis, and for easy reference may be said to be a hand's breadth below the xiphi-sternal joint. It is at the level of the lower border of the first lumbar vertebra, and receives its name from the fact that it passes through the pylorus. (See p. 602 and Fig. 514.)

Peritoneal Cavity.—This cavity may be regarded as a large and complicated lymph-sac which is intimately related to the abdominal viscera, and more especially to the gastro-intestinal canal. Inflammatory infections of the peritoneum are therefore almost always secondary to lesions of the viscera. The healthy peritoneum is endowed with great absorptive and reparative properties, and, when irritated, has the power of throwing out an abundant exudation, the cell-elements of which are actively phagocytic.

The reflexion of the peritoneum and its relations to the various organs have been fully described in the Section on the Digestive System.

The attachment of the **transverse mesocolon** to the posterior abdominal wall is at the level of the second lumbar vertebra. The attachment, which ascends slightly as it passes from right to left, crosses the head of the pancreas, after which its attachment follows the lower border of the body of the pancreas. The *peritoneal compartment above that attachment* is roofed in by the diaphragm, and includes the upper part of the great sac of peritoneum, and, posteriorly, the larger portion of the lesser sac. The organs related to that area of the peritoneum are the liver with the bile-ducts and gall-bladder, the stomach and part of the duodenum, the spleen, the pancreas, the upper parts of the kidneys, and the suprarenal glands. Suppuration connected with any of those organs is liable to spread upwards under the cupola of the diaphragm, producing what is known as *subphrenic abscess*.

The attachment of the **mesentery** of the **small intestine** extends from the left side of the second lumbar vertebra downwards to the right iliac fossa. The attachment may be mapped out on the surface by a line drawn from a point 2·5 cm. below the transpyloric line, 2·5 cm. to the left of the median plane, to the intersection of the intertubercular and right vertical planes.

Compartments of Peritoneal Cavity.—From the surgical point of view the peritoneal cavity may be arbitrarily divided into **four great compartments**: namely, a supracolic, a right infracolic, a left infracolic, and a pelvic. All these divisions communicate freely with one another behind the anterior abdominal wall, as well as along the gutter-like channels in the loins. It is along those gutters that pus readily makes its way from the upper part of the abdomen downwards into the pelvis; on the other hand, the pus may ascend from the pelvis along the same channels, especially when the patient is in the recumbent posture.

The highest (subphrenic) region of the **supracolic compartment** is further sub-

divided into a right and left portion by the falciform ligament; and the **lesser sac** may be looked upon as a diverticulum of the right subdivision.

The subphrenic lymph-plexus communicates, by means of lymph-vessels which pierce the diaphragm, with the subpleural plexus on its upper surface; hence, pus confined under tension in either of the subphrenic spaces is apt to give rise to secondary infection of the corresponding pleural cavity. By adhesions of the transverse colon and greater omentum to the anterior abdominal wall, the supracolic compartment of the peritoneal cavity may become more or less completely shut off from the rest of the abdomen. Suppuration in the right half of the supracolic compartment is generally secondary to leakage from an ulcer of the first part of the duodenum or to disease of the gall-bladder and bile-ducts; the left half of the space is more usually infected from the stomach. The supracolic compartment of the peritoneal cavity may be drained through the anterior abdominal wall, or preferably by resecting the twelfth rib through an incision over it, and inserting the drainage tube in the angle between the bed of the rib and the lateral border of the sacro-spinalis muscle.

The **right infracolic compartment** is above and to the right of the mesentery. It is bounded laterally by the cæcum and ascending colon, and superiorly by the right and middle thirds of the transverse colon and the corresponding part of its mesocolon. At its right lower angle are the ileo-cæcal junction and the vermiform appendix; at its right upper angle is the right flexure of the colon; and at its left upper angle is the third part of the duodenum, crossed by the superior mesenteric vessels. In rare instances the third part of the duodenum may be compressed between those vessels and the vertebral column. The condition is named *duodeno-mesenteric ileus*.

The organs related to that compartment are—in addition to the parts of the large intestine already mentioned—coils of small intestine, the lower third of the right kidney, the right ureter, the third part of the duodenum and the lower half of the second part. Suppuration in connexion with the organs in that area may extend upwards along the colon into the sub-diaphragmatic region, or downwards into the pelvis. Drainage of the area is established through a wound in the right iliac fossa, the drainage material being placed medial to the ascending colon.

The **left infracolic compartment** is below and to the left of the mesentery; it narrows as it passes upwards, and reaches a higher level than the right infracolic compartment. Inferiorly, it is directly continuous with the peritoneal cavity of the true pelvis. Above, it is bounded by the left third of the transverse colon and its mesocolon, and, still farther back, by the inferior surface of the body of the pancreas; laterally, it is bounded by the descending colon. At its right upper angle is the duodeno-jejunal flexure, lying immediately to the left of the vertebral column, on the psoas and below the pancreas. At its left upper angle is the left flexure of the colon, while at its left lower angle is the junction of descending with pelvic colon. This compartment of the peritoneal cavity, in addition to containing the majority of the coils of the small intestine, is related to the lower third of the left kidney, the left ureter, the lower part of the abdominal aorta and vena cava, and the inferior mesenteric and common iliac vessels. Drainage of the compartment may be established through the left iliac fossa, or by a tube introduced down to the bottom of the pelvis—into the recto-vesical pouch in the male, and into or through the recto-vaginal pouch in the female.

On account of the oblique manner in which the mesentery is attached to the posterior abdominal wall, it follows that, in order to examine the organs related to the right infracolic compartment of the abdomen, the surgeon must push coils of small intestine downwards and to the left, while to investigate the left infracolic compartment he must displace them upwards and to the right.

ABDOMINAL VISCERA

Liver.—The *inferior margin of the liver* extends from a point a finger's breadth below the right costal margin at the side of the trunk to the fifth left intercostal space below the nipple in a line dropped from the middle of the

clavicle; in the infracostal angle it passes from the tenth right costal cartilage to the eighth left and crosses the median plane at the transpyloric plane; in this region the position can be determined by light percussion and occasionally by palpation. The *highest part of the liver*, which corresponds also to the highest part of the right arch of the diaphragm, reaches, during expiration, to the level of the fourth right intercostal space opposite the nipple or in the mid-clavicular line. To the right of the median plane the superior surface of the liver is too far removed from the anterior wall of the chest, and overlapped by too thick a layer of lung substance, to be accurately determined by percussion. *Behind the sternum* the superior surface is opposite the xiphi-sternal joint. To the left of the median plane the upper limit of the liver cannot be determined by percussion, since it merges into the cardiac dullness. The base or **right lateral surface** extends from the level of the seventh rib to the level of the eleventh rib in the mid-axillary line, and is separated by the diaphragm from the lower part of the right lung and pleura.

The **falciform ligament**, at its attachment to the liver, is a little to the right of the median plane.

By dividing the *round ligament*, which passes backwards and upwards in the free margin of the falciform ligament, the surgeon is enabled to rotate the liver backwards around its transverse axis so as to expose more of its inferior surface; that procedure is sometimes taken advantage of in cases in which there is unusual difficulty in reaching the cystic and hepatic ducts or the bile-duct. The ligament is sutured before the abdominal wall is closed.

The **anterior surface** of the liver may be reached through a median incision which extends downwards from the xiphoid process, or by an oblique incision a finger's breadth below and parallel to the right costal margin. To obtain free access to the **superior surface,** the eighth and ninth costal cartilages of the right side are divided; the seventh cartilage should, if possible, be avoided, for the pleural cavity may be opened into. Division of the round and falciform ligaments allows of greater downward displacement of the liver. To reach the upper part of the **lateral surface** of the right lobe, portions of the seventh and eighth ribs in the mid-axillary line are removed, and both the pleural and peritoneal cavities are traversed.

Gall-Bladder.—The relation of the fundus of the **gall-bladder** to the surface of the body is subject to considerable variation. Normally it is situated behind the angle between the ninth costal cartilage and the lateral border of the right rectus; exceptionally, it is pendulous and suspended from the liver by a more or less distinct mesentery; or it may be elongated and drawn downwards by adhesion to the duodenum or colon. When displaced downwards it is liable to be mistaken for a movable kidney, but may be distinguished from it by the fact that although it may be pushed backwards into the lumbar region it returns at once to its habitual position, immediately behind the anterior abdominal wall, as soon as the pressure is discontinued.

The **cystic duct** is enclosed in the right end of the upper border of the lesser omentum. It is about 3·8 cm. in length, and is sharply bent upon itself close to its origin at the neck of the gall-bladder. It joins the common hepatic duct at a very acute angle. The passage of a probe along the *normal* duct is made difficult by the marked flexure at its commencement, and also by the folded condition of its mucous membrane; these features explain the frequency with which calculi become impacted at the neck of the gall-bladder.

In excising the gall-bladder, the cystic artery and duct are ligated and divided before proceeding to detach the organ from the liver; by this routine, bleeding is lessened and the difficult part of the operation is carried out before the field is obscured by blood from the under surface of the liver.

The outline of the normal gall-bladder is demonstrable on X-ray examination after the oral administration of the compound salt sodium tetra-iodo-phenol-phthalein (Pl. LX, p. 649). The procedure is employed in the investigation of cases of gall-stones and infections of the gall-bladder. A calcified gall-bladder may be visible in an ordinary radiograph (Pl. LII, p. 609).

Bile-Duct.—The bile-duct is about 8·8 cm. in length. Its *upper third* lies in the lesser omentum, close to the right, free border. That is the most accessible part of the duct, and, when cutting into it, it is drawn forwards by the finger introduced

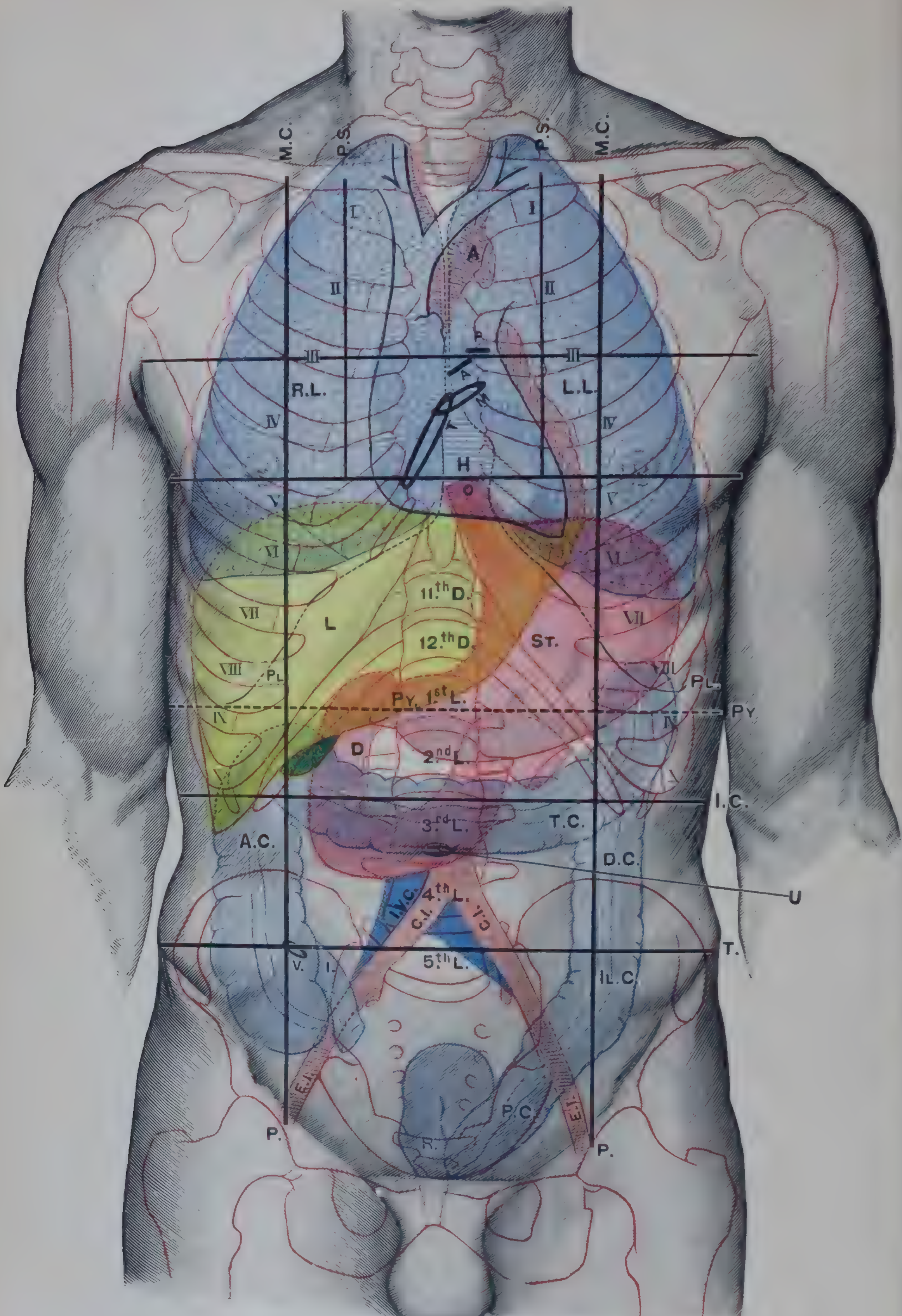

FIG. 1220.—ANTERIOR ASPECT OF TRUNK, SHOWING SURFACE TOPOGRAPHY OF VISCERA.

A.	Aorta.	I.V.C.	Inferior vena cava.	Py.	Pylorus and transpyloric plane.
A.	Aortic orifice.	L.	Liver.	R.	Rectum.
A.C.	Ascending colon.	L.L.	Left lung.	R.L.	Right lung.
C.I.	Common iliac artery.	M.	Mitral orifice.	St.	Stomach.
D.	Duodenum.	M.C.	Mid-clavicular line.	T.	Intertubercular plane.
D.C.	Descending colon.	O.	Œsophagus.	T.	Tricuspid orifice.
E.I.	External iliac artery.	P.	Inguinal vertical line.	T.C.	Transverse colon.
H.	Heart.	P.	Pulmonary orifice.	U.	Umbilicus.
I.	Ileum.	P.C.	Pelvic colon.	V.	Ileo-colic valve.
I.C.	Subcostal plane.	Pl.	Pleura.		
Il.C.	Lower part of descending colon.	P.S	Parasternal line.		

lies immediately behind the duct. The *middle third* of the duct lies a little to the right of the gastro-duodenal artery behind the first part of the duodenum about two finger-breadths from the pyloro-duodenal junction. The *lower third* of the duct, which passes downwards and to the right, is intimately related to the back of the head of the pancreas; in about two out of three bodies it is so embedded in the substance of the gland that it cannot be freed by blunt dissection. Close to its termination the duct is joined by the main pancreatic duct, the two opening separately, but close together, into an *ampulla* which pierces the wall of the duodenum obliquely and opens on the summit of a small papilla situated at the middle of the medial wall of the second part of the duodenum. When a calculus becomes impacted in the ampulla there is retention of the pancreatic secretion as well as of the bile. Frequently, however, the pancreas has an accessory pancreatic duct which opens into the duodenum at a higher level than the main duct.

The surgeon may reach a calculus in the ampulla either by opening the duodenum from the front (trans-duodenal route) or by freeing the duodenum and gaining access to the bile-duct from behind (retro-duodenal route). In the latter instance an incision is made, lateral to the right border of the second part of the duodenum, through that portion of the peritoneum which passes upwards and to the right from the upper layer of the transverse mesocolon over the upper part of the second part of the duodenum on to the anterior surface of the right kidney. By blunt dissection directed medially behind the duodenum, the duodenum, along with the adjacent part of the head of the pancreas, can be separated from the kidney and vena cava, and folded over towards the left. As the bile-duct is freed from the back of the head of the pancreas a vein of considerable size will be encountered; this vein returns the blood from the pancreatico-duodenal system of arteries; it lies close to the bile-duct as it ascends behind the head of the pancreas to open into the commencement of the portal vein. Of the lymph-glands related to the bile-passages it is to be remembered that one lies at the neck of the gall-bladder, another at the junction of the cystic and hepatic ducts, while a third lies close to the termination of the bile-duct. When these glands are enlarged and indurated, care must be taken not to mistake them for impacted gall-stones. On account of the very free anastomosis between the lymph-vessels of the gall-bladder, bile-ducts, and pancreas, infective inflammatory processes readily spread from one organ to the other.

Stomach.—The stomach lies almost entirely in the left hypochondrium and in the left half of the epigastrium. The **cardiac orifice**, which is 2·5 cm. below and to the left of the œsophageal opening in the diaphragm, is about 10 cm. from the surface, and corresponds, on the anterior surface of the body, to a point over the seventh left costal cartilage 2·5 cm. from the median plane. The **pylorus** lies behind the quadrate lobe of the liver in the transpyloric plane, usually a little to the right of the median plane; when the stomach is *empty* the pylorus generally lies in the median plane, when *distended* it may reach 5 to 7·5 cm. to the right of the median plane. Passing from the upper to the lower border of the pylorus at its junction with the duodenum is the **prepyloric vein**. This vein is a useful visible guide to the position of the pylorus. Another guide is the ring-like thickening of the pyloric sphincter, which projects into the commencement of the duodenum and can be readily palpated through the duodenal wall. The highest part of the **fundus of the stomach** corresponds to the left vault of the diaphragm, and lies at the level of the fifth rib in the mid-clavicular line, a little above and behind the apex of the heart. The **greater curvature** crosses behind the left costal margin opposite the tip of the ninth costal cartilage. The lowest part of the great curvature, situated generally in the median plane, is a little above the level of the umbilicus. The **lesser curvature** and the adjacent part of the anterior wall of the stomach are overlapped by the left lobe of the liver.

Radiography of Stomach.—Radiographs taken after an "opaque meal" show that the form and position of the stomach in the living subject differ considerably from those which it presents in the cadaver—see also p. 620 and Pls. LII, LIII, LIV, pp. 609, 612, 613.

In the cadaver, owing to loss of muscular tone, the stomach presents itself as a more or less empty pear-shaped bag with collapsed and flaccid walls.

In the living subject, the form and position of the stomach are found to vary, not only according to the amount of food it contains, but also according to whether the patient occupies the erect or the recumbent posture (Fig. 530, p. 622). The most

the motor activity of the stomach is obtained by "screen" examinations and radiographs taken with the patient in the erect posture. When examined in that way after the stomach is partly filled with an "opaque meal", it is seen to have a distinctly J-shaped form (Pl. LII). The stem of the J, which represents the **body of the stomach**, lies immediately and entirely to the left of the vertebral column. The **fundus**, which is slightly more expanded than the body, reaches up to the left cupola of the diaphragm; it is represented in the radiograph as a dark semilunar area, the horizontal lower margin of which corresponds to the upper limit of the meal. That dark semilunar area is due to the presence of air which has been swallowed and which naturally rises to the highest part of the cavity. The **cardiac orifice** is seen to lie opposite the left side of the disc between the tenth and eleventh thoracic vertebræ. The shadow of the **pyloric portion of the stomach**, after crossing the left side of the vertebral column opposite the third and fourth lumbar vertebræ, ascends as the **pyloric canal** to join the duodenum to the right of the median plane opposite the second (not infrequently the third) lumbar vertebra. The **pylorus** itself is represented by a narrow streak of barium when the pyloric sphincter is contracted. The lowest portion of the **greater curvature**, which lies at or a little to the left of the median plane, reaches, in the erect posture, down to the level of the fourth lumbar vertebra or even lower.

As more food enters the stomach its capacity is increased by expansion of the organ and downward extension of its greater curvature. The normal tonic action of the gastric muscle is able to hold up the meal against the action of gravity to the level of the cardiac orifice. When, as not infrequently happens, the normal muscular tonicity of the stomach is lost, the barium is no longer held up against the action of gravity, but at once sinks to the most dependent part of the stomach, where it lies as in a flaccid sac, and gives rise to a crescentic shadow which may reach down almost, or even quite, to the level of the pubes.

In gastroptosis, and in general visceroptosis, the stomach may extend downwards without any great loss of its tonicity (Pl. LIV, Fig. 2, p. 613).

During a "screen" examination after an opaque meal, the peristaltic movements of the stomach can be seen to pass in distinct wave-like indentations from left to right along the greater curvature, and to increase in force as they approach the pylorus (Pl. LVI, p. 621). When the stomach is hypertrophied and dilated, as a result of pyloric obstruction, the peristaltic waves are at first more pronounced but in a short time they disappear and the organ takes on the atonic appearance described above. In the infant and young child the stomach is flask-shaped rather than fish-hook or J-shaped, and its axis is less vertical than in the adult (Pl. LV, Fig. 1, p. 620). The elongated form of the adult stomach is acquired as a result of the erect posture. Occasionally the axis of the adult stomach inclines more towards the horizontal and has a shape more like the horn of a steer (steer-horn stomach—Pls. LIV, Fig. 1, p. 613, and LV, Fig. 2).

It must be remembered that the only really fixed part of the stomach is the region of the cardiac orifice, and the form and position of the organ may therefore be considerably influenced by the condition of the neighbouring organs. For example, it may be displaced downwards and to the left by enlargement of the liver, upwards by distension of the intestines, and to the right by distension of the left colic flexure.

Ulcer of Stomach.—Perforation of an ulcer on the *anterior wall* of the stomach leads to extravasation into the greater sac of the peritoneum; and if the perforated ulcer is on the *posterior wall*, extravasation takes place into the lesser sac. The close relation of the splenic artery and its branches to the posterior wall of the stomach explains the severe hæmorrhage which is sometimes caused by a posterior gastric ulcer. The surgeon may reach the posterior wall of the stomach through the greater omentum near the stomach or, after throwing the greater omentum and transverse colon upwards, by traversing the transverse mesocolon; by the former route the posterior wall of the stomach is reached through the anterior wall of the lesser sac, by the latter through its posterior wall.

Operations on Stomach.—In partial resection of the stomach the main vessels are ligated at an early stage of the operation. The arteries are the right and left gastrics at the lesser curva-

ture, the gastro-duodenal behind the first part of the duodenum, and the right and left gastro-epiploics at the greater curvature. If the operation is for cancer, the left gastric is ligated as near the cardiac orifice as possible, in order that the whole chain of lymph-glands along the lesser curvature may be removed. The glands that lie behind the first part of the duodenum in relation to the gastro-duodenal artery and head of the pancreas also are removed, as well as those along the right half of the greater curvature in relation to the right gastro-epiploic artery. If the disease has spread to the retroperitoneal lymph-glands around the cœliac artery, *i.e.*, above the pancreas, the chances of a permanent recovery are very remote.

In the classical "no-loop" **gastro-enterostomy operation**, a longitudinal opening in the commencement of the jejunum is anastomosed by suture to an opening in the posterior wall of the stomach near the greater curvature. To bring the surfaces of the two organs in contact, surgeons are in the habit of protruding the posterior wall of the stomach through an opening made in the transverse mesocolon on the proximal side of the arch formed by the middle and left colic arteries. Another plan is to make an opening also into the lesser sac through the greater omentum a little below the gastro-epiploic vessels, and then to bring the jejunum into contact with the posterior wall of the stomach by drawing it (the jejunum) upwards through the opening in the transverse mesocolon. By that plan the posterior wall of the stomach along with the jejunum can be protruded through the opening in the greater omentum; they can then easily be delivered out of the abdominal cavity. Another advantage is that the transverse colon can be replaced into the abdominal cavity while the anastomosis is being made. When the posterior wall of the stomach and transverse colon are held down by adhesions, a long loop of jejunum is brought up in front of the greater omentum and transverse colon and anastomosed to the anterior wall of the stomach.

Duodenum.—The duodenum is the widest, thickest, and most fixed part of the small intestine. For descriptive purposes it is divided by anatomists into four parts. From the surgical standpoint it may with advantage be divided into a supracolic and an infracolic portion—above and below the attachment of the transverse colon. To expose the supracolic portion, the greater omentum and the transverse colon are pulled downwards; to expose the infracolic portion they are thrown upwards along with the transverse mesocolon.

The **first part** lies medial to the gall-bladder, overlapped by the quadrate lobe of the liver. As regards its **blood-supply**, it occupies the frontier zone between the cœliac and superior mesenteric vascular areas, and the vessels which supply it vary considerably in their size and mode of origin. The peculiarity of its blood-supply may partly account for the relative frequency with which that portion of the intestine is the seat of ulceration.

The first 2·5 cm. of the duodenum possesses some degree of mobility, being surrounded by the same two layers of peritoneum as invest the stomach. Beyond that it is in direct contact posteriorly and inferiorly with the pancreas, while descending behind it are the bile-duct and the gastro-duodenal artery. When an ulcer of the first part perforates, extravasation takes place, in the first instance, into the supracolic compartment of the peritoneum, thence into the recess between the liver and kidney, and subsequently down along the ascending colon into the right iliac fossa—hence the possibility of mistaking the condition for an acute appendicitis. Perforation of the ulcer into the peritoneal cavity is often prevented by the duodenum becoming adherent—especially to the pancreas, to the gall-bladder, or to the omentum.

If the finger is passed upwards, backwards, and to the left, immediately above the first part of the duodenum and behind the free border of the lesser omentum, it will pass through the opening into the lesser sac. Another method of finding the opening is to pass the finger along the under surface of the gall-bladder from the fundus towards the neck.

The **second part** of the duodenum descends from the neck of the gall-bladder to the level of the third lumbar vertebra. The transverse colon crosses it about its middle, while posteriorly it lies in front of the hilum and medial border of the right kidney, from which it is separated by loose areolar tissue. The procedure necessary to free that portion of the duodenum has been referred to already (p. 1499).

The **third part** of the duodenum crosses the inferior vena cava and the aorta about 2·5 cm. above a line joining the highest part of the iliac crests; the upper part of the right ureter is behind its commencement.

The **fourth part** ascends on the left psoas opposite the third and second lumbar vertebræ.

The X-ray shadow of the first part of the duodenum usually takes the

directed towards the pylorus (Pl. LII, p. 609). Owing to the fact that th opaque meal is held up for a short time in the cap, the shadow is denser than th caused by the other divisions of the duodenum, which are rapidly traversed by th meal; and as the first 2·5 cm. of the duodenum contains no circular folds of mucou membrane the outline of the cap is smooth and nearly symmetrical. In duoden ulcer the outline of the cap is generally distorted—owing partly to fibrosis an partly to the spasm which the ulcer sets up.

Duodeno-Jejunal Flexure.—This flexure is 2·5 cm. below the transpyloric plan and the same distance to the left of the median plane, and it is the landmark whic the surgeon makes for when he wishes to identify the commencement of the jejunu (Fig. 568, p., 669 and Pls. LIII, LIV, Fig. 1, p. 612). To find the flexure, the great omentum and the transverse colon are thrown upwards, and the finger is passed alon the lower layer of the transverse mesocolon to the left side of the vertebral column. Th flexure lies in the angle between the left psoas major and the inferior surface of the bod of the pancreas. With the finger in that angle the commencement of the jejunum ma be hooked forward a little to the left of the superior mesenteric vessels at the root the mesentery.

Peritoneal Recesses.—There may be one or more small peritoneal recesses in th neighbourhood of the end of the duodenum. The one that is surgically the mo important is the **paraduodenal recess**, which is a little to the left of the fourt part of the duodenum, with its mouth looking towards the right. An intern hernia may develop in it; and should strangulation occur, the incision to relieve is made in the lower margin of the mouth to avoid the inferior mesenteric vein, fo the vein first ascends in the peritoneal fold which forms the anterior margin an then curves medially in the upper margin (see also p. 632).

Jejunum and Ileum.—To expose the coils of the jejunum and ileum completel the greater omentum is turned upwards along with the transverse colon and th greater curvature of the stomach. On account of the oblique attachment of th mesentery, the greater number of the coils lie in the left infracolic peritone compartment, where they extend upwards to the left of the vertebral column a far as the attachment of the transverse mesocolon and the inferior surface of th pancreas; here they lie in front of the lower part of the left kidney, in the ang of the left colic flexure.

The only certain means which the surgeon has of distinguishing the uppe from the lower coils of small intestine is by their relation to the duodeno jejunal flexure and the ileo-cæcal junction. The lower coils of the ileum lie in th true pelvis, and the *terminal portion of the ileum*, which is attached by the lowes part of the mesentery to the floor of the right iliac fossa, crosses the brim of th pelvis, and ascends along the medial side of the cæcum to reach its openin into the large intestine. The terminal loop of the ileum may be hooked up b the finger passed along the medial side of the cæcum downwards over the media border of the right psoas major and the external iliac vessels into the true pelvis.

To bring out a loop of the upper jejunum in the operation of jejunostomy, the abdomen i opened through the left rectus muscle at the level of the umbilicus or a little above it. Th duodeno-jejunal flexure is then identified and a catheter is introduced into the jejunum, an the bowel itself is then sutured to the edges of the opening in the divided peritoneum.

The **diverticulum ilei**, which is due to persistent patency of the proximal portio of the vitello-intestinal duct, is situated on the anti-mesenteric border of the ileum, usuall from 60 to 90 cm. above the ileo-cæcal junction; its average length is 5 cm. Its termina tion is usually free, but it may be adherent either to the anterior abdominal wall, to th mesentery, or, more rarely, to one of the adjacent viscera. When its termination i fixed it may give rise to strangulation of the intestine.

Cæcum.—The cæcum occupies the right iliac region from the anterior superio iliac spine to the brim of the pelvis (Pls. LVII and LVIII, p. 648). **When empty**, it generally more or less completely overlapped by small intestine, and frequentl also by the greater omentum. **When partly distended**, the cæcum comes in contac with the anterior abdominal wall immediately above the lateral half of the in guinal ligament. **In the normal condition** it is completely clothed with peritoneun

and can, therefore, along with the vermiform appendix, be readily delivered out of the abdomen. In chronic constipation associated with intestinal atony, the cæcum is thin-walled and dilated; and stretching of its attachments to the posterior abdominal wall results in abnormal mobility so that it may sink into the pelvis and rest upon the pelvic floor.

The position of the **ileo-colic valve** corresponds, on the surface of the body, to the lower medial angle between the intertubercular and right vertical lines, and the orifice of the vermiform appendix is 2·5 cm. lower. It is to be noted that the lower end of the ileum protrudes into the cæcum, and that its circular muscular fibres are prolonged into the flaps of the ileo-colic valve. Both of those anatomical arrangements favour the occurrence of intussusception. In infants, other predisposing causes are: (1) the striking disproportion in size of the lumen of the large and small intestines; (2) the greater mobility of the cæcum; and (3) the frequent presence of a mesentery to the ascending colon.

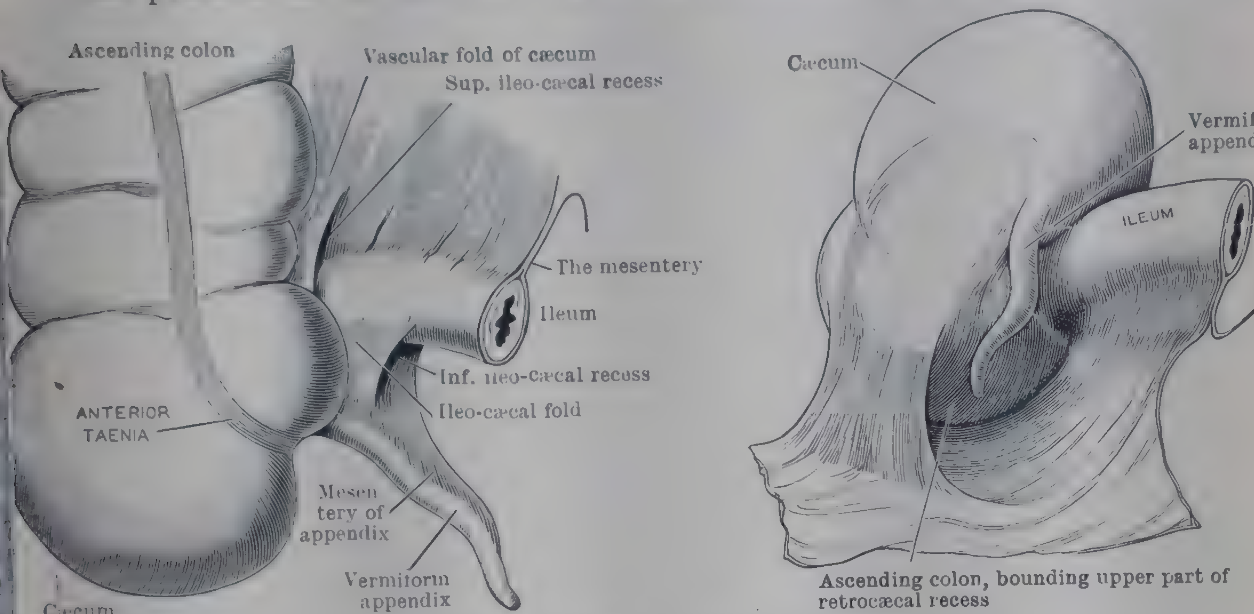

Fig. 1221.—Ileo-Cæcal Region and Recesses.

Vermiform Appendix (Pl. LVII, p. 648).—The vermiform appendix springs from the postero-medial aspect of the cæcum 2·5 cm. below the ileo-cæcal junction; and it is provided with a small but well-formed mesentery derived from the posterior layer of the lowest part of the mesentery of the ileum. That portion of the posterior layer of the mesentery sometimes develops a band-like thickening which, by dragging upon the lower end of the ileum, produces the kink to which attention was directed by Arbuthnot Lane. The vermiform appendix is supplied by one artery; it occupies the free border of its mesentery and gives off several branches to the organ. In amputating the vermiform appendix, the artery is ligated on the proximal side of its first branch in order to control the blood-supply to the stump of the appendix. The fact that the vermiform appendix is supplied by a single artery predisposes it to gangrene should the vessel become thrombosed, or should the circulation in it be interfered with as

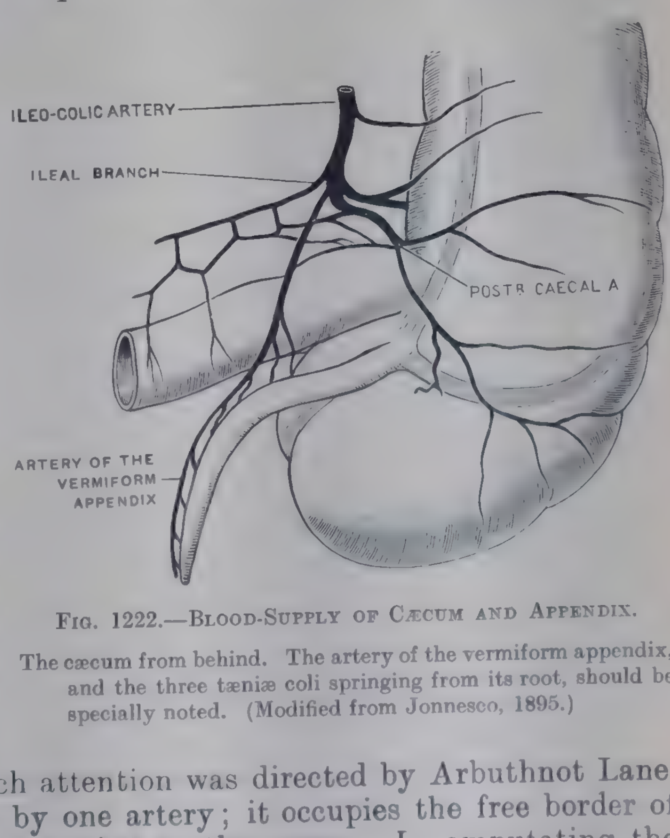

Fig. 1222.—Blood-Supply of Cæcum and Appendix.

The cæcum from behind. The artery of the vermiform appendix, and the three tæniæ coli springing from its root, should be specially noted. (Modified from Jonnesco, 1895.)

The vermiform appendix will generally be found to pass either upwar medially behind the lower end of the ileum, or downwards and medially ov external iliac vessels into the pelvis; less frequently it ascends in the recess the caecum (Fig. 1221). When an inflamed appendix occupies the last-men situation a retrocaecal abscess may result. The abscess may perforate the po wall of the caecum, or it may ulcerate through the posterior peritoneum; latter case the suppuration may spread upwards, in the loose, fatty extraper tissue behind the colon, into the lumbar and perinephric regions; and it may even the under surface of the diaphragm and form a subphrenic abscess. caecum remains undescended, the appendix lies in relation to the pyloro-du junction, the neck of the gall-bladder, and the lower half of the right k When it dips downwards into the pelvis it may become adherent to the colon, the rectum, or the bladder, or, in the female, to the uterine tube ovary.

To find the vermiform appendix, the caecum is pulled out of the wound, and if the p normal the appendix will be delivered along with it; but, if the caecum and appendix are down by adhesions, it is identified by following the anterior taenia coli to its root.

Ascending Colon.—The ascending colon, after crossing the iliac crest, l the fascia covering the quadratus lumborum and the adjacent aponeurotic or the transversus abdominis. Between the bowel and the fascia there is a qu of loose, fatty areolar tissue which may be the seat of an abscess; the source which such an abscess may arise are—(1) the ascending colon, (2) a ret vermiform appendix, (3) the right kidney. The areolar tissue is directly conti above with a thin layer that lines the lower surface of the diaphragm suppurative process may therefore extend upwards and give rise to a subp abscess. The ascending colon is occasionally completely clothed with perito and it may even be provided with a mesocolon. A mesocolon is almost inva present in infants who develop ileo-caecal intussusception; after the intussus has been reduced, the mesentery of the ileum is seen to be continuous, throu ascending mesocolon, with the transverse mesocolon.

In order to resect the caecum and ascending colon, the surgeon frees them by divid peritoneum along its line of reflexion from the colon on to the side-wall of the ab The colon, along with the posterior peritoneum medial to it, is then stripped, fr lateral side towards the median plane, off the quadratus lumborum, the psoas, and th part of the right kidney. While that is being done, the branches of the ileo-colic an colic vessels, which pass laterally to supply the gut, are secured, and the lymph-vess associated lymph-glands are removed along with the bowel. As the peritoneum is strip care must be taken not to injure the important structures which lie behind it, name duodenum, the ureter, and the testicular or ovarian vessels.

The **right colic flexure** lies between the lower part of the right kidne the liver, immediately to the right of the gall-bladder, opposite the tenth cartilage—just below the level of the transpyloric plane. It is separated fro kidney by a quantity of loose areolar tissue; therefore, after the peritoneum its right side is divided, it is an easy matter to dissect it from the kidney.

Transverse Colon.—The transverse colon crosses the abdomen immed above the level of the umbilicus and below the greater curvature of the st (Pls. XLVIII, p. 538, LVII and LVIII, p. 648). In cases of visceroptosis i form a U-shaped or V-shaped loop that extends down to the level of the pub

The transverse colon receives its blood-supply from the arch formed b middle and left colic arteries. The arch lies in the posterior wall of the sac between the two layers of the transverse mesocolon.

In resecting portions of the stomach for malignant disease, the surgeon removes the which lie in the greater omentum in relation to the right gastro-epiploic vessels. At th of the operation care must be taken not to endanger the blood-supply of the transvers by injury to the middle colic artery.

The **left colic flexure** is more acute and more fixed than the right flexure it is at a higher level as well as deeper. A tumour that originates in the f is generally under cover of the left costal margin, and it is therefore diffic palpate it.

To expose the left colic flexure, the omentum is turned upwards along with the transverse olon and the body of the stomach. To free it for the purpose of resection, the surgeon must vide: (1) the phrenico-colic ligament, which attaches it to the diaphragm opposite the eleventh b; (2) the left border of the greater omentum, which attaches it to the stomach; and (3) the ft portion of the transverse mesocolon, which attaches it to the pancreas.

Descending Colon.—The *upper part* of the descending colon, like the ascend-ng, is deeply placed in the lumbar region and is related to the lower half of the teral border of the left kidney. It is less frequently provided with a mesocolon han is the ascending colon.

The *lower part* (iliac colon) begins at the iliac crest, and ends at the inlet f the pelvis by joining the pelvic colon. It has no mesocolon, and is connected the fascia covering the iliacus and psoas major muscles by loose areolar tissue. owards its termination it turns medially immediately above and parallel to the guinal ligament, and at its junction with the pelvic colon it lies in front of the sticular (or ovarian) and external iliac vessels. Although, as a rule, it is entirely verlapped by coils of small intestine, it can frequently be felt by firm palpation at e lateral part of the left iliac fossa, because its muscular wall is comparatively hick and generally is contracted.

Pelvic Colon (Pls. LVII and LVIII, p. 643).—The pelvic colon, in con-equence of having a well-developed mesocolon, is a freely movable loop which, hough usually confined to the true pelvis, may, when distended, rise well up into e abdomen. It is the section of the large intestine which is opened for the urpose of making an artificial anus in malignant disease of the rectum.

The pelvic colon varies considerably in length, the average being 40 cm. It is latively longer and of greater calibre in the child than in the adult. It is the part the large intestine especially involved in the condition known as **megalocolon**—a ngenital abnormality in which the large intestine is greatly dilated and its walls ypertrophied.

When the pelvic colon is thrown upwards and to the right, its mesocolon is read out and is seen to be attached in an inverted V-shaped manner to the sterior wall of the pelvis. At the apex of the Λ there is occasionally a small ritoneal pouch, called the **recess of the pelvic mesocolon**, situated in front of the eter as it crosses the termination of the common iliac artery to enter the pelvis. hat recess is one of the situations at which an internal retroperitoneal hernia ay originate. The mouth of the recess looks downwards and to the left, while ove and to its right there is a branch of the lower left colic artery. The recess a guide to the position of the left ureter (p. 647).

It is to the proximal part of the pelvic colon that the divided lower end of the um is anastomosed in the short-circuiting operation of **ileo-sigmoidostomy**.

In the operation of transplanting the ureters into the large intestine r incontinence of urine—the result of epispadias in the female, and of ectopia sicæ in either sex—the left ureter is implanted into the proximal part of the lvic colon and the right ureter into its distal part.

In the operation of abdomino-perineal excision of the rectum, division of the achments of the pelvic mesocolon is the first step. The colon is then divided; its oximal end is brought out through a small opening in the left iliac fossa (*colostomy*); distal segment is passed through the floor of the pelvis, and removed with the tum by a perineal incision. Further, the mobility of the pelvic colon is such that er the whole descending colon is resected and the left colic flexure is freed, the vided ends of the bowel can be sutured together without undue tension.

Kidneys.—The kidneys lie behind the peritoneum; they are higher up than often supposed, and they are not so far away from the vertebral column as is en depicted; hence it is that, unless enlarged, the kidneys can seldom be felt rough the abdominal wall. The right kidney as a rule is a little lower than left, as well as a little farther away from the median plane. The hilum of the ht kidney is 5 cm. from the median plane; that of the left rather less. For actical purposes the **hilum** of the kidney may be regarded as opposite a point the anterior abdominal wall a finger's breadth medial to the tip of the ninth

Fig. 1223.—Anterior Aspect of Trunk, showing Surface Topography of Viscera.

A.	Ascending aorta.	L.U.	Left ureter.	Q.L.	Quadratus lumborum.
A′.	Descending aorta.	M.C.	Mid-clavicular line.	R.K.	Right kidney.
C.I.	Common iliac artery.	O.	Œsophagus.	R.L.	Right lung.
D.	Duodenum.	P.	Inguinal vertical plane.	R.U.	Right ureter.
E.I.	External iliac artery.	Pa.	Pancreas.	Sp.	Spleen.
I.C.	Subcostal plane.	Pl.	Pleura.	S.R.	Suprarenal gland.
I.V.C.	Inferior vena cava.	P.S.	Parasternal line.	T.	Intertubercular plane.
L.K.	Left kidney.	Ps.	Psoas major.	T.	Trachea.
L.L.	Left lung.	Py.	Transpyloric plane.	U.	Umbilicus.

first and second lumbar vertebræ—that is, a little below the transpyloric line. The position of the other parts can be judged from the situation of the hilum.

A great part of the upper half of the anterior surface of the **right kidney** is covered with peritoneum and can be felt by the hand passed upwards behind the right lobe of the liver and pressed backwards. Its lower half is felt immediately below the right lobe; and the small part of it that is covered with peritoneum lies in the angle of the right flexure of the colon. The second part of the duodenum overlaps the medial border. When the right kidney is excised by the abdominal route, the peritoneum is divided lateral to the ascending colon and right colic flexure, and these structures, along with the second part of the duodenum, are stripped off the organ in a medial direction, until the hilum and the renal vessels are exposed.

The **left kidney** is crossed transversely, about its middle, by the body of the pancreas and the splenic vessels. To palpate the suprapancreatic portion, the

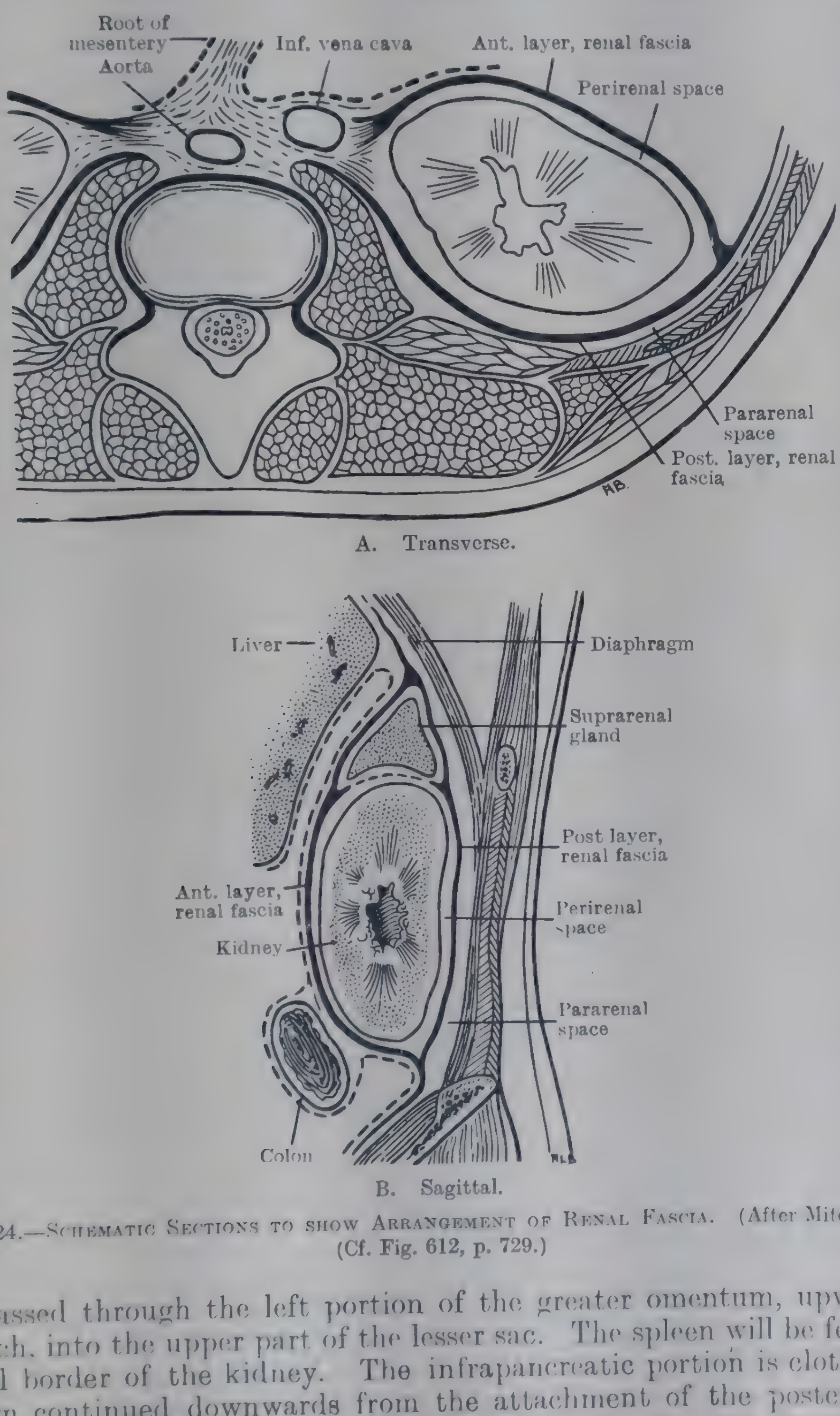

Fig. 1224.—Schematic Sections to show Arrangement of Renal Fascia. (After Mitchell, 1950.) (Cf. Fig. 612, p. 729.)

hand is passed through the left portion of the greater omentum, upwards behind the stomach, into the upper part of the lesser sac. The spleen will be felt to overlap the lateral border of the kidney. The infrapancreatic portion is clothed with the peritoneum continued downwards from the attachment of the posterior layer of the transverse mesocolon; coils of jejunum overlie it; the descending colon may overlap its lateral border; and, underneath the peritoneum, it is crossed by

branches of the upper left colic vessels. To palpate this part of the left kidney the hand is passed deeply into the upper part of the left infracolic peritoneal compartment as far as the angle of the left flexure of the colon, and pressed backwards. When the left kidney is excised by the transperitoneal route, the surgeon frees the left colic flexure and the descending colon by dividing the peritoneum, and he chooses the lateral side in order to avoid the branches of the left colic artery.

The kidney is surrounded by a variable quantity of **renal fat**, and is enclosed with its fat in an ill-defined sheath of **renal fascia**. The sheath is a continuation of the fascia transversalis. At the lateral margin of the kidney the fascia splits into two layers (anterior and posterior renal fasciæ). The anterior layer passes in front of the kidney and merges into the mass of connective tissue that surrounds the great vessels, while the posterior layer passes behind the kidney, blends with the fascia of the psoas, and is attached to the intervertebral discs close to the medial border of that muscle (Mitchell, 1950). The two layers remain separate for some distance, or are only weakly united, below the kidney, and it is int[o] that downward extension of the fascial compartment that the kidney descend[s] in the condition known as **movable kidney**. The posterior layer also fuses with the connective tissue around the aorta and inferior vena cava: and the attachment of both layers around these vessels forms a kind of septum which prevents a perinephric abscess from extending across the median plane to the opposite side (see also p. 728) The suprarenal gland is enclosed in the renal fascia, separate from the kidney by a thin fascial lamina only, and above the gland the two layers are firmly united to each other and to the diaphragmatic fascia (Fig. 1224). Fat lying between the renal fascia and the kidney is described as *perirenal fat*, and outside the renal fascia there is a second layer of fat sometimes spoken of as the *pararenal fat.*

The lower pole of the kidney may receive a special blood-supply either directly from the aorta or from the renal artery.

The branches of the renal artery are distributed to the cortex of the kidney in an anteri[or] and a posterior group; therefore, in splitting the kidney substance to reach the pelvis of th[e] ureter, the incision is made along the frontier line between the two vascular areas, viz., abo[ut] 1·3 cm. behind and parallel to the lateral border of the kidney.

Ureters.—Each ureter is about 25 cm. in length. It lies behind the peritoneum on the psoas major muscle, and it descends almost vertically about 4 cm. from th[e] median plane. At the level of the pelvic brim it crosses the origin of the extern[al] iliac artery and then passes backwards and downwards into the true pelvis in fro[nt] of the internal iliac artery.

The diameter of the ureter is not uniform. Its intravesical portion has th[e] smallest lumen, and it is there that calculi are most likely to become impacte[d]. A second narrowing occurs at or a little below the origin of the ureter proper fro[m] its pelvis, and a third where it crosses the brim of the pelvis.

The ureter has a fairly thick muscular wall, and its rich blood-supply favou[rs] rapid healing. Its abdominal portion is supplied by the renal and testicular (or ovarian) arteries; its pelvic portion by the vesical and the middle rectal arteries. B[y] their anastomoses they form a continuous and slightly tortuous chain which [is] generally visible through the peritoneum along the whole course of the tube.

The outline of the pelvis of the ureter and the relations of it and of the uret[er] proper to the skeleton may be demonstrated by X-rays after injection of the lum[en] by a radio-opaque fluid such as sodium iodide ("*retrograde pyelography*", Pl. LX[X], p. 744).

Similar but less well-defined appearances are obtained by the intraveno[us] injection of a radio-opaque substance excreted by the kidneys ("*excreti[on] urography*" or "*descending pyelography*", Pl. LXXI, Fig. 1, p. 745)—see p. 155[…]

The shape of the normal pelvis of the ureter and the arrangement of [the] major and minor calyces vary considerably (Pls. LXX, LXXI). The shadow[s] opposite the tips of the transverse processes of the first and second lumbar verteb[ræ] —the upper calyces generally overlapping a portion of the twelfth rib.

The radiographic shadow produced by an opaque catheter in the ureter crosses the tips of the transverse processes of the lumbar vertebræ and then descends to a point opposite the lower end of the sacro-iliac joint; from there the shadow descends with a curve, almost parallel to the shadow of the side of the pelvic brim, and ends opposite a point a little above and medial to the pubic tubercle. Laterally the shadow reaches almost to that caused by the ischial spine (Fig. 1225). The ureter is occasionally double throughout, or it may be bifid above or below. When the kidney is prolapsed, the abdominal portion of the ureter acquires a tortuous outline.

Normally the pelvis of the ureter can contain about 7 c.c. of fluid without discomfort to the patient. Its wall, like that of the ureter proper, is very distensible; it is therefore capable of great expansion in cases of gradually increasing urinary obstruction (hydronephrosis); and, for the same reason, incisions into these structures heal rapidly because the edges of the wound fall into apposition. To avoid branches of the renal vessels, incisions into the pelvis of the ureter are made horizontally through its posterior wall.

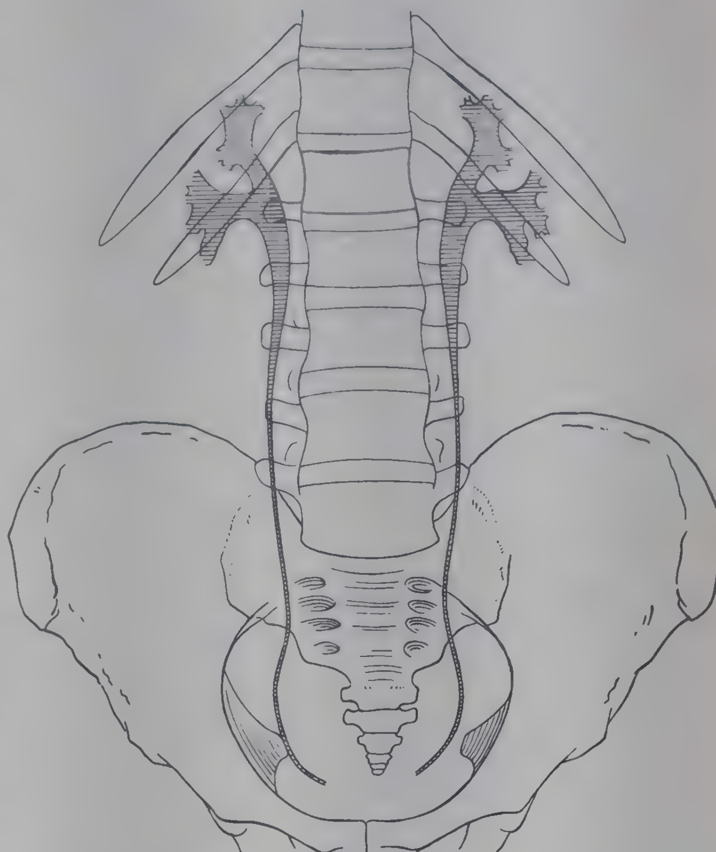

Fig. 1225.—Outlines of Pelves of Ureters and of Ureters proper in relation to the Skeleton. (Drawn from radiograph; cf. Pls. LXX, LXXI, p. 744.)

Pancreas.—The *head of the pancreas* occupies the curve of the duodenum and is at the level of the second lumbar vertebra. The *neck* is opposite the first lumbar vertebra, in the transpyloric plane, and the body lies partly above that plane. The relations of the pancreas to the transverse mesocolon and to the neighbouring viscera have been sufficiently referred to already.

After opening the abdomen in the median line, the pancreas is exposed by passing through the greater omentum near the greater curvature of stomach. Access to the organ through either the lesser omentum or the transverse mesocolon is more limited and therefore less satisfactory.

A pancreatic cyst gives rise to a tumefaction of the abdomen either in the epigastrium or in the umbilical region, depending on whether it pushes the lesser omentum before it and develops between the liver and stomach, or whether it extends forwards below the stomach. In severe contusions of the abdomen the pancreas may be ruptured against the vertebral column.

Vessels of Abdomen.—The commencement of the **abdominal aorta** and the **cœliac artery** are situated one finger's breadth above the transpyloric plane. The **abdominal aorta** bifurcates a little to the left of the median plane, on a level with the highest part of the iliac crest, and about 1·3 cm. below the level of the umbilicus.

The **inferior vena cava** lies immediately to the right of the aorta; its most important surgical relation is the right ureter, which is to the right of it and may lie close to its right side.

The **common** and **external iliac arteries** may be mapped out by a line drawn, with a slight lateral curve, from a point opposite the bifurcation of the aorta to the mid-inguinal point; the upper third of the line corresponds to the common iliac artery, the lower two-thirds to the external iliac.

In ligaturing the lower part of the common iliac artery or the upper part of the exter iliac, the close relation of the ureter and the ovarian vessels must be remembered: in ligat of the lower part of the external iliac in the male, the testicular vessels and the vas defer have to be avoided.

The common **iliac veins** lie in a plane posterior to their arteries; but the l vein, as it crosses the fifth lumbar vertebra, is also below and to the right of artery, and it ends behind the right artery by uniting with the right vein form the inferior vena cava.

The fact that the end of the left common iliac vein is *behind* the right comm iliac artery has long been regarded as a sufficient explanation for the greater f quency with which thrombosis of the femoral vein is met with on the left side th on the right: but a probable contributory factor is the close relation of the colon the left external iliac vessels, for a loaded colon, exerting pressure on them, m retard the blood-flow in the vein.

The great vessels on the posterior abdominal wall, along with the adjace lymph-vessels and lymph-glands, lie in the extraperitoneal fat, and therefore witl the general fascial envelope of the abdomen. Abscesses which originate from retroperitoneal lymph-glands are, therefore, like perinephric abscesses, extrap toneal but intrafascial; abscesses of vertebral origin, whether lumbar, iliac, psoas, are extrafascial. Abscesses connected with the vermiform appendix primarily intraperitoneal; occasionally they ulcerate through the parietal pe toneum and burrow in the extraperitoneal fat.

MALE PERINEUM AND PELVIS

The male perineum is a heart-shaped space, the osseous boundaries of which the same as those of the outlet of the pelvis. A line drawn transversely across perineum between the anterior part of the tuberosities of the ischium crosses median plane immediately in front of the anus and divides the space into anterior or urogenital triangle and a posterior or anal triangle.

Urogenital Triangle.—This triangle is divided into a superficial and a d compartment or pouch by the perineal membrane.

The **superficial perineal pouch** contains the root of the penis, which gives rise a longitudinal fullness on the surface. Anteriorly, the surface of the triangle continued on to the scrotum, while on each side a distinct groove separates it fr the medial surface of the thigh. The **perineal body** (central point) is the comm tendon of the perineal muscles, mingled with fat and continuous with the mid of the posterior border of the perineal membrane: it lies a finger's breadth front of the anus. In front of it, about 2·5 cm. from the centre of the anus the posterior end of the **bulb of the penis.**

The pouch is bounded below by the membranous layer of the superficial fas which is attached posteriorly to the posterior border of the perineal membrane on each side to the margin of the pubic arch. Anteriorly the membranous fa passes on to the scrotum, the penis, and spermatic cord, to become continuous w the membranous layer of the superficial fascia on the front of the abdomen.

When the urethra is ruptured distal to the perineal membrane, the course infiltration of the extravasated urine is determined by the attachments of membranous layer of fascia; at first, therefore, the urine is confined within superficial pouch, but it gradually travels forwards on to the lower par the anterior abdominal wall; it is prevented from passing into the front of thigh by the attachment of the membranous fascia of the abdomen to the fa lata a little distal to the inguinal ligament.

The **deep perineal pouch** is the interval between the perineal membrane the fascia of the pelvis. The most important structures in the pouch are membranous part of the urethra surrounded by its sphincteric muscle, the bu urethral glands, the dorsal nerve of the penis, the internal pudendal vessels, the artery to the bulb.

The **membranous part of the urethra** lies 2·5 cm. behind the lower border of pubic symphysis. When that portion of the urethra is ruptured, the extravas

urine, after filling the deep pouch, may reach the superficial pouch by bursting through the perineal membrane where the vessels pierce it; or it may penetrate the fascia of the pelvis, infiltrate the perivesical areolar tissue and the retropubic space, and ascend on the anterior abdominal wall between the fascia transversalis and the parietal peritoneum.

The **bulbo-urethral glands** lie immediately behind the membranous part of the urethra, separated from the bulb of the penis by the perineal membrane. The **internal pudendal vessels** and the **dorsal nerve** lie just within the margin of the pubic arch. The **artery to the bulb** runs transversely and medially 0·5 cm. in front of the posterior border of the perineal membrane.

Male Urethra.—The male urethra measures about 20 cm. from the external to the internal orifice; the narrowest point is at the external orifice; a second narrowing occurs at the perineal membrane. It is behind these narrow points that a calculus is apt to become impacted. The *most dependent part* of the urethra is the portion in the bulb, and it is there that stricture is most frequently encountered. The membranous part of the urethra, situated between the perineal membrane and the fascia of the pelvis, is surrounded by the sphincter urethræ muscle, which, when thrown into spasm, may firmly grip an instrument as it is passed into the bladder. *Rupture of the urethra* from a fall on the perineum generally involves the portion in the bulb. A *false passage* made during the passage of an instrument generally traverses the floor of the urethra at the perineal membrane; to prevent that injury the point of the instrument is directed upwards, and at the same time the handle is depressed as soon as the instrument is felt to encounter the resistance of the perineal membrane. When the *prostate is hypertrophied* the prostatic part of the urethra is elongated, and its internal orifice may look directly forwards; and if the lateral lobes are unequally enlarged it may deviate to one side. Patients with prostatic hypertrophy are seldom able to empty the bladder completely, on account of the dependent well which is formed behind the enlarged middle lobe.

From the clinical point of view surgeons speak of an "anterior urethra", situated distal to the membranous portion, and a "posterior urethra", situated proximal to it. The anterior urethra is the least sensitive portion of the canal, but the posterior urethra is highly sensitive and more vascular; and when its mucous membrane is injured toxic agents may be rapidly absorbed by the abundant blood-vessels and lymph-vessels of its submucous tissue. The anterior urethra is shut off from the posterior urethra by the tonic contraction of the sphincter urethræ muscle.

Viewed with an endoscope the mucous membrane of the anterior urethra is seen to be smooth and glistening and to have a pale yellowish-pink colour. The mucous membrane of the posterior urethra is of a redder colour. The opening of the prostatic utricle is seen as a small slit-like orifice on the most prominent part of the urethral crest, while immediately on each side of it is the minute orifice of the ejaculatory duct. In the floor of the sulcus on each side of the crest are the minute openings of the majority of the prostatic ducts.

Cystoscopic Examination of Bladder.—In a cystoscopic examination of the bladder special attention is paid to the **trigone**, as most of the pathological lesions are associated with that region. The **internal urethral orifice** is at its inferior angle: and at its supero-lateral angles there are the small oblique, slit-like **orifices of the ureters**, each surrounded by a very slight lip-like elevation of the mucous membrane. At the base of the trigone the mucous membrane is raised into a smooth *transverse ridge* which stretches between the ureteric openings with a slight forward convexity. The ridge is caused by a bundle of transverse muscular fibres continuous with the longitudinal fibres of the ureters. The distance of the ureteric orifices from each other is rather more than 2·5 cm., and their distance from the internal urethral orifice is slightly less than 2·5 cm.

The urine is ejected into the bladder intermittently at intervals of a minute or so. During each ejection the ureteric orifice is seen to pucker up, and, as it relaxes the gush of urine takes place in the form of a characteristic whirl "resembling an injection of glycerine into water". The **mucous membrane** of the trigone is closely connected with the subjacent muscular wall, and is therefore smooth; whereas

over the rest of the bladder it is thrown into folds owing to the looseness of the submucous tissue. Further, the mucous membrane of the trigone has a pink tinge, while over the rest of the bladder it is of a pale straw colour. This contrast is due to the difference in the number and arrangement of the blood-vessels. Over the trigone they are larger, more numerous, and form so close a network that, when the surface is inflamed, the dilated, congested vessels form a continuous vascular layer. Over the rest of the bladder one sees, here and there in the mucous membrane, small segments of fine vessels giving off a cluster of short branches, the finer anastomoses of which are not visible when the mucous membrane is healthy.

The form and shape of the trigone in women may be distorted by prolapse of the bladder, by alterations in the size and position of the cervix uteri, and by the presence of fibroids. In the male, distortion is usually due either to the enlargement of the prostate or to disease of the seminal vesicles.

When the normal bladder is comfortably filled, the bladder walls appear almost smooth, but when the bladder contracts the delicate muscular trabeculæ become visible through the mucous membrane. When the bladder is hypertrophied as the result of urethral obstruction the muscular trabeculæ become greatly hypertrophied, and stand out prominently, even when the bladder is full. The spaces between the trabeculæ may become so deeply pitted as to lead to the formation of little pockets known as **false diverticula**.

Prostate.—With the body erect the **base** of the prostate is in a horizontal plane at the level of the middle of the pubic symphysis, while its **apex** is 1·3 cm. behind and below the lower border of the symphysis. It follows, therefore, that the vesical orifice and the base of the prostate are within easy reach of the finger introduced through a suprapubic cystotomy-incision. The **anterior surface** of the prostate is about 2 cm. behind the pubes, to which it is connected by the pubo-prostatic ligaments. Above those ligaments is the *retropubic space*, occupied by fatty tissue which passes upwards in front of the anterior wall of the bladder, between the umbilical arteries, as far as the umbilicus, while laterally it extends on each side, between the peritoneum and pelvic fascia, as far back as the internal iliac arteries. The **posterior surface** of the prostate is related to the part of the rectal ampulla immediately above the anal canal, and is therefore accessible to palpation *per rectum*. Between the rectum and the posterior part of the fascial sheath of the prostate there is a layer of loose areolar tissue which is taken advantage of in the operation of excision of the rectum and when the posterior surface of the prostate is exposed in the operation of perineal prostatectomy. The areolar tissue between the rectum and the prostate is traversed by a fibrous sheet, called the *recto-vesical septum*, which extends in a coronal plane from the floor of the recto-vesical pouch of peritoneum to the perineal body and is the remains of the walls of the lower part of the recto-vesical pouch, which originally extended down behind the prostate. The **lateral surfaces** of the prostate cannot be felt through the rectum; they are related to the anterior parts of the levatores ani, from which they are separated only by the fascial sheath of the gland.

The *prostatic substance* is made up of branching tubular glands supported by a fibro-muscular stroma. The gland tissue is most abundant in the posterior and lateral parts of the organ; anteriorly the stroma is more abundant and extends backwards from the capsule to the urethra to form a sort of anterior commissure. By the term "*capsule*" of the prostate is understood the immediate or proper envelope of the gland; that envelope consists of parallel layers of fibro-muscular tissue continuous with the stroma of the organ and forming part of it. In some instances it is so thin that the gland tissue reaches almost to its surface, while in other instances it is so thick as to deserve to be regarded as the cortical portion of the gland. By the term "*sheath*" of the prostate is meant the fibrous envelope derived from the pelvic fascia; the veins of the *prostatic plexus* lie between the lamellæ of the sheath.

In what is known as "**senile**" **hypertrophy** of the prostate the organ may be uniformly enlarged, or the enlargement may affect chiefly one or other of the lateral lobes, or the posterior lobe, which may project into the bladder. The intravesical overgrowth may take the form of a more or less pedunculated projection, situated behind the internal

urethral orifice, or it may surround the orifice as a prominent ring-like elevation. As the intravesical growth enlarges, it makes its way towards the bladder within the ring of the sphincter vesicæ, and, having pushed the internal longitudinal fibres of the bladder before it or having separated them, it comes ultimately to be separated from the cavity of the bladder by mucous membrane only. In the operation of *suprapubic prostatectomy* the surgeon tears through the mucous membrane that overlies the prostate at its highest point. His finger then finds the plane of separation between the true capsule and the

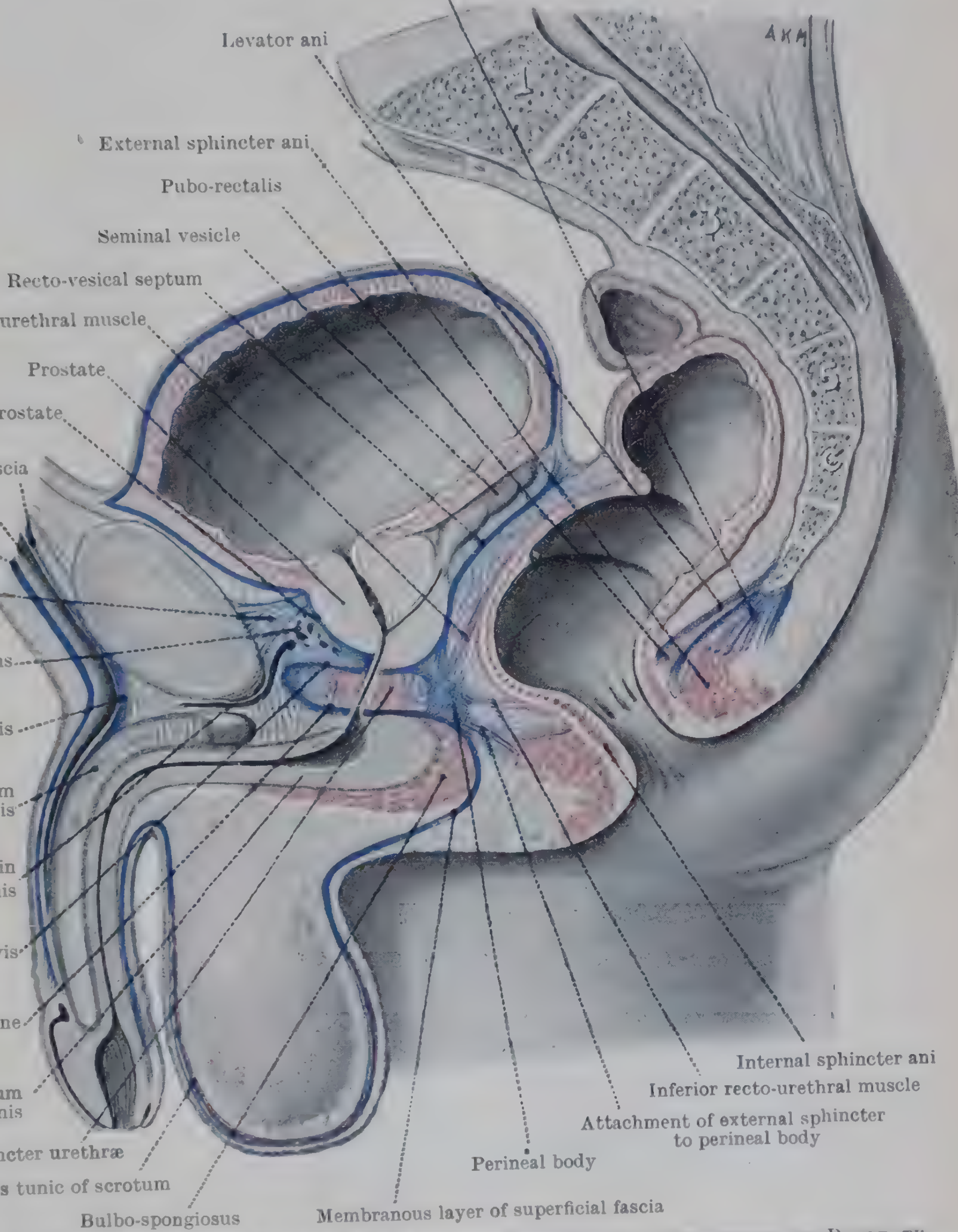

FIG. 1226.—SAGITTAL SECTION OF MALE PELVIS SHOWING POSITION AND RELATIONS OF PROSTATE.
The fascial structures are coloured blue.

hypertrophied tissue of the gland and completes the enucleation of the gland. As the sheath is markedly thicker and denser in the hypertrophied than in the normal prostate, the enucleation can be accomplished without injuring the veins of the prostatic plexus, for they are protected by such of the outer fibres of the capsule as may be left behind. The cavity, left behind after removal of the prostate, contracts at once owing to the natural shrinking of the fascial sheath and approximation of the bladder, rectum, and the two levatores ani at the sides.

In *perineal prostatectomy* the posterior surface of the prostate is exposed through a horseshoe-shaped incision whose convexity reaches forwards to a point immediately behind the bulb; at the sides, the incision sinks into the ischio-rectal fossæ, its extremities ending at the anterior part of the ischial tuberosities. After reflexion of the skin and

subcutaneous tissue, the incision is carried through the perineal body. The bulb, the superficial transverse perineal muscles, and the perineal membrane are then drawn forwards, and the fibres of the recto-urethral muscle (which connect the anterior wall of the rectal ampulla with the sphincter urethræ) are divided; that allows the anal canal and the lower end of the rectum to be pulled backwards. The dissection is now carried in a forward direction, between the anterior borders of the levatores ani, towards the prostate, so as to strike the loose non-vascular tissue which intervenes between the posterior part of the prostatic sheath and the thin fascia outside the muscular coat of the rectum. The posterior surface of the prostate is reached through an incision in its fascial sheath. The prostate, along with its capsule and the urethra, may either be enucleated entire from the sheath, or the capsule may be incised as well as the sheath, and the adenomatous masses removed separately. The operation is greatly facilitated if the prostate is pulled down into the wound by a special retractor inserted into the bladder through a median incision into the floor of the membranous part of the urethra.

In *retropubic prostatectomy* (Millin, 1947), the prostate is approached through a suprapubic incision, the bladder being displaced downwards and backwards. The anterior and lateral aspects of the prostate are displayed. In turn, the prevesical fascia, the true capsule of the prostate and the false capsule are incised. This exposes the adenomatous mass, which is enucleated by dissection with a finger. The incisions in the true capsule and in the prevesical fascia are then closed by suture.

Epididymis, Spermatic Cord, and Scrotum.—The **epididymis**, which can be felt as an elongated curved body applied vertically to the posterior margin of the testis, is especially involved in gonorrhœal and tuberculous infections. Occupying the posterior part of the spermatic cord is the **vas deferens**, which, when grasped between the finger and thumb, feels like a piece of whip-cord. The testicular veins form a **pampiniform plexus** in the substance of the cord; a varicose condition of these veins is known as *varicocele*. Besides the testicular artery, the testis receives its blood-supply from the artery to the vas deferens and the artery to the cremaster muscle. The marked swelling which attends *œdema and hæmatoma of the scrotum* is due to the loose and delicate character of the areolar tissue which intervenes between the dartos muscle and the subjacent external spermatic fascia.

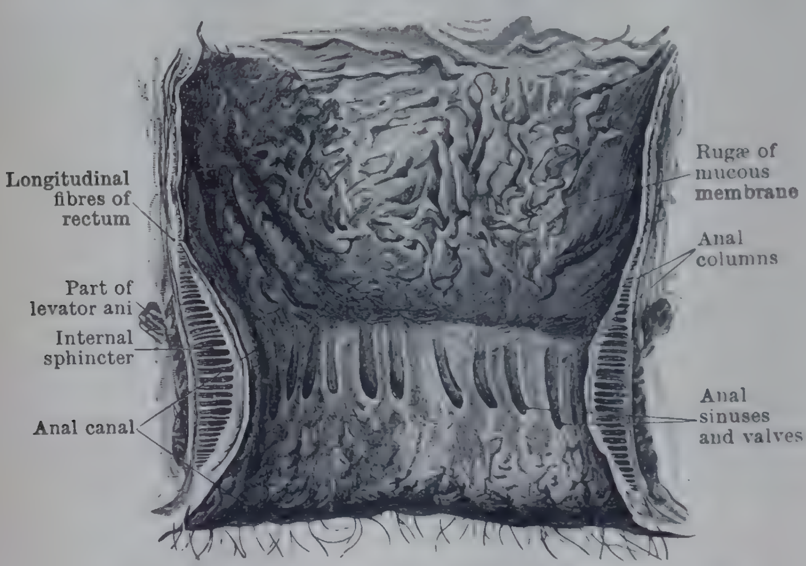

FIG. 1227.—INTERIOR OF ANAL CANAL AND LOWER PART OF RECTUM.

The anal columns were more numerous in this specimen than usual.

Anus and Anal Canal.—The **anus** is situated about 4 cm. in front of and below the tip of the coccyx. The skin around the orifice is pigmented and thrown into radiating folds. The painful linear crack or ulcer, known as *fissure of the anus*, generally occupies one of the furrows at the posterior margin of the anus. The skin of the anus is provided with large sebaceous and sweat glands which are occasionally the site of small and very painful *anal abscesses*.

In a *rectal examination* the finger, before it reaches the cavity of the rectum traverses the **anal canal**. That canal is directed from below upwards and forward from the anal orifice to the ampulla of the rectum and is about 3·5 cm. in length.

Internal haemorrhoids are developed from the veins in the upper part of the anal canal and invest 2·5 cm. of the rectum. The first to appear (*primary haemorrhoids*) are in association with the veins accompanying the three terminal branches of th

superior rectal artery: therefore they occupy left lateral, right postero-lateral and right antero-lateral positions on the circumference of the anus.

In the upper half of the anal canal the mucous membrane is thrown into longitudinal ridges called *anal columns*. At the lower end of the grooves between the columns there are little flaps, called *anal valves*, which bound small pockets called the *anal sinuses* (Fig. 1227). Fissure of the anus is generally caused by the tearing downwards of an *anal valve* during the passage of a scybalous mass.

Ischio-Rectal Fossa (Fig. 1228).—The apex of the **ischio-rectal fossa** is at the origin of the levator ani from the obturator fascia; it is directed upwards

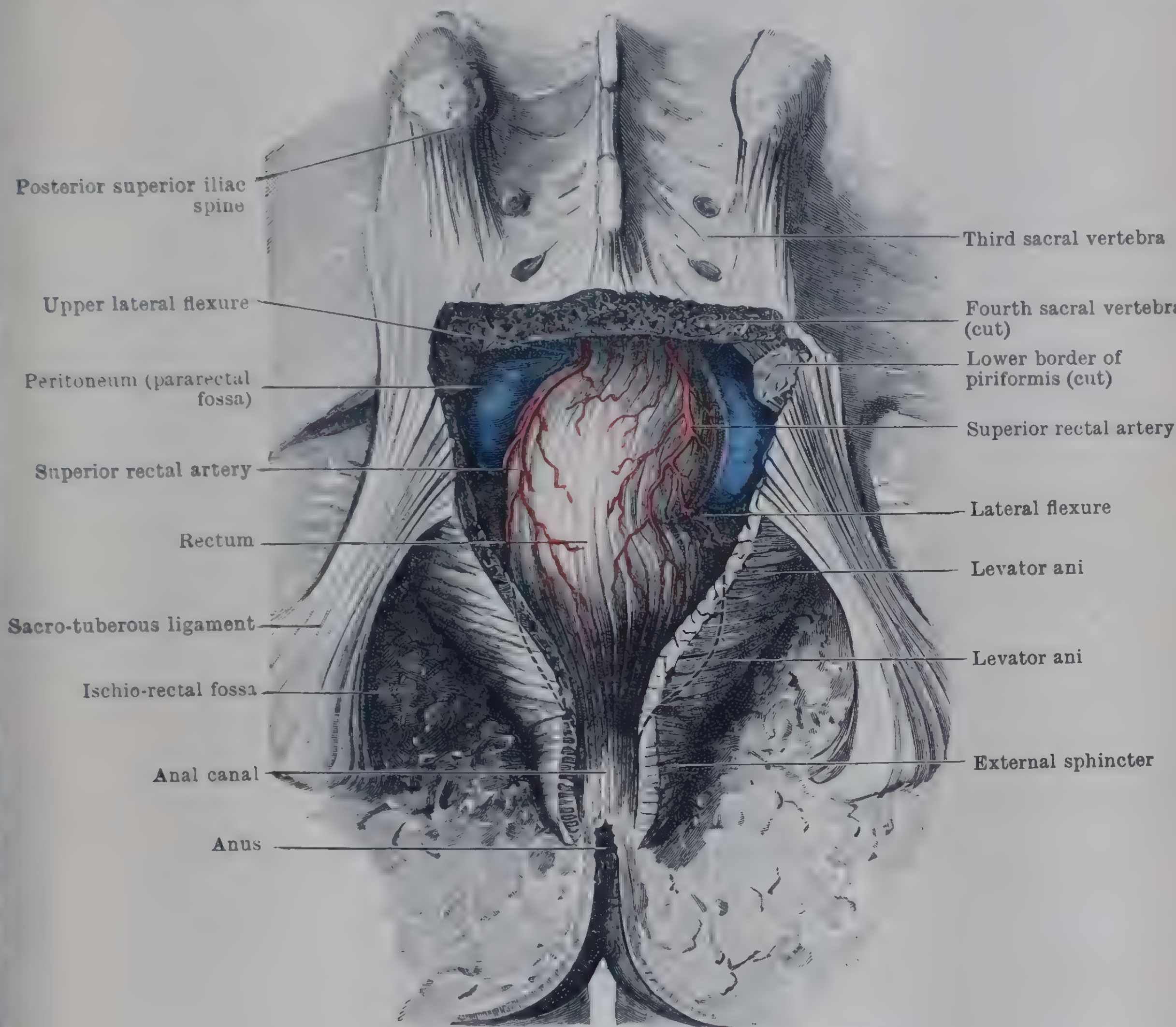

FIG. 1228.—DISSECTION OF RECTUM FROM BEHIND.
From a formalin-hardened male body, aged thirty.

towards the pelvis and is 6 cm. from the surface. The fossa is bounded medially by the levator ani covered with fascia (anal fascia); and laterally by the obturator internus muscle covered with the obturator fascia.

An abscess in the ischio-rectal fossa is usually the result of an infective process in the lower part of the rectum or anal canal, the fossa being infected by way of the lymphatics accompanying the inferior rectal vessels. When the abscess is opened surgically, or bursts through the skin of the fossa, it may continue to discharge because of a communication with the bowel (*fistula-in-ano*). In other cases the cutaneous opening communicates with the cavity of a *submucous* rectal abscess, or with an abscess (*pelvi-rectal*) which starts in the areolar tissue surrounding the upper part of the rectum, perforates the levator ani muscle, and so reaches the ischio-rectal fossa and breaches the skin over it.

Lymphatic Drainage.—The *lymph-vessels* from the skin of the anus pass along the perineo-femoral grooves to the most medial glands of the groin—both superficial and deep inguinal. Those from the region of the white line end in glands which lie in front of the internal iliac artery, while those from the mucous membrane of the upper part of the anal canal and the rectum traverse a few minute glands placed between the muscular and fascial coats of the rectum, along the superior rectal vein

and its two branches, and pass thence to the sacral glands which lie medial to the anterior sacral foramina.

The distribution of lymph from the ano-rectal segment is arranged in three "pedicles"—inferior, middle, and superior. The inferior pedicle collects lymph from each lateral half of the anus; it passes to the inguinal glands, and in a lesser degree to the lateral sacral glands and to the common iliac glands that lie on the sacral promontory. The middle pedicle drains that portion of the rectum which extends from the level of the third transverse fold to the ano-rectal junction. It follows the courses of the middle rectal, the lateral sacral, and median sacral arteries, and it passes into the external and internal iliac and the median common iliac glands. The superior or abdominal pedicle drains the rectum from the level of the third fold upwards; its course corresponds to that of the superior rectal and inferior mesenteric arteries. Three groups of vessels constitute it, the division being according to their relative lengths. The short group lies to the right of the superior rectal artery and opens into a rectal gland at the bifurcation of that vessel. The group of vessels of medium length is found to the left of the superior rectal artery and terminates in a gland which lies immediately below the origin of the lowest left colic artery. The long group also lies to the left of the superior rectal artery and passes into glands that lie below the inferior mesenteric artery at the level of the origin of the upper left colic artery.

Digital Examination of Rectum.—In making a *rectal examination*, the finger is carried forwards from the tip of the coccyx so as to enter the anus from behind. The finger is then gently pressed upwards and slightly forwards through the sphincteric region, in the axis of the anal canal, until it reaches the ampulla of the rectum. The horizontal folds of the rectum, three in number, project into the cavity of the bowel in the form of prominent crescentic shelves; the lower fold, which may be large enough to impede the passage of the finger, must not be mistaken for a pathological condition. Through the anterior wall the finger can palpate from below upwards the bulb of the penis, the membranous part of the urethra, the bulbo-urethral glands (when inflamed and enlarged), the prostate, the seminal vesicles, and the back of the bladder. With the left fore-finger in the rectum, an instrument passed into the bladder can be distinctly felt as it traverses the membranous urethra; as it lies in the prostatic urethra it is separated from the finger by the prostate. Hence, when a *false passage* is made through the part of the urethra which lies in the bulb or through the membranous portion, the instrument, if pushed onwards towards the bladder, will be felt immediately outside the rectum between it and the prostate. In the child, owing to the rudimentary condition of the prostate, the instrument is distinctly felt close to the rectum as it lies in the prostatic as well as in the membranous portion of the urethra. When the prostate is not enlarged the tip of the finger can just reach the back of the bladder, which is most distinctly felt when the bladder is full. The seminal vesicles, indistinctly felt when healthy, may be readily palpated when enlarged and indurated from disease. Through the side-wall of the rectum may be palpated the ischio-rectal fossa, the bony wall of the pelvis, and, when enlarged, the internal iliac lymph-glands; through the posterior wall the sacrum and coccyx, and (when enlarged) the lymph-glands in the retrorectal fibro-areolar tissue.

In the child rectal examination enables one to palpate, in addition to the structures in the cavity of the pelvis, those which occupy the lower segment of the abdomen. When the bladder is empty even a small calculus can be readily felt in it by recto-abdominal palpation.

Recto-Vesical Pouch.—The distance of the apex of this pouch of peritoneum from the anus varies considerably according to the degree of distension of the bladder and rectum; when both are empty it reaches to about 5 cm. from the anus; when both are distended it is at least 2·5 cm. higher (Figs. 620, 621, pp. 740, 741).

Examination by Sigmoidoscope.—In introducing the sigmoidoscope into the pelvic colon, the direction of the anal canal and the curve of the rectum must be remembered; as the instrument traverses the anal canal it must be directed forwards as well as upwards; it is then pushed onwards, in a backward and upward direction towards the hollow of the sacrum; and, finally, in order to reach the pelvic colon it is again directed forwards and also a little to the left so as to clear the promontory of the sacrum. The instrument is more difficult to pass in women, on account of the greater abruptness of the curvature of the sacrum.

When examined with the sigmoidoscope the mucous membrane of the rectum is seen to possess a deep red colour; and an excellent view is obtained of the horizontal folds. The most conspicuous fold projects from the right wall about the level of the recto-vesical peritoneal reflexion, *i.e.*, about 7·5 cm. from the anus. The highest fold gives rise to a distinct narrowing which must not be mistaken for a stricture. The pulsations of the left common iliac artery can generally be seen to be communicated, through the pelvic colon, to the postero-lateral wall of the rectum about 10 cm. from the anus.

Removal of Rectum by Perineal Route.—When the rectum and anal canal are removed for malignant disease an incision is carried round the anus and then upwards and backwards over the coccyx and lower part of the sacrum. The *ano-coccygeal body* is divided longitudinally and the *coccyx* is removed after division of the structures attached to its margins, viz., the lower fibres of the gluteus maximus, the coccygeus, and the sacro-tuberous and sacro-spinous ligaments. The **median sacral artery** is ligatured. There is now seen, stretching across the floor of the wound, a well-defined sheet of fascia; this is divided longitudinally and stripped to each side off the posterior surface of the rectum, and the branches of the **middle rectal arteries** are ligatured. Anteriorly, the anal canal is detached from the **perineal body**, after which the anterior surface of the rectum is freed from below upwards from—(1) the sphincter urethræ containing the **membranous urethra**, (2) the **prostate**, (3) the **bladder**, the **seminal vesicles** and the **vasa deferentia.** The procedure is facilitated by the existence of a layer of areolar tissue. In order to reach that tissue, the surgeon, after dividing the perineal body transversely, deepens the incision up to the apex of the prostate. In doing that he divides a band of muscular fibres (**recto-urethral muscle** (Fig. 1226)), which passes from the anterior wall of the lowest part of the rectal ampulla to blend with the muscle-fibres that surround the urethra at the apex of the prostate. It is those recto-urethral fibres which, by pulling forwards the ampulla, bring it into close relation with the urethra; hence it is especially at that stage of the operation that great care must be taken not to open into the rectum or to wound the urethra. After exposing the apex of the prostate he next retracts the anal canal well backwards and defines the anterior borders of the **levatores ani.** Each of those muscles is then divided well above its insertion into the anal canal. The posterior surface of the prostate, covered with recto-vesical septum, is then exposed.

The separation of the rectum upwards along the layer of areolar tissue above mentioned is continued, and the bottom of the **recto-vesical pouch** of peritoneum will be reached. The peritoneum can usually be stripped for some distance off the rectum without risk of opening into the peritoneal cavity. As the rectum is freed on each side, bands of fibro-areolar tissue containing branches of the **middle** and **superior rectal vessels** are divided. If the tumour is situated at the upper part of the rectum, the recto-vesical pouch of peritoneum is freely opened by a transverse incision. The surgeon then sets free the **colo-rectal junction** by dividing the sacral attachment of the **pelvic mesocolon** and securing the superior rectal artery. After dividing the rectum well above the tumour, he closes the opening into the peritoneal cavity by suturing together the anterior and posterior walls of the recto-vesical pouch. Since a permanent colostomy has been established previously, the divided bowel is closed.

When malignant lesions arise in the upper portion of the rectum close to its junction with the pelvic colon a combined abdomino-perineal excision of the rectum may be performed. A preliminary division and mobilization of the bowel is carried out from the abdominal area, the mobilized segment being removed from below, as in the perineal operation.

FEMALE PELVIS AND PERINEUM

Pelvic Organs.—When the abdomen is opened by a median incision from the umbilicus to the pubis, and the pelvis is looked into from above, after displacement of some coils of the small intestine upwards, the **fundus of the uterus**, directed forwards and a little upwards, is seen resting upon the upper surface of the bladder. Behind the uterus is the rectum, and between the two the **recto-uterine pouch**, containing the pelvic colon and the lower coils of the ileum. The **ovary** lies on the side of the pelvis, a little below the level of the brim, closely attached to the upper layer of the broad ligament. When the vermiform appendix hangs into the pelvis its tip may be in close relation with the right ovary—a condition which often leads to a difficulty in distinguishing an inflammation of that ovary from appendicitis. The **round ligament** of each side is seen passing forwards and laterally from the upper part of the border of the uterus to the deep inguinal ring, which lies immediately above and in front of the termination of the external iliac artery. Inferiorly and at the medial side of the round ligament, as it enters the ring, is the **inferior epigastric artery**. If the uterus is pulled upwards the attachments of the **broad ligament** to the floor and side-wall of the pelvis are brought into view, as also are the utero-vesical and recto-uterine peritoneal pouches. The

utero-vesical pouch is a shallow recess; the deepest part of the recto-uterine pouch covers the upper fourth of the posterior wall of the vagina and is in relation, therefore, with the posterior fornix.

The utero-vesical peritoneal reflexion takes place at the junction of the body of the uterus with the cervix. The anterior wall of the cervix is in relation, therefore, with the upper part of the base of the bladder, from which, however, it is separated by a layer of loose areolar tissue. It is the existence of that areolar tissue which enables the surgeon to separate the bladder readily from the uterus in the operation of hysterectomy.

The anterior wall of the vagina is firmly united to the urethra, but its posterior wall can be readily separated from the rectum, because of the interposition of loose areolar tissue between them.

The **ureter** crosses the bifurcation of the common iliac artery and then passes backwards and downwards into the pelvis, where it lies at first on the side-wall immediately below and in front of the internal iliac artery under cover of the peritoneum, through which it can be seen. It then courses medially and forwards in the parametric areolar tissue below the root of the broad ligament. In that position it lies above the lateral fornix of the vagina, about 2 cm. lateral to the upper part of the cervix uteri; finally, immediately before it pierces the lateral angle of the bladder, it inclines medially to lie in front of the upper lateral part of the vaginal wall.

The relation of the parts of the ureters that lie in the pelvis are of special importance in the female as their close relation to the cervix uteri and upper part of the vagina renders them liable to injury, more especially in the operation of hysterectomy performed for malignant disease of the uterus.

Pelvic Vessels.—The **uterine artery**, in the first part of its course, passes downwards and forwards a little anterior and lateral to the ureter. At the level of the upper end of the cervix uteri it takes a medial direction and passes along the root of the broad ligament and crosses above and in front of the ureter from lateral to medial side; it then passes above the lateral fornix of the vagina and finally ascends close to the side of the body of the uterus, and ends by anastomosing with the ovarian artery below the isthmus of the uterine tube.

The **ovarian artery** enters the pelvis between the layers of that portion of the broad ligament known as the **infundibulo-pelvic ligament**; it is there that the vessel may be most readily ligatured in abdominal hysterectomy and in ovariotomy.

The **lymph-vessels** from the lower part of the vagina pass to the inguinal and ano-rectal glands. Those from the rest of the vagina, from the cervix uteri, and from the greater part of the body of the uterus, pass to the internal and external iliac and the sacral glands. The ano-rectal glands lie on the wall of the ampulla of the rectum. The internal iliac glands are situated on the side-wall of the pelvis in close relation to the origins of the branches of the internal iliac artery. The sacral glands form a chain along the medial side of the anterior sacral foramina. Some of the lymph-vessels from the fundus of the uterus, and those from the uterine tube and the ovary, terminate in the glands around the aorta and inferior vena cava: but others from the fundus run along the round ligament to the inguinal glands.

Perineum.—The external genital organs are fully described in the Section on the Urogenital System. The **external orifice of the urethra**, surrounded by a slight annular prominence, is situated about 2·5 cm. posterior to the clitoris, in the smooth triangular, anterior division of the vestibule of the vagina, immediately in front of the vaginal orifice. When a *catheter* is passed the instrument is directed along the forefinger (introduced just within the vaginal orifice with the palmar surface towards the pubic symphysis) to the base of the smooth triangle, where it is tilted slightly upwards so as to bring its point opposite the urethral orifice.

The **greater vestibular glands** are a pair of glands placed at the sides of the posterior third of the orifice of the vagina, on the lower surface of the perineal membrane. Each has a slender duct, nearly 2·5 cm. in length, which opens into the angle between the labium minus and the hymen. Abscesses and cysts not infrequently develop in connexion with these glands.

The **bulbs of the vestibule** are a pair of piriform collections of erectile tissue

situated one on each side of the lowest part of the vagina, between the bulbo-spongiosus muscle and the perineal membrane. Rupture of the bulbs gives rise to the condition known as *pudendal hæmatocele.*

Vagina.—The **cervix uteri** projects downwards and backwards into the upper part of the vagina and is separated from the vaginal wall by a distinct **fornix.** The relations of the fornix are of so much practical importance that for descriptive purposes it is customary to divide it into an anterior, a posterior, and two lateral portions. The **anterior fornix** is shallow, and it is related to the base of the bladder and to the areolar tissue below the utero-vesical pouch of peritoneum. The **posterior fornix** is much deeper; it extends upwards for some little distance in front of the anterior wall of the lowest part of the recto-uterine pouch. The septum between the fornix and the pouch is merely the wall of the vagina; hence the readiness with which the pelvis may be drained by an incision in the posterior vaginal wall.

The **lateral fornix** (Pl. LXXII, p. 745) is below the medial part of the root of the broad ligament. An incision carried through it would therefore open into the para-metric areolar tissue and would expose the uterine artery as it passes transversely to the uterus after crossing the ureter.

Vaginal Examination.—In making a *vaginal examination,* the patient is placed on her back with the thighs well flexed; the index-finger of the right hand is carried along the fold of the buttock towards the median plane, where it will impinge against the posterior part of the **vestibule of the vagina,** and then passed upwards and backwards into the vagina; to make a more thorough examination the middle finger also may be introduced. When the uterus is in its normal position the **vaginal part of the cervix uteri** is felt as a knob-like body projecting downwards and backwards into the upper part of the vagina. In nulliparæ the external os is a small transverse slit, whereas in women who have borne children it is larger and its lips are more or less fissured. Above and behind the cervix is the **posterior fornix,** which is in close proximity to the **recto-uterine** or **recto-vaginal pouch**; the pouch, though normally occupied only by a loop of ileum or of pelvic colon, is the frequent site also of displaced abdominal and pelvic organs, and collections of intraperitoneal effusions and exudations. A loaded rectum can be detected through the vagina by the characteristic way in which the contents can be pitted by the finger. In front of the cervix is the **anterior fornix,** through which the body of the uterus and the base of the bladder may be felt. Through the lower half of the anterior vaginal wall the **urethra** may be detected as a cylindrical, cord-like thickening which may be rolled against the lower border of the symphysis. If the **ureter** is enlarged, the finger, in the anterior part of the lateral fornix, can recognize it by compressing it against the pubic bone.

By the *bimanual examination* the pelvic organs are steadied and pushed downwards towards the outlet of the pelvis by the pressure of the left hand applied above the pelvis, so that they can be more readily reached and palpated by the finger placed in the vagina with its palmar surface directed upwards. The **ovary,** when enlarged, may be felt if fingers are pushed well up into the lateral fornix towards the side-wall of the pelvis. The healthy **uterine tubes** cannot, as a rule, be felt per vaginam.

Rectal Examination.—By rectal examination the finger can palpate, from below upwards, the recto-vaginal septum, the cervix uteri, the posterior fornix of the vagina the floor of the recto-vaginal pouch, and the body of the uterus.

THE BACK

Median Line of the Back.—In the median line of the back is the **vertebral furrow,** which is deepest in the lower thoracic and upper lumbar regions. Over the upper sacral region, where the sacro-spinales muscles are tendinous, there is a flattened area forming an equilateral triangle, the angles of which correspond to the posterior superior iliac spines and the third sacral spine. The **vertebral spines** can be palpated at the bottom of the vertebral furrow; it is possible to identify and count them if it is remembered that the first thoracic is the lower of the two knobs at the root of the back of the neck, that the third thoracic is on a level with the root

of the spine of the scapula, the seventh thoracic with its inferior angle, the fourth lumbar with the highest part of the iliac crest, and the second sacral with the posterior superior iliac spine.

Lateral Region of the Back.—Above the spine of the scapula is the **supra-scapular region,** which is padded by a thick mass of muscle consisting of the supraspinatus and levator scapulæ, covered by the trapezius; shrugging the shoulders brings the two trapezius muscles into relief.

In the **interscapular region** are the trapezius and rhomboid muscles, which are thrown into prominence when they brace back the shoulders.

Below the inferior angle of the scapula the last five ribs can readily be felt lateral to the sacro-spinalis muscle; when the twelfth rib does not reach beyond this muscle, the eleventh rib will be mistaken for it, unless the ribs are counted from the second rib downwards.

The **lower border of the trapezius** is indicated by a line drawn upwards and laterally from the twelfth thoracic spine to the tubercle of the crest of the scapula; the **upper border of the latissimus dorsi** by a line drawn from the seventh thoracic spine horizontally across the inferior angle of the scapula.

The lateral border of the **sacro-spinalis** is indicated on the surface by a shallow groove on the loin about a hand's breadth from the median line. The lateral border of the **quadratus lumborum,** which passes upwards and slightly medially, lies a little lateral to the lateral border of the sacro-spinalis at the iliac crest, and a little medial to it at the twelfth rib.

The Loin.—The anatomy of the muscles and fasciæ which complete the abdominal wall between the last rib and the iliac crest is of importance in connection with operations in the **region of the loin.** The space between the last rib and the iliac crest varies greatly according to the length of the rib, and according to the general shape of the chest and slope of the ribs as a whole. As a rule, the **tip of the twelfth rib** lies about 5 cm. vertically above the middle of the iliac crest. From a surgical point of view the costo-iliac space may be said to be limited medially by the lateral edge of the sacro-spinalis, and, more deeply, by the tips of the lumbar transverse processes; laterally it is bounded by the posterior, free border of the external oblique, and, more deeply, by the line of reflexion of the peritoneum from the colon on to the side-wall of the abdomen. The space is roofed over by the latissimus dorsi, except below, where a narrow, triangular interval is left between its lateral border and the posterior border of the external oblique, the base of the triangle being formed by the iliac crest just behind its middle. This **lumbar triangle** is a weak area through which a lumbar abscess may come to the surface, and through which a lumbar hernia occasionally develops. When the latissimus dorsi and the lower part of the serratus posterior inferior are removed, another triangle is exposed, which constitutes a second weak area in the loin; it is bounded above by the last rib, medially by the sacro-spinalis, and laterally by the posterior muscular fibres of the internal oblique; the floor of the triangle is formed by the aponeurosis of origin of the transversus abdominis muscle; that aponeurosis splits into three layers to form two compartments, the anterior enclosing the quadratus lumborum and the posterior the sacro-spinalis.

Kidneys.—The upper limit of the kidney is indicated by a line drawn transversely across the loin opposite the eleventh thoracic spine, the lower limit by a line on a level with the third lumbar spine. The upper pole reaches to the eleventh rib; the lower, which lies immediately lateral to the tip of the transverse process of the third lumbar vertebra, is 1·3 to 5 cm. above the iliac crest. About a third of the kidney lies above the lower margin of the twelfth rib. The left kidney is usually about 1·3 cm. higher than the right. The most lateral point of the lateral border is 10 cm. from the median plane, while the hilum is about 5 cm. lateral to the median plane in front of the interval between the tips of the transverse processes of the first and second lumbar vertebræ.

The psoas major muscle intervenes between the postero-medial surface of the kidney and the transverse processes, and the kidney is therefore protected from contact with the bony processes in the event of a blow directed from the front. Between the upper end of the kidney and the eleventh and twelfth ribs is the

dia ragm and the costo-diaphragmatic recess of the pleura (Fig. 1214). The relat ons of the pleura to the last rib have been considered already (p. 1485).

Exposure of Kidney.—To expose the kidney by an oblique incision in the loin, the latissimus dorsi and serratus posterior inferior muscles are divided at the medial part of the wound; the posterior fibres of the external and internal oblique muscles are divided at its lateral part; next, the aponeurotic origin of the transversus muscle is split to expose the extraperitoneal fat and the peritoneum as it is reflected from the colon on to the side of the abdominal wall. The peritoneum and the colon are then stripped forwards and medially off the front of the kidney, until the hilum and renal vessels are reached. The sacro-spinalis and quadratus lumborum muscles are pulled well medially; and it may be necessary to divide the lateral fibres of the quadratus muscle.

To expose the upper part of the ureter, the division of the abdominal muscles is extended

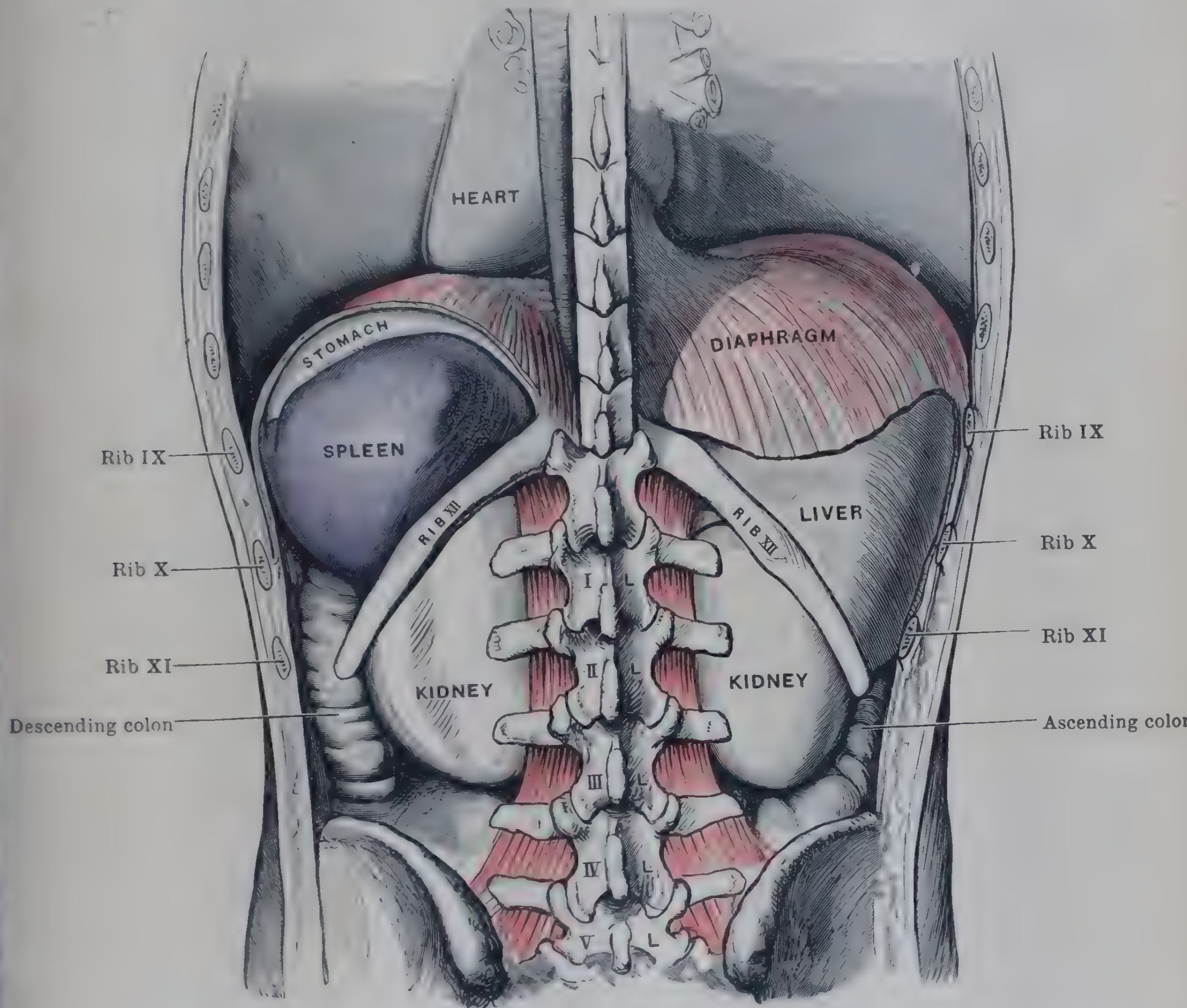

FIG. 1229.—DISSECTION OF SPLEEN, LIVER, AND KIDNEYS FROM BEHIND, IN A SUBJECT HARDENED BY FORMALIN INJECTION.

still farther downwards and forwards into the iliac region. After the peritoneum is stripped off the quadratus and psoas muscles, the ureter will be found clinging to the peritoneum. Care is required to avoid injury to the testicular or ovarian vessels, which cross in front of the ureter from the medial to the lateral side. The ureter is surrounded by a quantity of loose areolar tissue, and, owing to an abundance of elastic fibres in its adventitious coat, is very extensible, so that it can be readily brought to the surface.

To deliver an enlarged kidney out of the loin, it is generally necessary to prolong the incision upwards so as to divide the lateral arcuate ligament; and it may be necessary to resect the twelfth rib also.

The subcostal and the ilio-hypogastric and ilio-inguinal nerves, which lie at first behind and then lateral to the organ, must not be injured; the subcostal nerve should be displaced upwards and laterally, the other two downwards and medially.

The pus of a **perinephric abscess** lies in the renal fat, and is, therefore, within the fascial envelope of the abdomen; the pus in a **psoas abscess**, on the other hand, lies external to the fascia.

A needle passed through the medial extremity of the eleventh intercostal space will transfix **the suprarenal gland.**

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Diaphragm, Liver, Stomach, and Large Intestine.—Posteriorly the righ **arch of the diaphragm** and the right lobe of the liver extend upwards to the level of the angle of the scapula (eighth rib), while the **left arch** and the **fundus** of the stomach are 2·5 cm. lower (eighth interspace); the central tendon reaches up to the eighth thoracic spine. The **right lobe of the liver** is covered posteriorly by the eighth to the twelfth ribs, and is overlapped by the base of the right lung as far as a line drawn horizontally laterally from the tenth thoracic spine; therefore on the back, the upper limit of the liver cannot be defined by percussion, and its lower limit merges into the dullness of the loin-muscles and kidney.

The **cardiac orifice of the stomach** is opposite a point 2·5 cm. to the left of the ninth thoracic spine. The fundus, overlapped by the ninth to the twelfth ribs extends upwards to the level of the eighth thoracic spine, 2·5 cm. below the inferior angle of the scapula. The **pyloric portion** crosses the median plane opposite the first and second lumbar spines, the **pylorus** itself being situated 2·5 cm. to the right of the first lumbar spine.

Viewed from behind, the **large intestine**, on both sides, overlaps the latera border of the kidney and lies parallel to the lateral border of the sacro-spinali muscle. The peritoneum is reflected from the colon on to the posterior abdomina wall along a line drawn vertically upwards from the middle of the iliac crest The **right flexure** is at the level of the first lumbar spine and the left flexure is little higher.

Spleen.—The *spleen* is situated in the left hypochondrium behind the stomach It varies greatly in size and outline, but a spleen of average size is opposite th ninth, tenth, and eleventh ribs, its long axis corresponding approximately to tha of the tenth rib. Between the upper third of the spleen and the chest-wall (pleur and diaphragm intervening) is the lower part of the left lung, the inferior margi of which crosses the spleen horizontally at the level of the tenth thoracic spin The costo-diaphragmatic recess of the pleura reaches down as far as the inferic angle of the spleen. The upper limit of the spleen cannot therefore be defined b percussion; and when a spleen puncture is done from behind, the needle wi traverse the pleural as well as the peritoneal cavity unless the spleen is enlarge or displaced downwards.

The *lateral end* of the spleen reaches the ninth intercostal space in the mic axillary line. The *medial end* is at the same level as the lower margin of the lun about 3·8 cm. lateral to the tenth thoracic spine. The *highest point* is opposi the ninth rib in the scapular line. The only parts of the splenic outline whic can be defined by percussion are the lateral, crenated part of the upper margi and the lateral end; and it is those parts which may be felt below the cost margin when the organ is considerably enlarged.

To excise the spleen, the abdomen is opened by a vertical incision through the upper half the left rectus muscle a little lateral to the median line. The spleen is drawn forwards into th wound after displacing the stomach and transverse colon downwards and to the right. The sho gastric vessels are secured as they course between the two layers of the gastro-splenic ligame The splenic vessels, which form the main pedicle, lie between the two layers of the lieno-ren ligament. Care must be taken not to injure the tail of the pancreas, which is in relati with the lower part of the gastric surface of the spleen. In a *floating spleen* the two peritone ligaments are elongated to form distinct pedicles.

Pancreas.—The head of the **pancreas** lies opposite the first and second lumbar spine the tail lies at the same level as the left flexure of the colon.

Vertebral Column and Spinal Cord.—The spinal cord usually ends opposi the lower border of the first lumbar spine but may do so one vertebra higher lower; in the infant it reaches the interval between the second and third lumb spines. The *cervical enlargement*, which corresponds to the lower four cervical an the first two thoracic segments, ends opposite the first thoracic spine. The fi lumbar segments are opposite the last three thoracic spines. The fourth cervic segment is opposite the third cervical spine, the eighth cervical segment opposi the interspace between the fifth and sixth cervical spines, the fourth thorac opposite the second thoracic spine, the eighth thoracic opposite the fifth thorac spine, the twelfth thoracic opposite the ninth thoracic spine, the second lumb

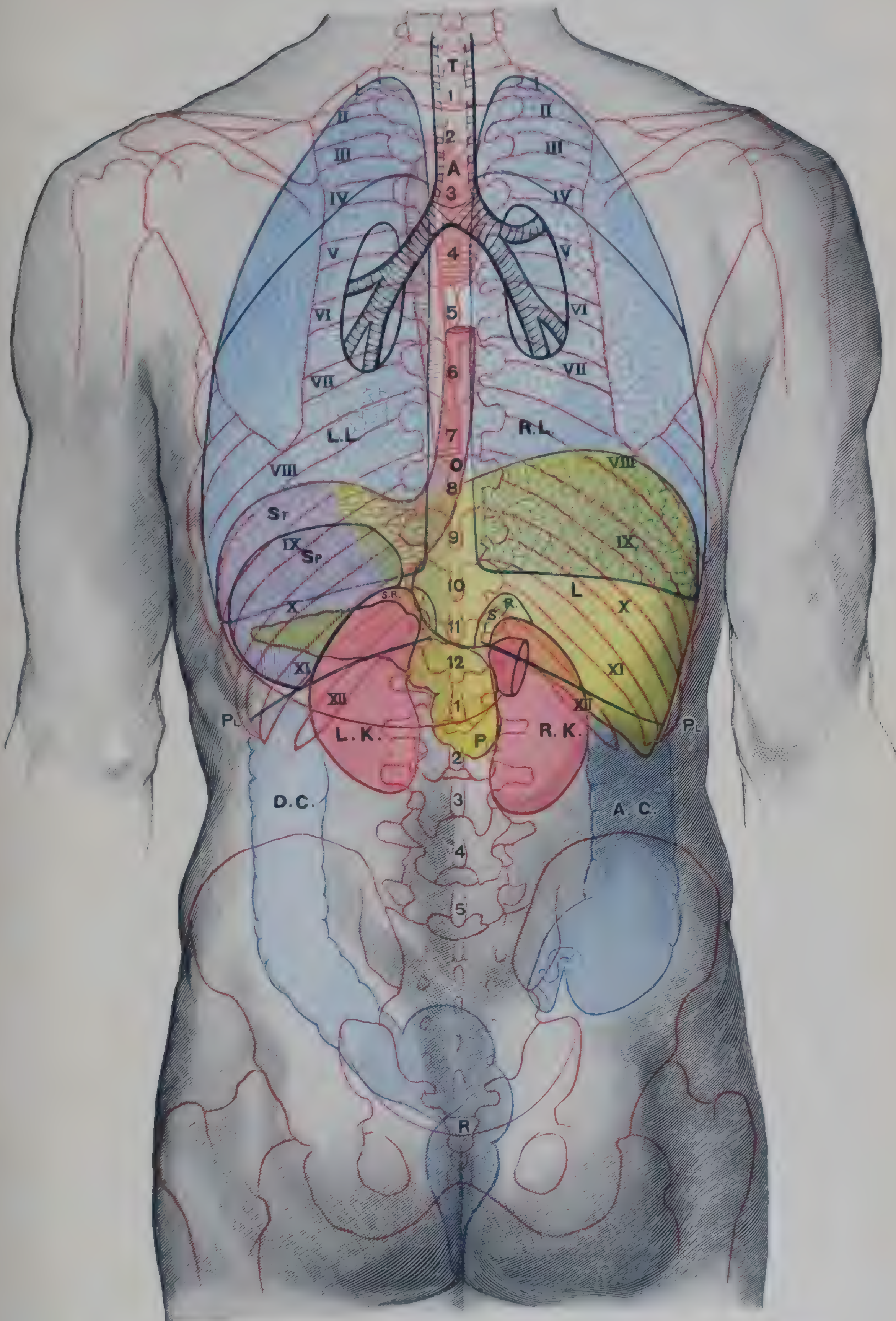

FIG. 1230.—POSTERIOR ASPECT OF TRUNK, SHOWING SURFACE TOPOGRAPHY OF VISCERA.

A. Aorta.
A.C. Ascending colon.
D.C. Descending colon.
L. Liver.
L.K. Left kidney.
L.L. Left lung.
P. Pancreas.
Pl. Pleura.
R. Rectum.
R.K. Right kidney.
R.L. Right lung.
Sp. Spleen.
S.R. Suprarenal gland.
St. Stomach.
T. Trachea.

opposite the tenth thoracic spine. The sacral segments correspond to the last thoracic and first lumbar spines (see Figs. 742, 914, pp. 856, 1051).

The nerve-roots which arise below those of the first lumbar, and form the cauda equina, are arranged in a right and a left bundle, with a median space between them. The highest roots occupy the most lateral position in the cauda, and the lowest are nearest the filum terminale.

To expose the spinal cord by the operation of laminectomy, the surgeon, after separating the muscles from the spines and laminæ, removes certain of the spines along with their

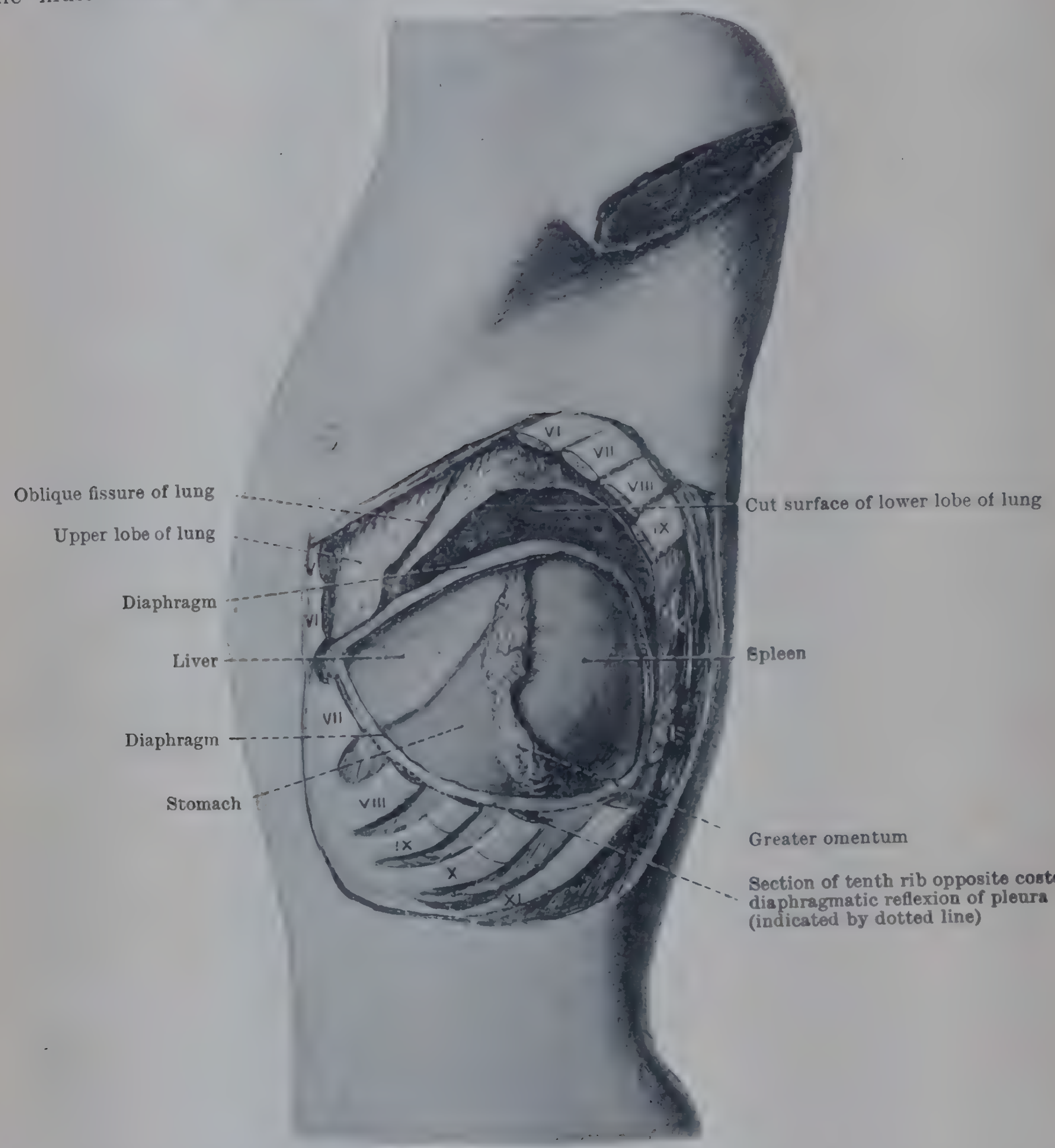

FIG. 1231.—DISSECTION OF LEFT HYPOCHONDRIUM TO SHOW RELATIONS OF SPLEEN TO SIDE-WALL OF CHEST, DIAPHRAGM, AND ADJACENT VISCERA. Portions of several ribs and a part of the base of the left lung have been removed ; and a window has been made in the diaphragm down almost to the level of the costo-diaphragmatic reflexion of the pleura.

supraspinous and interspinous ligaments. The next step is the removal of the corresponding laminæ. That is not difficult in the cervical region, for there they are comparatively slender and do not overlap. In the thoracic region there is more difficulty owing to the greater size of the laminæ and to their imbricated arrangement ; in the lumbar region the difficulty arises from the greater depth at which the laminæ lie and their greater thickness. The bleeding comes mainly from (1) the plexus of veins on the backs of the vertebral arches, and (2) from the plexus which occupies the fatty tissue outside the dura mater. After the dura and arachnoid mater are incised, cerebro-spinal fluid escapes. The anterior and posterior nerve-roots are now exposed and are seen to be separated by the denticulate ligament, which ends below in a fork-like manner opposite the first lumbar vertebra. As the first lumbar posterior root rests on the "fork", the ligament serves as a guide to that nerve. Tumours which arise outside the spinal cord, but within the dura, are classified according to their relationship to the anterior and

posterior nerve roots and to the denticulate ligament. The classification is therefore anterior, antero-lateral, postero-lateral, and posterior. To reach an anterior tumour one of the teeth of the ligament is divided and the spinal cord (thus freed) may be rotated gently.

The **subdural space** extends down to the level of the second or third sacral spine. In the operation of *lumbar puncture* the needle is introduced into the subarachnoid space below the level of the spinal cord, the puncture being made in the interval between the third and fourth or fourth and fifth lumbar spines. The fourth spine is at the level of the highest part of the iliac crest. The instrument should be directed very slightly upwards. In the adult the distance of the dura mater from the surface is from 5 to 7·5 cm., in the infant 2 cm.

Owing to the shape and arrangement of the articular surfaces of the vertebræ, **dislocations** without fracture are practically confined to the cervical region; they are commonest between the fifth and sixth vertebræ. The dislocation may be unilateral, but it is more frequently bilateral and incomplete. In both instances the spinal cord may be only slightly bruised, and then the paralysis will be only partial. In complete bilateral dislocations the spinal cord is usually completely crushed, and when the lesion is at, or above, the level of the fourth cervical segment (origin of the phrenic nerves) death may ensue rapidly from respiratory paralysis.

Fracture-dislocations of the vertebral column are commonest in the lower cervical region and the thoraco-lumbar region—that is to say, where the movable cervical and lumbar regions join the more fixed thoracic region. The vertebral column above the injury is generally displaced forwards, and the spinal cord is often severely lacerated or completely torn across by the upper end of the portion of the column below the fracture. It is important to remember that, in consequence of the shortness of the cord as compared with the vertebral column, the origins of the spinal nerves are at a higher level than their exits from the vertebral canal. The distance between origins and exits becomes greater the farther down the nerves are—the lowest nerve-roots running almost vertically downwards. The cervical nerves leave the vertebral canal *above* the vertebræ after which they are named (except the *eighth,* which is above the first thoracic vertebra); the thoracic, lumbar, and sacral nerves leave the canal *below* their vertebræ.

To understand the effect of **lesions of the spinal cord**, it is necessary to be familiar with the sensory and motor distributions of the various spinal segments (see Figs. 916, 918, pp. 1055, 1059, and 929, p. 1075). Transverse lesions of the cord *above the fifth cervical spine* (that is, above the disc between the fourth and fifth cervical vertebræ) are quickly fatal, owing to paralysis of respiration, as the phrenic nerves arise mainly from the fourth segment. In transverse lesions of the cervical enlargement the *cutaneous insensibility* does not extend higher than a horizontal line at the level of the second costal cartilage. The diagnosis of the particular segment involved is arrived at by testing the motor and sensory functions of each segment. The sensory areas which correspond to the *lower four cervical* and the *first two thoracic segments* are in the upper limbs, and they are placed in numerical order from the lateral to the medial side of the limb. The sensory area which corresponds to the *second, third,* and *fourth cervical segments* occupies the occipital region of the scalp, the back of the auricle, the masseteric region, the whole of the neck, and the shoulders and upper part of the chest down to a horizontal line at the level of the sternal angle. In a total transverse lesion of the cord in the *thoracic region*, the upper limit of the anæsthesia is horizontal, and reaches the level of the terminations of the anterior primary rami of the nerves that arise from the segment opposite the vertebral injury. The upper limit of the anæsthesia is, therefore, at a much lower level than that of the injured vertebra. For example, a fracture-dislocation at the level of the eighth thoracic vertebra involves the origin of the tenth thoracic nerve, which ends at the level of the umbilicus. The sensory zone that corresponds to the *fifth thoracic segment* is at the level of the nipples, that of the *seventh thoracic segment* is at the level of the xiphoid process, that of the *tenth* at the level of the umbilicus, while that of the *twelfth* reaches down, anteriorly, almost to the pubis. The sensory areas that correspond to the lumbar and sacral segments are seen in Fig. 942, p. 1097. See also Figs. 916, 918, 920; and 945, p. 1102.

Congenital Abnormalities and Postural Errors.—Abnormalities in the ossification of the bodies of the vertebræ are occasionally encountered. In rare cases ossification of the body of the vertebra is confined to one of the twin ossific centres,

with the result that the body of the vertebra is distorted, and, if the error is a pronounced one, deformity of the vertebral column results (*scoliosis* or *kyphosis*).

Abnormal development of the laminæ and spines also occurs, and therein lies the foundation of *spina bifida*. The least serious deformity of this type implies a split or gap between the right and left halves of one or more of the spines, and through the space a band of fibrous tissue establishes continuity between the deep surface of the overlying skin and the posterior surface of the spinal meninges (*spina bifida occulta*). In the more

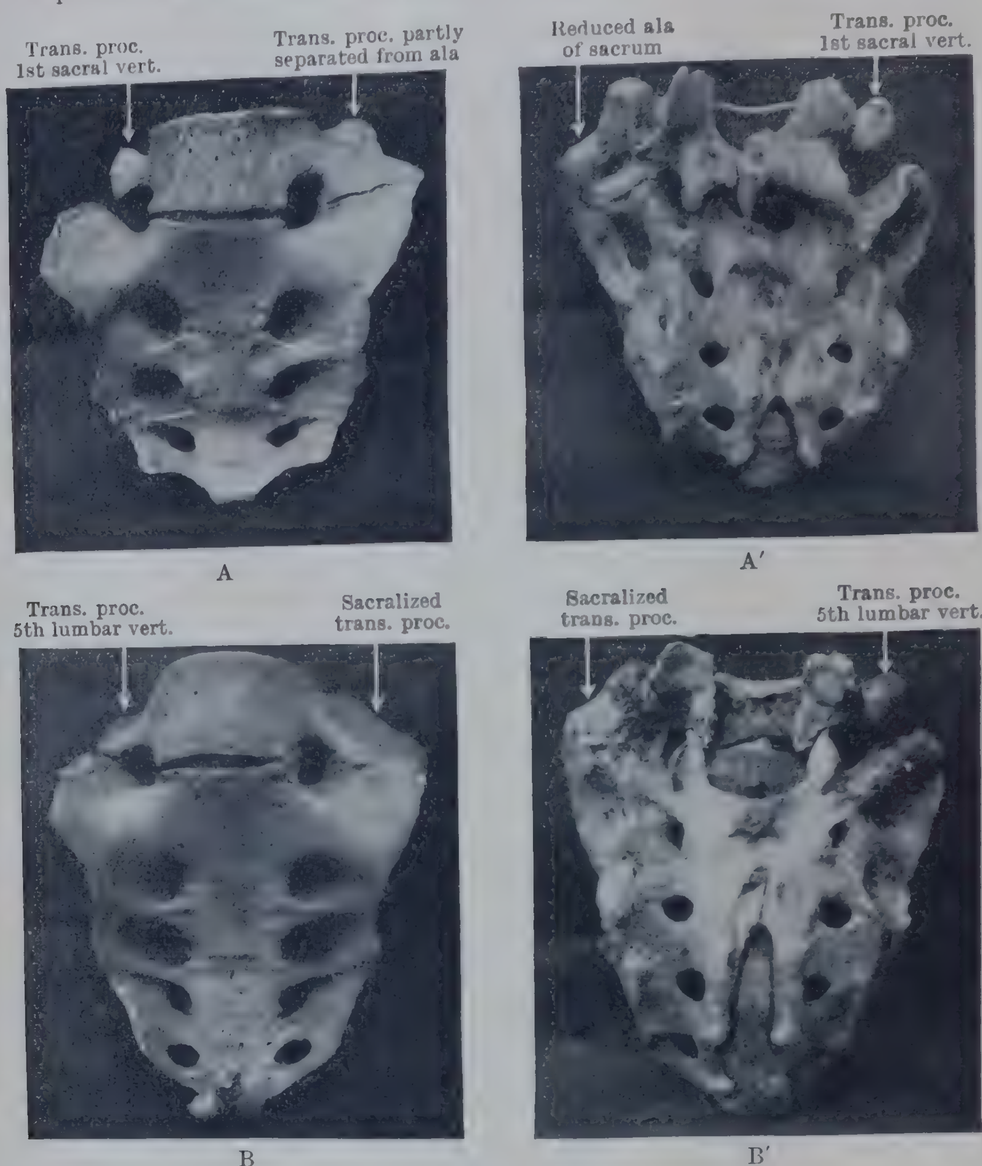

FIG. 1232.—PHOTOGRAPHS OF TWO SACRA SHOWING (A) UNILATERAL LUMBARIZATION OF FIRST SACRAL VERTEBRA AND (B) BILATERAL BUT ASYMMETRICAL SACRALIZATION OF FIFTH LUMBAR VERTEBRA. (Brailsford, 1929.)

Note in B the relation of the right transverse process of the fifth lumbar vertebra to the ala of the sacrum and the almost complete fusion on the left side ; and compare with A.

complete malformations, where the spines are absent and the laminæ rudimentary, a saccular protrusion of meninges and nerve-tissue may appear.

In other instances development is arrested at the stage of the neural groove, so that skin, muscles, spines, laminæ and the posterior part of the spinal cord are absent over a certain area. This is the condition of *myelocele*, and it is incompatible with post-natal existence.

Abnormalities may be encountered in the *articulation between the fifth lumbar vertebra and the first piece of the sacrum*. The normal arrangement is one in which the articular processes lie in the coronal plane, the sacral articular facets being directed backwards. In an appreciable percentage of subjects the articular processes occupy the sagittal plane, with the result that the facets are directed medially. Such a condition results in a lessening of stability at the lumbo-sacral joint, and, in respect of this, leads to various postural disturbances in the lumbar part of the vertebral column and in the sacro-iliac joints.

The transverse processes of the fifth lumbar vertebra are sometimes abnormal in length and in shape (Figs. 1232, 1233). On one or both sides the process may pass downwards to articulate with the sacrum (*sacralization*), or it may extend laterally to impinge upon or to articulate with the posterior portion of the ilium. These irregularities may be responsible for pain, either local or referred, along the distribution of the fifth lumbar nerve, while in some cases they appear to cause a lateral curvature of the lumbar part of the vertebral column. Asymmetrical separation of the first sacral vertebra (*lumbarization*) is less common but simulates sacralization of the fifth lumbar vertebra (Fig. 1232).

The angle of the lumbo-sacral junction in a well-developed adult is 120°. Minor variations are common and are of no significance, but a gross abnormality may lead to pain and to secondary disabilities in related parts. When the angle is notably increased so that the sacrum and the lumbar vertebræ are in relative alignment, or when the angle is notably diminished as the result of backward tilting of the sacrum, an additional strain is thrown upon the sacro-iliac joints, and in a certain number of cases the increased stress results in local or referred pain.

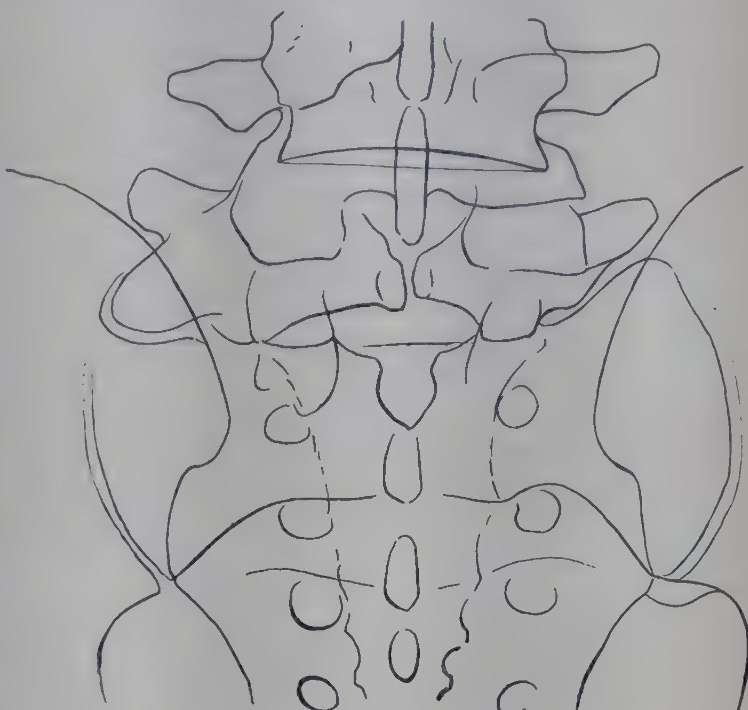

FIG. 1233.—OUTLINE DRAWING OF RADIOGRAPH OF LUMBO-SACRAL AND SACRO-ILIAC REGIONS. Cf. Pl. XVII, p. 272.

On the right side (left in the figure) there is an incomplete "sacralization" of the transverse process of the fifth lumbar vertebra with the development of a bursa at the point of contact.

A forward displacement of the fifth lumbar vertebra upon the sacrum is sometimes encountered, and this condition is given the name of *spondylolisthesis*. It is apt to be associated with local pain, limitation of flexion in the lumbar region, an alteration in gait, and, if the displacement is ex-centric, pressure on the fifth lumbar nerve of the side towards which the displacement is directed may lead to weakness of the muscles supplied by the nerve. The significance of spondylolisthesis is recognized by the obstetrician, because a severe deformity of this character may interfere with parturition.

As a result of trauma, the central part of an intervertebral disc (*nucleus pulposus*) may be forced into the spinal canal, where it presses on the nerve-roots at the corresponding level, giving rise to pain and possibly muscular weakness and wasting. The most commonly affected roots are the fifth lumbar and first sacral, and the clinical picture is that of one type of sciatica.

In addition to these local abnormalities, the orthopædic surgeon recognizes *two general types of bodily habitus* associated with structural variation of the vertebral column—the narrow-backed, long-waisted, slender figure, and the broad-backed, thick-set, heavy one. The former, sometimes classed as the *visceroptotic type* because ptosis of the abdominal viscera is such a frequent accompaniment, is associated with a slender and unduly mobile vertebral column; and, on account of the increased mobility, postural errors are apt to arise. The lumbar part of the column loses its natural lordosis, there is increased backward displacement of the sacrum, the thoracic part of the column becomes unduly straight, while the lordotic curve of the cervical region is increased. The effect of these changes is to throw an undue strain upon the sacro-iliac joints, so that the ligaments which support them are stretched and weakened, and minor degrees of displacement occur at these joints.

In the second type, the back is thick-set and broad, and the movements of the vertebral column tend to be more restricted than is normal. The lumbar vertebræ are broad and massive, the curve of the lumbar lordosis is reduced, and the longitudinal axis of the sacrum tends to come into line with the lumbar bodies. An undue strain is thrown upon the lumbo-sacral joint, and symptoms of this may become apparent. In addition, there is limitation of flexion of the lower portion of the body, so that this movement takes place at

the hip joints rather than in the vertebral area; in the same way the range of lateral movement of the lumbar part of the column is lessened.

UPPER LIMB

SHOULDER, AXILLA, AND BREAST

Landmarks.—The bony landmarks of the shoulder must be systematically examined in all injuries about that region.

Clavicle.—The **sternal end** of the **clavicle** is prominent; its articulation with the sternum is essentially a weak joint, and it is liable to be dislocated, especially from blows on the lateral part of the shoulder which drive the medial end of the clavicle forwards against the anterior sterno-clavicular ligament. The **shaft** of the **clavicle**, subcutaneous throughout, is weakest at the junction of its two curves; it is in that region that the bone is so frequently fractured as the result of force transmitted through it to the trunk. The displacement of the lateral fragment varies according to whether the break takes place medial or lateral to the coraco-clavicular ligament; in the former case the weight of the upper limb, acting through the coraco-clavicular ligament, pulls the lateral fragment downwards; when the fracture is lateral to the ligament, the lateral end of the clavicle swings forwards, but there is no downward displacement. In fractures of the intermediate third of the clavicle the subclavian vessels are protected by the subclavius muscle. The **acromial end** of the **clavicle** is on a plane behind its sternal end, and in that way the clavicle braces the shoulder backwards away from the thorax; therefore, in fractures of the clavicle, both medial and lateral to the coraco-clavicular ligament, the point of the shoulder swings forwards and medially. The groove that corresponds to the **acromio-clavicular joint** runs in the sagittal direction, and can be felt 3 cm. medial to the lateral border of the acromion, immediately lateral to a slight prominence made by the acromial end of the clavicle. When the acromio-clavicular joint is dislocated the clavicle almost invariably overrides the acromion, and the summit of the shoulder presents a conical appearance.

Scapula.—The **tip** of the **acromion** looks directly forwards, and is a finger's breadth lateral to and a little in front of the acromial end of the clavicle. The **lateral border** of the **acromion** can readily be followed to its junction with the spine of the scapula, and the spine can be followed to its root, which is at the level of the third thoracic spine. The **medial border** of the **acromion** and the clavicle meet at an angle into which the point of the finger can be pressed. The **upper angle** of the **scapula**, covered by the trapezius and the supraspinatus muscles, is too deeply placed to be palpated distinctly. The **inferior angle** and the **medial border**, from the root of the spine downwards, form visible prominences which are readily felt; the inferior angle overlies the seventh intercostal space at the level of the seventh thoracic spine; and the medial border is a little medial to the angles of the ribs.

The **tip** of the **coracoid process** may be felt by the finger pressed firmly on the anterior border of the deltoid at a point 2·5 cm. below the junction of the middle and lateral thirds of the clavicle. Medial to the coracoid there is a triangular depression which corresponds to the upper end of the interval between the pectoralis major and deltoid muscles. Behind that triangular depression are the termination of the cephalic vein, a lymph-gland, the first part of the axillary vessels, and the cords of the brachial plexus. By pressing firmly in that situation one can feel the pulsations of the **axillary artery**, and further pressure arrests the circulation in the artery by compressing the vessel against the second rib. The *first part* of the axillary artery may be cut down upon by a longitudinal incision in the interval between the pectoralis major and the deltoid. The **axillary vein** lies in front of the artery as well as to its thoracic side—thus adding to the difficulty of exposing the artery.

Humerus.—The **upper end** of the **humerus**, covered by the deltoid, gives rotundity to the shoulder. The **greater tuberosity** projects beyond the acromion

and is the most lateral bony landmark of the shoulder. When the head of the bone is dislocated, the lateral border of the acromion then becomes the most lateral bony landmark, and the shoulder presents a square contour. The **lesser tuberosity**, small but conical, can be felt through the deltoid. Pointing directly forwards, it is 2·5 cm. lateral to the tip of the coracoid process and a little below its level. In examining the upper end of the humerus for fracture, the tuberosities are grasped between the finger and thumb of one hand, and the flexed elbow is rotated with the other hand. The **head** of the **humerus** has the same direction as the medial epicondyle; its lower part can be palpated through the axilla, the arm being meanwhile abducted to bring the head into contact with the lower part of the capsule. It is through that—the weakest part of the capsule—that the head is driven in the common varieties of dislocation of the shoulder, viz., those due to forcible abduction. The **proximal epiphysis** of the humerus includes the head and both tuberosities (Pl. XV, Fig. 1, p. 268). The capsule is attached mainly to the epiphysis; in children, therefore, separation of the proximal epiphysis takes the place of dislocation. Disease in the upper part of the shaft does not necessarily involve the cavity of the joint. The **bicipital groove** is immediately lateral to the lesser tuberosity; it may be mapped out on the surface by a line, 5 cm. in length, drawn downwards along the axis of the humerus from the tip of the acromion. When there is *effusion into the joint*, the arm becomes slightly abducted, and there is fullness in front, along the line of the long tendon of the biceps. With the elbow at the side, the lower part of the capsule of the shoulder joint is loose and folded upon itself to form a dependent pocket; if, after an injury, the arm is retained too long in that position, the patient may be unable to abduct the arm, in consequence of the formation of adhesions in and around the pouch.

Access to the joint and to the upper end of the humerus, sufficient for excision of the joint or exploration of the bone, is obtained by an incision which begins immediately lateral to the coracoid process and follows the outline of the anterior border of the deltoid muscle downwards and laterally; a short incision parallel to the clavicle laterally from the upper end of the oblique incision may be added. That addition permits the lateral displacement of the anterior half of the deltoid muscle.

Axilla.—The **anterior fold** of the **axilla**, formed by the lower border of the pectoralis major, extends from the fifth rib to the middle of the anterior border of the deltoid. With the arm abducted, the interval between the sternal and clavicular fibres of the pectoralis major is indicated by a slight groove that extends downwards and laterally from the sternal end of the clavicle. The sternal fibres, along with the pectoralis minor, are removed in a complete operation for malignant disease of the breast, the pectoral branches of the acromio-thoracic artery being secured as they cross the interval between the sternal and clavicular portions of the greater pectoral. The **posterior fold** of the **axilla**, formed by the latissimus dorsi and the teres major muscles, is on a lower level than the anterior fold, and leaves the chest a little in front of the inferior angle of the scapula. Between the two folds, and running in the long axis of the limb from the axilla to the middle of the upper arm, is the prominence of the **coraco-brachialis muscle**. The pulsations of the **third part of the axillary artery** may be felt in the furrow immediately behind that prominence.

The axillary fascia resists the spontaneous rupture of an axillary abscess, which, therefore, tends to spread upwards under cover of the pectorals towards the root of the neck. To open the abscess, an incision is made on the medial wall of the axilla, behind and parallel to the lateral thoracic artery, which runs under cover of the anterior wall.

The **axillary lymph-glands** vary greatly in size and number; many are no larger than a pin's head. In women, some of them undergo an adipose functional involution whereby they come to resemble fat-lobules. In health, one or two glands can usually be felt by the fingers thrust upwards and medially behind the anterior fold, the arm being abducted—but only slightly, so as not to stretch the axillary fascia. The *central group*, embedded in the fat immediately deep to the axillary fascia, become inflamed in poisoned wounds of the upper limb. The same group, along with the *pectoral group* (related

to the medial wall of the axilla at the infero-lateral border of the pectoralis minor), are usually the first to become diseased in malignant affections of the breast. When the disease is more advanced the *posterior* (subscapular) and the *apical* (infraclavicular) groups are generally affected as well; and in a considerable number of cases diseased glands are found in the *retropectoral fascia, i.e.*, between the pectoralis major and minor and, above the minor muscle, on the first intercostal space in relation to the superior thoracic artery.

Female Mammary Gland.—The glandular tissue is arranged to form a central portion or *body*, and a peripheral portion made up of branching processes which radiate into the surrounding fat and become continuous ultimately with the fibrous septa of the subcutaneous fatty tissue. The gland has, therefore, no distinct capsule. In the young adult nullipara, the body is compact and well defined, and contains little intramammary fat, and the

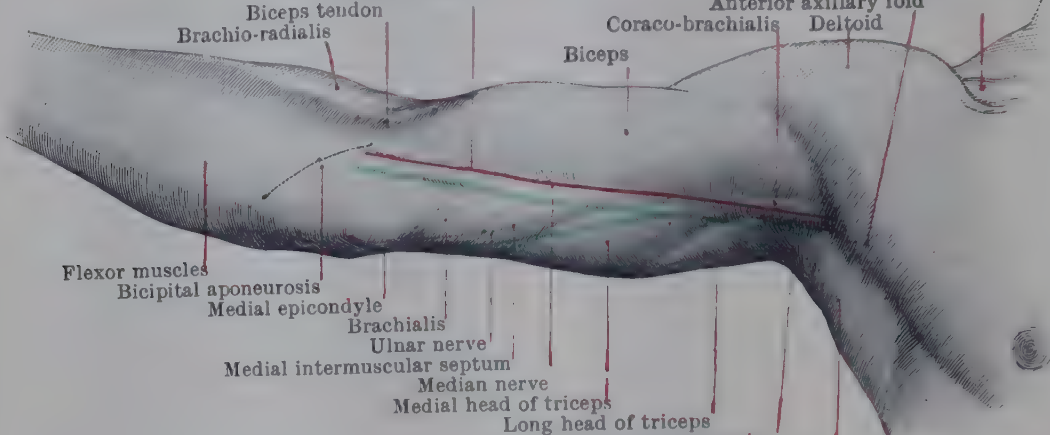

Fig. 1234.—Axilla and Medial Side of Arm and Elbow.

peripheral processes are relatively small. In the multipara, the body contains more fat, and the peripheral processes extend more widely into the surrounding fat.

The parenchyma is prolonged into the peripheral processes and into the loose retromammary areolar tissue and pectoral fascia. The gland has therefore a wide range. Vertically, it extends from the second rib to the sixth costal cartilage at the angle where it begins to ascend towards the sternum; horizontally, from a little medial to the edge of the sternum, opposite the fourth rib, to the fifth rib in the mid-axillary line. The *medial hemisphere* of the gland rests almost entirely on the pectoralis major; at its lowest part it slightly overlies the upper part of the aponeurosis covering the rectus abdominis muscle. The *superior quadrant* of the *lateral hemisphere* rests on the greater pectoral, on the edge of the lesser pectoral, and to a slight extent on the serratus anterior; on the serratus, however, it extends upwards into the axilla as high as the third rib, where it comes into relation with the *pectoral* group of axillary lymph-glands. The *remainder of the lateral hemisphere* rests almost entirely on the serratus anterior, except the lowest part, which overlaps the digitations of the external oblique which arise from the fifth and sixth ribs. It follows, therefore, that *fully one-third of the whole gland lies below and lateral to the axillary border of the pectoralis major muscle.* The surgeon must cut beyond the limits given if he wishes to remove the whole of the mammary tissue.

In operating for malignant disease of the breast, the surgeon removes, in addition to the whole gland and the greater part of the skin over it, both pectoral muscles (with the exception of the clavicular fibres of the pectoralis major), all the axillary lymph-glands, and, as far as possible, all the fat and fascia, including the sheath of the axillary vein. It must be remembered that the distal part of the axillary vein lies immediately under cover of the deep fascia of the lateral wall of the axilla; as the medial wall is cleaned, the nerve to the serratus anterior must not be injured; and as the posterior group of lymph-glands are removed, the nerve to the latissimus dorsi must be avoided,

as it is very important that the action of the latissimus dorsi should be retained when the pectoral muscles have been removed.

UPPER ARM

The anterior and posterior borders of the **deltoid** may be traced from the shoulder girdle to the insertion of the muscle. The surface relations of the anterior border have been referred to already; the posterior border forms a well-marked and important landmark as it crosses the angle between the lateral margin of the scapula and the upper part of the shaft of the humerus. By making an incision along that part of the posterior border of the deltoid, and pulling the edge of the muscle upwards and laterally, the surgeon exposes the **surgical neck** of the **humerus**, and the quadrilateral opening in the posterior wall of the axilla that transmits the **posterior circumflex artery** of the humerus and the **circumflex nerve**; a little lower down is the **radial nerve**. The **coraco-brachialis**, the guide to the upper half of the brachial artery, forms a prominence that occupies the upper half of the *medial bicipital furrow*. Traced downwards the medial bicipital furrow widens out into an elongated triangle. That triangle becomes continuous, distally, with the medial part of the cubital fossa, and is limited posteriorly by the medial intermuscular septum, which may be felt as a cord-like band extending upwards from the medial epicondyle; the floor of the space is formed by the medial part of the brachialis. Within the triangle are the following important structures, enumerated from the lateral to the medial side, viz.: the **brachial artery**, the **median nerve**, the **distal part of the basilic vein**, the **medial cutaneous nerve of the forearm**, and the **supratrochlear lymph-glands**, two or three in number. Extending upwards from the lateral epicondyle to the insertion of the deltoid is the lateral intermuscular septum, which is pierced at the junction of its upper and middle thirds by the **radial nerve**. Between the lateral intermuscular septum and the lateral edge of the biceps there is an ill-defined groove called the *lateral bicipital furrow*, the floor of which is formed by a strip of the brachialis, and, nearer the elbow, by the brachio-radialis and extensor carpi radialis longus.

The posterior compartment of the arm is occupied by the **triceps**, the *long head* of which can be traced upwards to the lateral margin of the scapula, in front of the posterior border of the deltoid and behind the posterior fold of the axilla. The *lateral head* of the triceps, after emerging from under cover of the distal part of the posterior border of the deltoid, is continued obliquely along the lateral side of the upper arm as a well-marked muscular elevation. Above the olecranon is the strap-like tendon of insertion of the triceps, which, when the elbow is fully flexed, forms an admirable posterior splint in fractures immediately above the epicondyles of the humerus.

The **brachial artery**—slightly overlapped in the upper half of the upper arm by the coraco-brachialis and in the lower half by the biceps—can be felt pulsating throughout the whole length of the anterior part of the medial bicipital furrow. To mark the course of the vessel on the surface a line is drawn from the medial border of the coraco-brachialis, at the level of the posterior fold of the axilla, to a point (opposite the neck of the radius) 1·8 cm. below the middle of the bend of the elbow. When the vessel is ligatured, the edges of the coraco-brachialis and biceps muscles, together with the median nerve, furnish valuable guides to the artery, the mobility of which is often a source of trouble in the operation.

The **basilic vein** is superficial to the deep fascia in the lower third of the upper arm, and is visible in the medial epicondylar triangle and the lower part of the medial bicipital groove. The **cephalic vein** ascends in the superficial fascia over the lateral surface of the biceps to reach the interval between the deltoid and pectoralis major.

The surface guide for the **median nerve** is the same as that for the brachial artery. The **ulnar nerve** is indicated superficially by a line drawn from the lateral wall of the axilla, immediately behind the prominence of the coraco-brachialis, to the back of the medial epicondyle; in the proximal half of the upper

arm the nerve lies close behind the brachial artery under cover of the basilic vein; in the distal half it lies a little behind the medial intermuscular septum, partially embedded in the fibres of the medial head of the triceps. The course of the **radial nerve** is traced by first marking the point where it pierces the lateral intermuscular septum, viz., the junction of the upper and middle thirds of a line drawn from the insertion of the deltoid to the lateral epicondyle; from that point a line is drawn obliquely downwards and forwards to the front of the lateral epicondyle, and then onwards to the lateral side of the lower end of the radius. To map out the nerve as it lies in its spiral groove on the humerus, a line is drawn from the same point obliquely upwards across the prominence of the lateral head of the triceps to the junction of the posterior fold of the axilla with the arm. In fractures of the humerus in the neighbourhood of the insertion of the deltoid, the nerve is not infrequently lacerated, or it is so involved in the callus as to produce the condition known as "*drop-wrist*"—the result of paralysis of the extensor muscles of

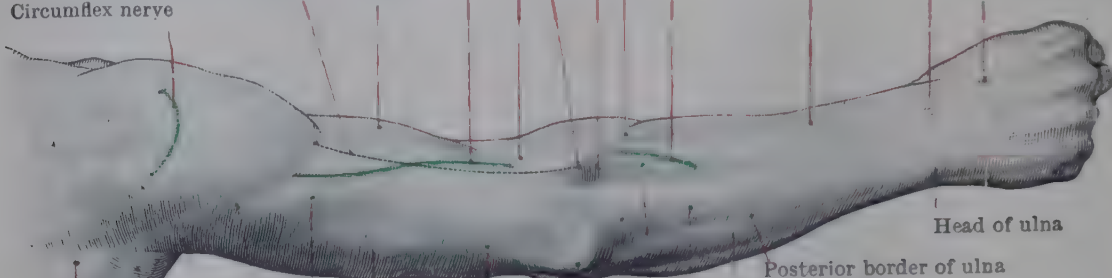

FIG. 1235.—BACK OF UPPER LIMB.

the forearm. To cut down on the nerve, the incision is begun a little below the point where it pierces the lateral intermuscular septum, and carried obliquely upwards and slightly backwards through the lateral head of the triceps.

The **shaft** of the **humerus**, nowhere subcutaneous, is most readily palpated in the region of the insertion of the deltoid, upwards along the lateral head of the triceps, and downwards behind the lateral supracondylar ridge. The **surgical neck** is the portion that intervenes between the tuberosities and the attachments of the muscles inserted into the lips and floor of the bicipital groove; it is related to the lateral wall of the axilla, and is on a level with the junction of the upper and middle thirds of the deltoid. The circumflex vessels and nerve are at the same level.

The shaft may be cut down upon with least injury to soft parts:—(1) In its *upper third, in front*, by an incision which extends downwards through the anterior fibres of the deltoid, parallel to the bicipital groove and a little lateral to it; the sheath of the biceps will thus be avoided, and the anterior circumflex artery will be the only vessel divided. (2) In the *upper third, behind*, by an incision through the posterior fibres of the deltoid, the bone being reached immediately lateral to the origin of the lateral head of the triceps, and the radial nerve thus avoided; the circumflex vessels and nerve will be exposed at the upper part of the wound. (3) In the *lower third*, by an incision which extends upwards from the back of the lateral epicondyle a little to the medial side of the lateral intermuscular septum.

The entire humerus, together with the shoulder joint and the elbow joint, may be exposed by an incision which begins at a point immediately lateral to the coracoid process and then follows the cephalic vein to the bend of the elbow. The incision is continued into the upper third of the forearm. Exposure of the upper third of the humerus and the shoulder joint

is achieved by lateral displacement of the deltoid; to get at the middle and lower thirds of the humerus the brachialis muscle is split a finger's breadth lateral to the biceps.

ELBOW

In injuries at the elbow, the diagnosis rests mainly upon the relative positions of the bony points, which are therefore of great importance. The **epicondyles** of the humerus are both subcutaneous and on the same level, the medial being the more prominent (Pl. XI, p. 256). In the extended position of the elbow the tip of the **olecranon** is on a level with a line joining the epicondyles; when the forearm is flexed the olecranon descends (Pl. XII, p. 257), and when full flexion is reached it lies 2·5 cm. distal to the epicondyles and in a plane in front of the posterior surface of the lower end of the humerus. The **head** of the **radius**, which lies nearly

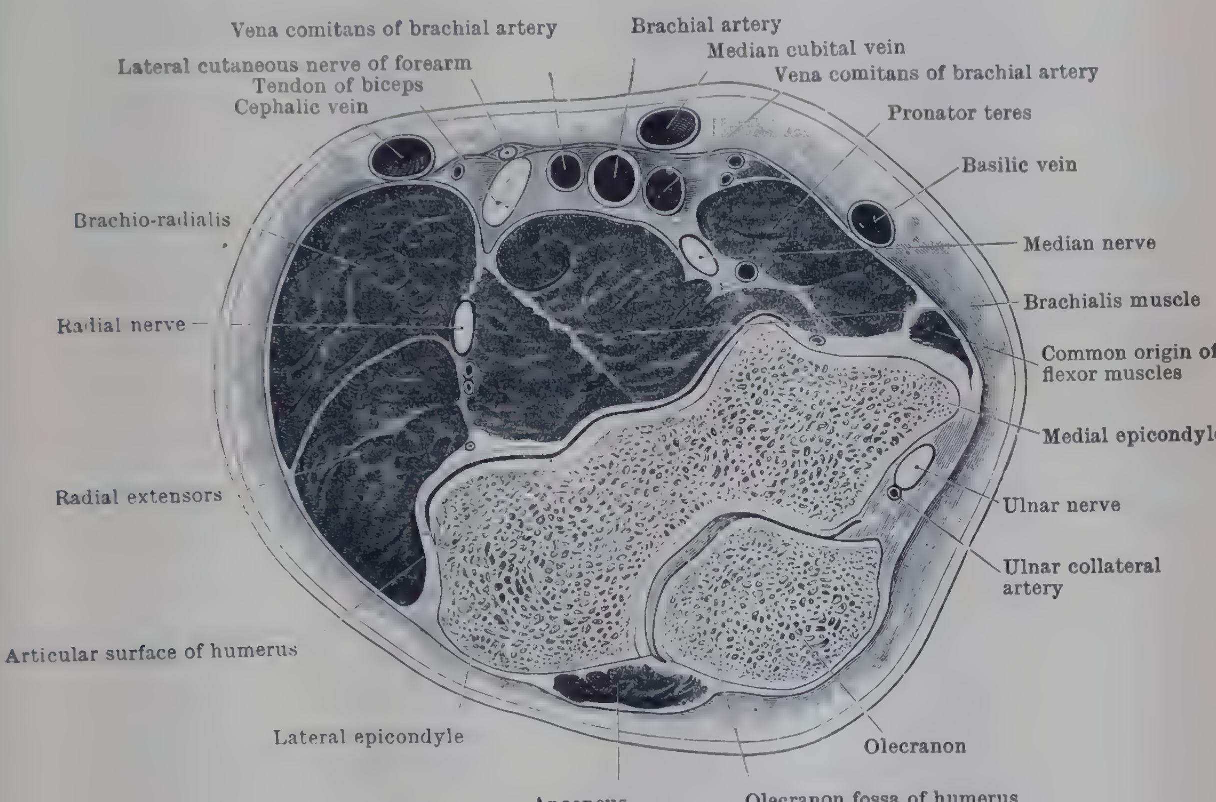

Fig. 1236.—Transverse Section through the Bend of the Elbow.

2·5 cm. below the lateral epicondyle, is felt best from behind; the thumb is placed on it while the semiflexed forearm is being alternately pronated and supinated. On the lateral part of the back of the extended elbow there is a distinct dimple which overlies the **radio-humeral joint**; that dimple, along with the hollows on each side of the olecranon, becomes effaced by synovial thickenings and effusions into the joint. The **coronoid process** is too deep to be felt distinctly. The **distal epiphysis** of the humerus includes the articular portion and the lateral epicondyle; it is therefore almost entirely intracapsular, and, because of that, foci of disease in its neighbourhood soon invade the cavity of the joint. The medial epicondyle ossifies as a separate epiphysis which unites with the distal end of the diaphysis (Pls. XIII, XIV, p. 260). In interpreting radiographs of the elbow in children of six years and older, care must be taken not to mistake this centre of ossification for a fracture; and after twelve years the same caution applies to the lateral portion of the main distal epiphysis of the humerus (Pl. XIII). In the commonest dislocation of the elbow, viz., with backward displacement of both bones of the forearm, the normal relative position of the bony points is lost, whereas in a transverse fracture above the epicondyles the normal relations are maintained. In the child the head of the radius is relatively smaller than in the

adult and is less firmly kept in position by the annular ligament; it is liable therefore to be partially dislocated—giving rise to the condition known as "*pulled elbow*".

To evacuate pus from the elbow joint a vertical incision is made over the back of the joint immediately lateral to the olecranon.

The **median vein** is seen to bifurcate into the median basilic and median cephalic veins 1 cm. below the middle of the bend of the elbow; opposite the same point, but behind the deep fascia, is the **bifurcation** of the **brachial artery**. The **median basilic** and **median cephalic** veins diverge as they ascend one on each side of the biceps tendon; the larger of the two veins, viz., the median basilic, is usually selected for the operations of venesection and transfusion. In the absence of a median vein (as in Figs. 1117, 1237), a **median cubital vein**, which passes from the cephalic to the basilic vein, takes the place of the median basilic vein. When the elbow is flexed, the **biceps tendon** can be traced vertically through the middle of the cubital fossa almost to its insertion. Passing downwards and medially from the medial edge of the tendon is the **bicipital aponeurosis**, which separates the median cubital vein from the brachial artery. If the finger-tip is insinuated behind the medial edge of the aponeurosis it will rest on and feel the pulsations of the brachial artery. The **median nerve** descends through the space a little medial to the brachial artery. The **radial nerve** descends in front of the capitulum of the humerus under cover of the brachioradialis. The **ulnar nerve** can be rolled beneath the finger on the back of the medial epicondyle; its position renders it liable to injury in severe fractures about the elbow; and when the joint is excised care must be taken not to injure the nerve.

FOREARM AND HAND

The upper half of the **radius** is deeply placed, but the lower half is easily palpated. The anterior border of its lower end is felt as a prominent transverse ridge about 2·5 cm. above the thenar eminence; immediately below the ridge is the **wrist joint** (radio-carpal). The **tip** of the **styloid process**—1 cm. lower than that of the ulna—is deeply placed at the lateral side of the wrist in the hollow between the extensor tendons of the first and second phalanges of the thumb. On the middle of the posterior surface of the lower end of the radius is the **dorsal tubercle of the radius**, which intervenes between the extensor pollicis longus and the short radial extensor of the wrist; the tubercle can be distinctly felt, and may be taken as a guide to the upper end of Lister's dorso-radial incision for excision of the wrist. The **posterior border of the ulna** is subcutaneous throughout, and can be felt along the medial side of the extensor carpi ulnaris. Above the wrist, on the ulnar side of the back of the limb, when the forearm is prone, there is the well-marked rounded prominence of the **head** of the **ulna**, and in front of it the **styloid process**—on the ulnar side of the limb; the deep groove between the two is occupied by the tendon of the extensor carpi ulnaris.

The **carpal bones** are built up so as to form an arch, converted by the **flexor retinaculum** into a tunnel for the transmission of the flexor tendons. At each end of the arch the two bony points to which the retinaculum is attached furnish important landmarks. Those bony points are: *laterally*, the tubercle of the scaphoid and the crest of the trapezium; *medially*, the pisiform and the hook of the os hamatum. The **tubercle** of the **scaphoid** is felt immediately above the thenar eminence, close by the radial side of the flexor carpi radialis; 1 cm. below the tubercle is the **crest** of the **trapezium**, felt deeply in the medial part of the thenar eminence. At the upper end of the hypothenar eminence, and crossed by the crease which separates the forearm from the hand, is the **pisiform bone**, above which is the tendon of the flexor carpi ulnaris descending to be inserted into it. The **hook** of the **os hamatum** is felt deeply in the radial part of the hypothenar eminence, and a full finger's breadth below and lateral to the pisiform.

The bases of the **first**, **third**, and **fifth metacarpals**, all of which can be readily

identified on the back, furnish a sufficient guide to the line of the carpo-metacarpal joints. At the base of the **third metacarpal** there is a tubercle, called its *styloid process*, which can be felt projecting upwards from its dorsal surface at a point 2·5 cm. vertically below the dorsal tubercle of the radius. The metacarpal styloid process marks the insertion of the extensor carpi radialis brevis—the favourite site for the development of a "*ganglion*", which in many cases can be ruptured by sudden firm pressure against the tubercle. Anteriorly, the **carpo-metacarpal joints** correspond to the distal border of the flexor retinaculum.

The **first row of knuckles** are the heads of the metacarpal bones. Anteriorly, the **metacarpo-phalangeal joints** are 2 cm. above the edge of the web of the fingers; posteriorly, the joints are immediately distal to the knuckles. A well-marked crease crosses obliquely over the front of the metacarpo-phalangeal joint of the thumb. The first and the terminal **interphalangeal joints** are opposite the most distal of the various creases that overlie the joints.

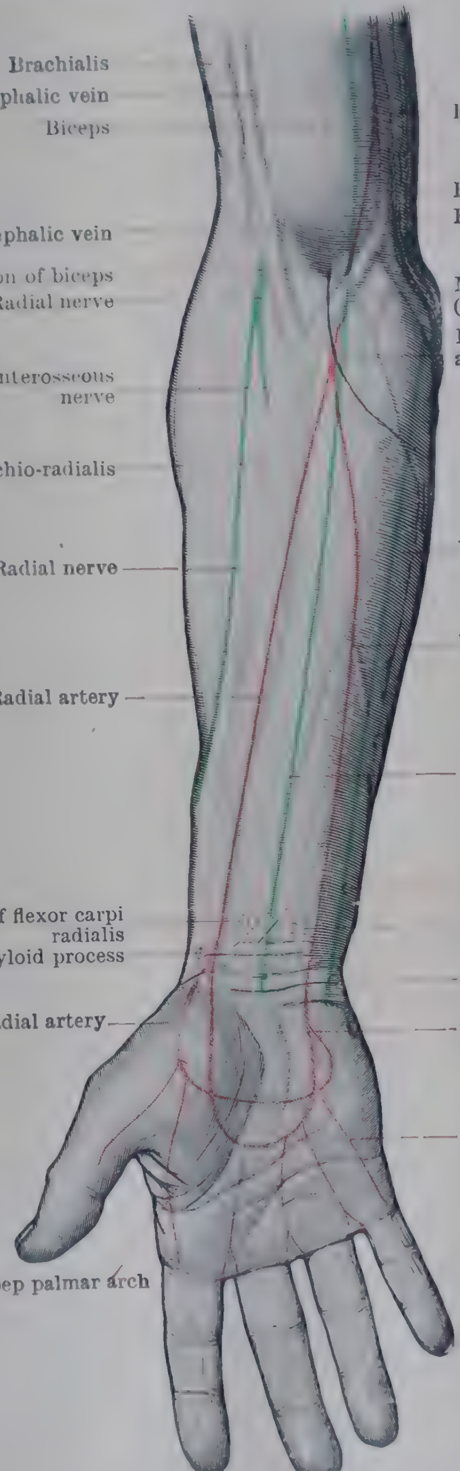

FIG. 1237.—FRONT OF ELBOW, FOREARM, AND HAND.

The most important *muscular* landmarks on the front of the forearm are the brachio-radialis, the flexor carpi radialis, and the pronator teres. The **brachio-radialis** is thrown into prominence when it flexes the semiprone forearm against resistance. At the junction of the upper and middle thirds of the forearm the **pronator teres** passes under cover of the brachio-radialis; between the two is the radial artery. The tendon of the **flexor carpi radialis** forms a prominent landmark descending along the middle of the front of the forearm towards the tubercle of the scaphoid; the tendon of the **palmaris longus**, when present, is seen at its medial side.

On the back of the forearm the intermuscular septum between the radial extensors of the wrist and the extensors of the fingers corresponds to the proximal part of a line drawn from the lateral epicondyle of the humerus to the dorsal tubercle of the radius. The **posterior interosseous nerve**, at the point at which it emerges from the supinator muscle, will be found at the bottom of that septum, 5 cm. below the head of the radius; below that point the septum is the best line along which to cut down upon the posterior surface of the radius. Winding

across the lower third of the back of the forearm there is an oblique prominence caused by the **abductor pollicis longus and extensor pollicis brevis muscles.**

If the front of the hand, the fingers being extended, is inspected, it is apparent that the palm may be divided into three areas—(1) the thenar eminence formed by the small muscles of the thumb, (2) the hypothenar eminence in association with the muscles of the little finger, (3) the hollow of the palm. Between the thenar and hypothenar areas, there are certain spaces filled with areolar tissue which are

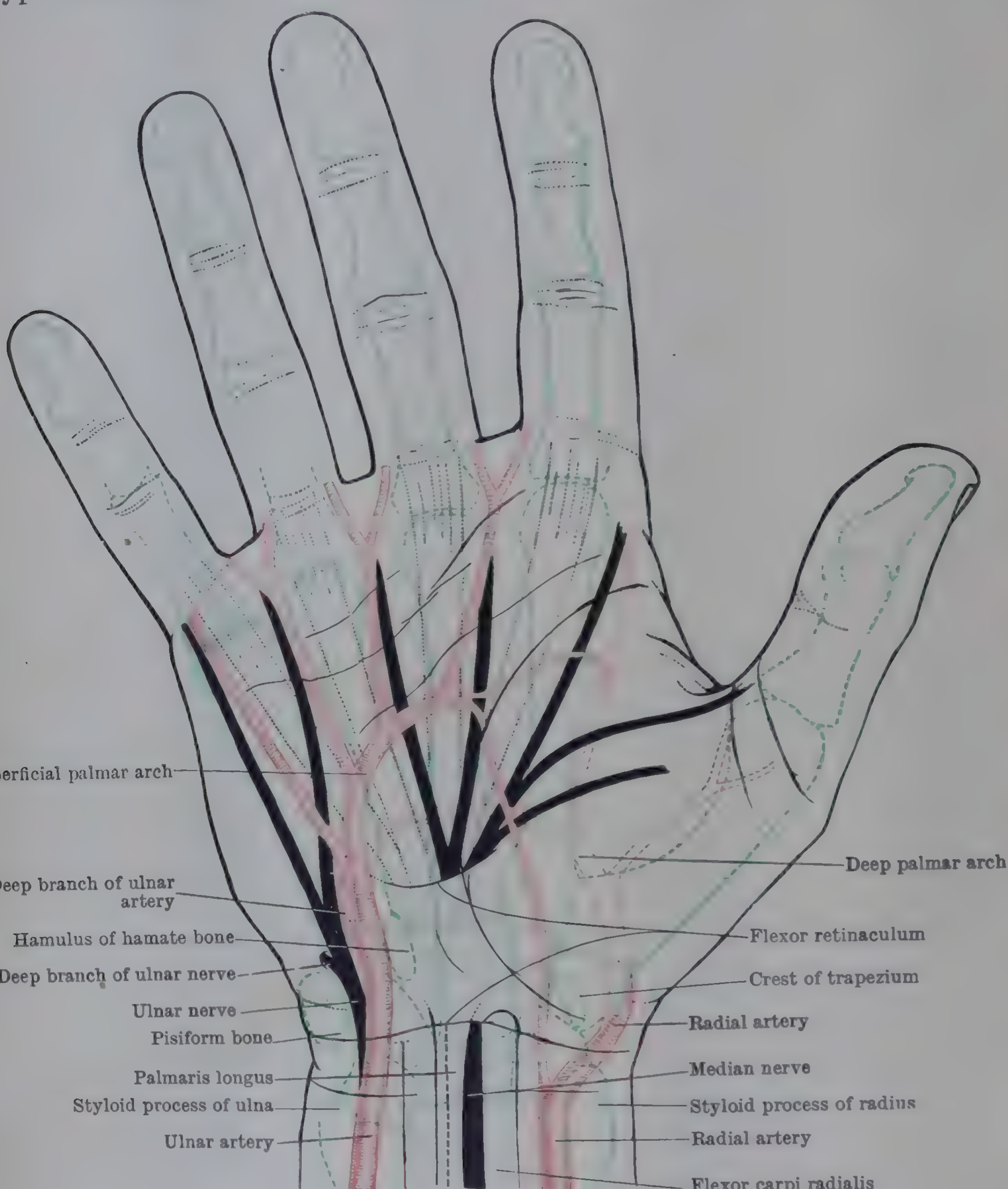

FIG. 1238.—PALM OF HAND. Cf. Pl. LXXXII, p. 1297.

of importance in connexion with acute pyogenic infections—they are the lateral and medial mid-palmar spaces (Fig. 1240).

The *lateral mid-palmar space* lies to the ulnar or medial side of the flexor pollicis longus tendon. Its anterior boundaries are the short muscles of the thumb, the overlying deep fascia, the flexor tendons of the index finger, and the first two lumbrical muscles; posteriorly lie the transverse and oblique heads of the adductor pollicis, and a portion of the first dorsal interosseous muscle. It is separated from the medial mid-palmar space by a fibrous septum, while the tendon of the flexor pollicis longus lies to its radial side. Deep to the flexor tendons of the third, fourth, and fifth digits is the *medial mid-palmar space*—bounded posteriorly by the interosseous muscles and metacarpal bones, medially by the hypothenar muscles, and laterally by a fibrous septum which extends from

the fascia behind the deep flexor tendon to the origin of the transverse head of the adductor.

The synovial flexor sheaths of the palm and of the digits (Fig. 437, p. 511) are of surgical importance in consequence of their liability to suppurative inflammation. The **common flexor sheath** begins 3·8 cm. above the flexor retinaculum and extends downwards behind it to a little beyond the middle of the palm. The **digital flexor sheaths** extend from the bases of the distal phalanges to the level of the distal

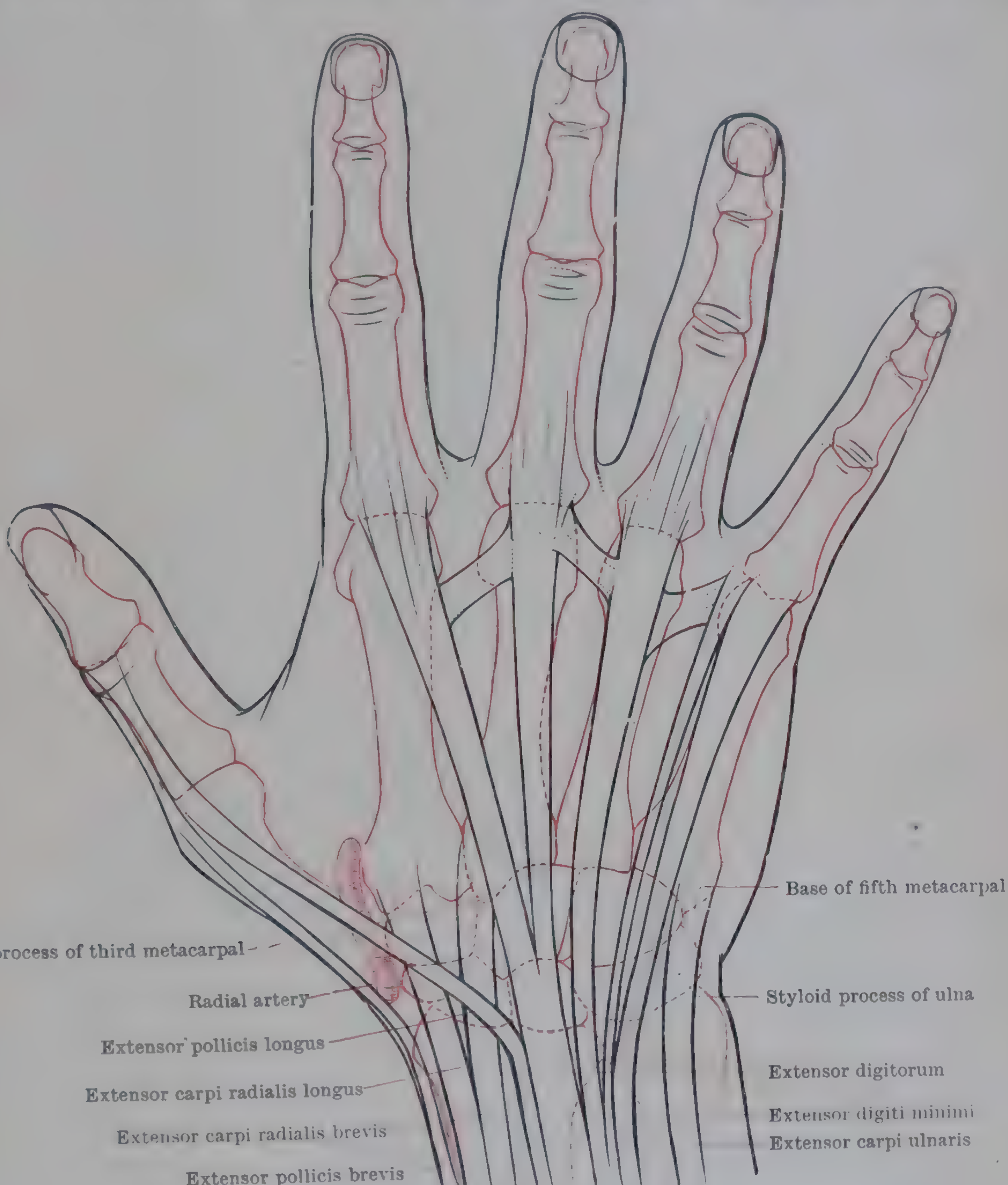

FIG. 1239.—BACK OF HAND.

transverse crease of the palm opposite the necks of the metacarpal bones, *with the exception of the sheath of the little finger*, which is continuous with the common flexor sheath of the palm. The **sheath of the flexor pollicis longus** extends from the base of the terminal phalanx to a point about 2·5 cm. above the retinaculum ; it sometimes communicates with the common flexor sheath. From the anatomical arrangement it follows that suppuration in the sheaths of the little finger and thumb is specially apt to spread upwards into the palm, and thence behind the flexor retinaculum into the forearm.

The pulsations of the **radial artery** can readily be felt in the lower third of the forearm, midway between the lateral border of the radius and the tendon of the flexor carpi radialis. The course of the vessel is indicated on the surface by a line drawn from the bifurcation of the brachial (1·3 cm. below the middle of the bend of the elbow) to the tubercle of the scaphoid ; above that tubercle and below the

tip of the styloid process, the artery winds to the dorsum of the radial side of the wrist; on the back of the wrist the vessel, after passing deep to the extensor tendons of the thumb, dips into the palm through the upper end of the first interosseous space. Incisions for opening or resecting the wrist are planned so as to avoid the vessel.

The upper third of the **ulnar artery** is deeply placed, and takes a curved course from the bifurcation of the brachial towards the medial part of the front of the forearm; the lower two-thirds of the vessel correspond to the lower two-thirds of a line drawn from the front of the medial epicondyle to the radial border of the pisiform bone. The course of the **ulnar nerve**, in the forearm, corresponds to the whole of that line.

The **median nerve** in the forearm is opposite a line drawn from a point midway between the middle of the cubital fossa and the medial epicondyle to a point midway between the styloid processes; in the lower third of the forearm the line follows the medial border of the tendon of the flexor carpi radialis.

To evacuate pus spreading deeply up the front of the forearm, an incision is

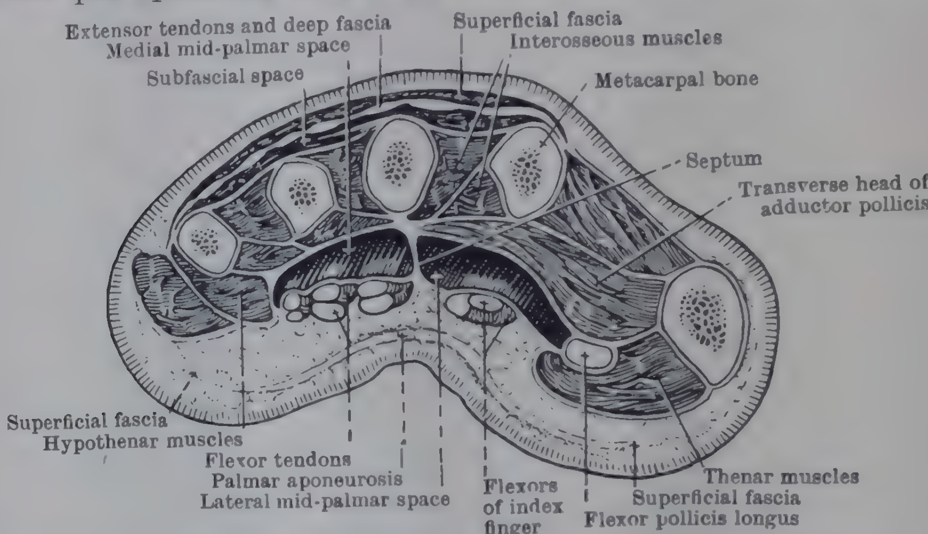

FIG. 1240.—TRANSVERSE SECTION THROUGH HAND TO SHOW THE MID-PALMAR SPACES. (Fifield, 1939.) (Cf. Fig. 438, p. 512.)

made along the anterior border of the lowest part of the radius, and the abscess is drained by Hilton's method. The **radial nerve** winds to the dorsum of the forearm round the lateral border of the radius deep to the tendon of the brachio-radialis, at the junction of the middle and lower thirds of the forearm.

The summit or most distal part of the **superficial palmar arch** corresponds to the mid-point of a line drawn from the middle of the most distal transverse crease of the wrist to the root of the middle finger; a line drawn from the radial border of the pisiform bone across the hook of the hamate bone, and thence in a curved direction downwards and laterally to that point, corresponds to the main part of the arch; the first and fourth digital branches overlie the fifth and third metacarpal bones respectively, and the second and third overlie the fourth and third interspaces respectively. The **deep arch** lies almost transversely, midway between the distal border of the flexor retinaculum and the superficial arch. The **radialis indicis** artery corresponds to the radial border of the index-finger.

The **ulnar nerve** and the commencement of its two divisions lie at the medial side of the superficial palmar arch; the pisiform and the hook of the hamate are therefore the guides to the nerve. The **median nerve** emerges from behind the flexor retinaculum opposite the medial edge of the thenar eminence. It then divides into two portions—the lateral one provides (1) the three digital branches for the supply of the thumb and the radial side of the index finger, and (2) a muscular branch to the three muscles of the thenar eminence. The digital branches to the thumb run along the medial or distal edge of the eminence; incisions for the removal of foreign bodies may therefore be made into the thenar eminence with greater freedom than into the hypothenar eminence. But the muscular branch passes laterally 0·5 cm. below the flexor retinaculum and must be avoided when an incision is made into the thenar space.

When pus forms in connexion with infections of the digits or hand it is encountered in one or other of the following situations: (1) the pulp of the digit; (2) the synovial sheath of the flexor pollicis longus; (3) the lateral mid-palmar space; (4) the medial mid-palmar space; (5) the flexor sheaths of the middle three digits; (6) the flexor synovial sheath of the little finger; (7) the common synovial flexor sheath. For each situation there is an appropriate incision:—Infection of the pulp requires a horse-shoe incision which passes round the periphery of the finger-pulp, so that the distal end of the flap is free. The sheath of the flexor pollicis longus is drained by an incision which extends from the distal crease of the thumb to the ulnar side of the thenar eminence, finishing 3·8 cm. below the distal wrist crease. The lateral mid-palmar space is entered through an incision made immediately dorsal to the edge of the web between the thumb and index finger; a forceps passed through the incision deep to the muscles of the thumb enters the space. The medial mid-palmar space is drained by an incision in the web between the middle and ring fingers. To evacuate the sheath of the little finger, an incision is made along the ulnar border of the palmar surface in the line of the tendon of the little finger and slightly to its ulnar side; from that incision the common sheath also can be explored by forceps pushed upwards, laterally and slightly backwards. A longitudinal incision between the median and ulnar nerves on the proximal side of the superficial palmar arch drains the common flexor sheath directly. To open the digital flexor sheaths, incisions are made along the antero-lateral aspect of the fingers opposite the proximal and middle phalanges.

LOWER LIMB

GLUTEAL REGION

The region of the hip and buttock extends from the iliac crest to the fold of the buttock. The highest point of the **iliac crest**, situated a little behind its middle, is

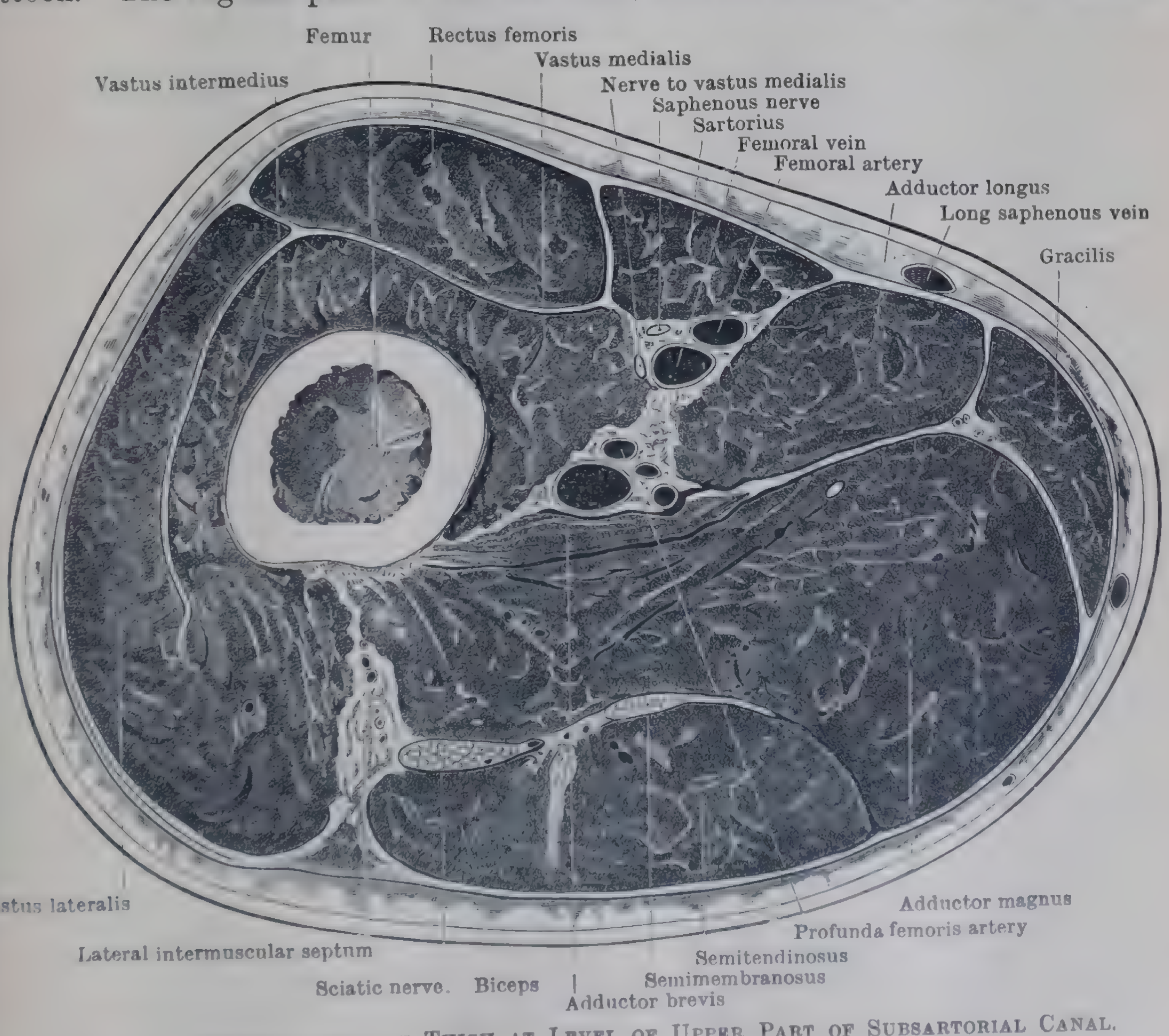

FIG. 1241.—SECTION THROUGH THIGH AT LEVEL OF UPPER PART OF SUBSARTORIAL CANAL.

at the level of the fourth lumbar spine; the **anterior superior iliac spine** is directed forwards, and belongs to the groin, which it limits laterally; the **posterior superior**

spine, situated in the floor of a dimple, is at the level of the second sacral spine and the middle of the **sacro-iliac joint**. Six centimetres above and behind the anterior superior spine there is a prominence on the outer lip of the iliac crest termed the **tubercle of the crest**; it is the most lateral part of the crest, and it has been referred to already. A handbreadth below the tubercle of the crest is the **greater trochanter** —the most lateral bony landmark of the hip. Its anterior and posterior borders are felt best between the fingers and thumb while the limb is slightly abducted to relax the ilio-tibial tract; and, if the thigh is then rotated, it will be noted that the trochanter rotates round the segment of a circle the radius of which is the head and neck of the femur. *Nelaton's line*, drawn from the anterior superior spine to the most

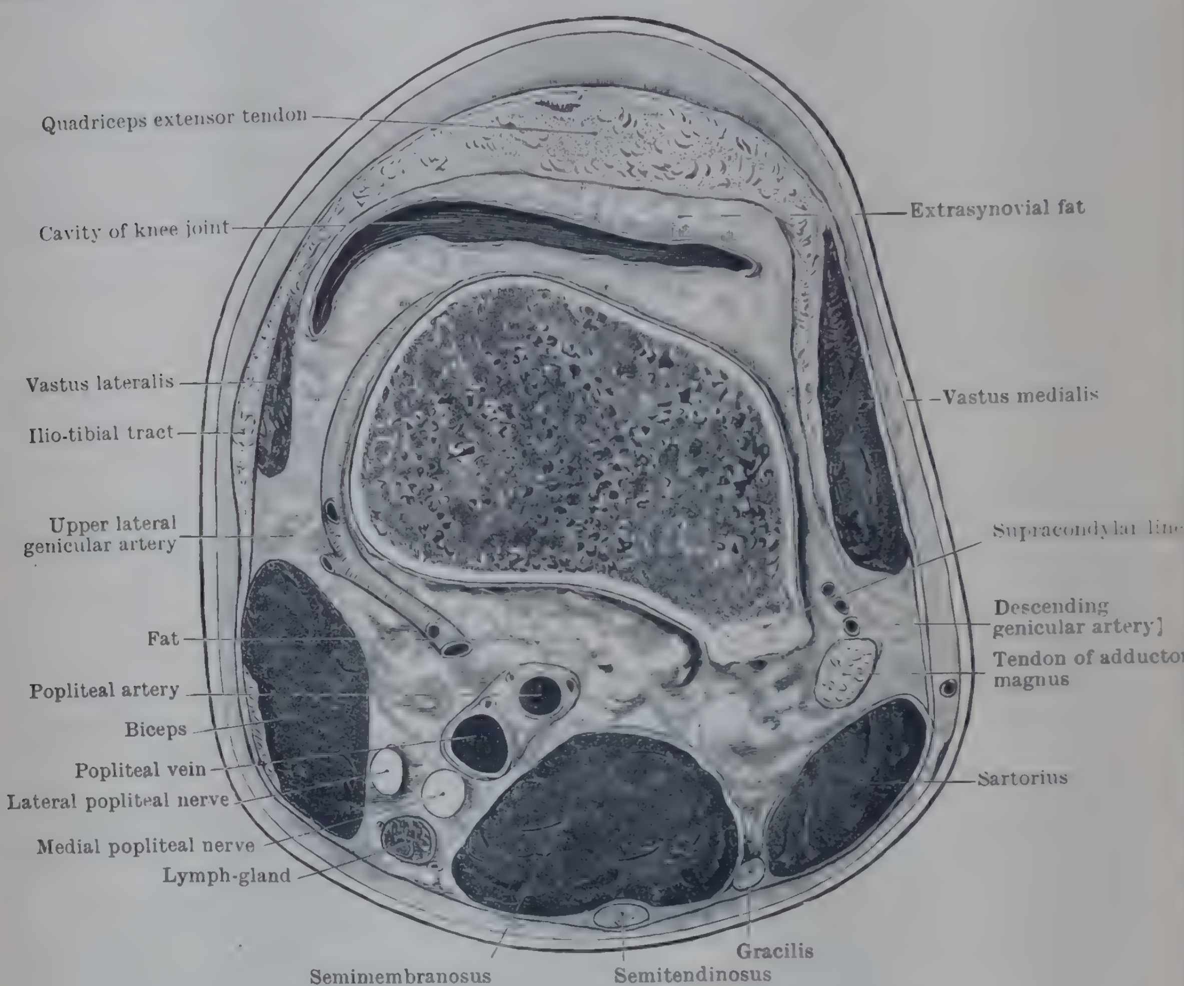

Fig. 1242.—Section through Thigh immediately above Patella.

prominent part of the ischial tuberosity, crosses the hip at the level of the upper border of the greater trochanter; that line is employed to ascertain the presence or absence of upward displacement of the trochanter. John Chiene demonstrated the relative height of the trochanters by stretching two tapes across the front of the pelvis, one between the anterior superior spines, and the other between the antero-superior angles of the trochanters; the lower tape converges towards the upper on the side of the upward displacement. The **ischial tuberosity**, in the erect posture, is overlapped by the lower border of the gluteus maximus; its most prominent part is felt a little above the medial part of the fold of the buttock. If the thigh is rotated medially, the **lesser trochanter** of the femur may be felt by deep palpation above the lateral end of that fold; it corresponds to the interval between the lower border of the quadratus femoris and the upper border of the adductor magnus, and therefore, also, to the level of the **medial circumflex artery** of the thigh.

The **lower border** of the **gluteus maximus**, in its medial half, is a little above the **fold of the buttock**, crosses it about its middle, and is continued downwards and laterally to meet the upper end of the furrow of the lateral intermuscular septum at the junction of the upper and middle thirds of the femur. The medial borders of the right and left great gluteal muscles are separated by the **natal cleft**, which

extends upwards and backwards from the perineum to the level of the third sacral spine, where it opens out into the triangle on the back of the sacrum. Anteriorly the hip is limited by the prominence of the **tensor fasciæ latæ** muscle, which extends downwards and slightly backwards from the anterior part of the iliac crest to join the ilio-tibial tract below the root of the greater trochanter.

The **superior gluteal artery** reaches the gluteal region through the upper part of the greater sciatic foramen, opposite a point at the junction of the upper and middle thirds of a line drawn from the posterior superior iliac spine to the upper border of the greater trochanter.

The **sciatic nerve** enters the gluteal region at a point opposite the junction of the upper and middle thirds of a line drawn from the posterior superior iliac spine to the ischial tuberosity; from that point the nerve passes downwards and slightly laterally on the ischium to a point midway between the ischial tuberosity and the greater trochanter. The **spine of the ischium** and the **internal pudendal vessels** are opposite the junction of the lower and middle thirds of the same line. The vessels and nerves which enter the gluteal region may be exposed by making an incision from the greater trochanter to the crest of the ilium, and continuing it backwards to the posterior superior iliac spine. The origin of the gluteus maximus is divided, and the musculo-cutaneous flap so fashioned is retracted posteriorly to display the region.

BACK OF THIGH AND POPLITEAL FOSSA

The **hamstring muscles**, and especially the tendons of the biceps and semitendinosus, are thrown into prominence when one stands on tiptoe with the knee slightly flexed, or flexes the leg against resistance. When the hamstrings are thrown into action, the line of the **lateral intermuscular septum** of the thigh is indicated by a well-marked furrow that extends from the lower edge of the insertion of the gluteus maximus to the lateral side of the knee; behind that furrow is the **biceps femoris**, and in front of it is the **vastus lateralis**, covered by the ilio-tibial tract. When the **shaft of the femur** has to be cut down upon, the incision that involves the least injury to the soft parts is one made along the whole length of that furrow. The popliteal surface of the femur and deep-seated popliteal abscesses are reached most conveniently through the lower part of the same incision.

The course of the **sciatic nerve** corresponds to the upper half of a line drawn from a point midway between the ischial tuberosity and the greater trochanter to the centre of the popliteal fossa. The nerve enters the thigh under cover of the lateral border of the biceps, whereas the **posterior cutaneous nerve** of the thigh, which takes the same line, descends superficial to the biceps, between it and the fascia lata.

The **lateral popliteal nerve** may be rolled under the finger as it descends along the medial side of the tendon of the biceps and behind the head of the fibula: so close is the nerve to the tendon that, when tenotomy is necessary, the tendon should be divided by the open method rather than subcutaneously.

Abscesses may reach the flexor compartment of the thigh from various sources: (1) from the back of the hip joint; (2) from the pelvis, through the greater sciatic foramen; (3) from one or other of the bursæ under the gluteus maximus; (4) from the front of the hip joint by passing backwards under cover of the tensor fasciæ latæ or by winding backwards below the neck of the femur and through the interval between the quadratus femoris and the adductor magnus; (5) from the iliac fossa behind the inguinal ligament into the femoral triangle, and thence to the back of the thigh by one or other of the routes already mentioned; (6) upwards from the popliteal surface of the femur, the knee, a popliteal gland, or a bursa.

When the knee is extended the **popliteal fascia** is put upon the stretch, and the hollow behind the knee is obliterated; when the knee is flexed the fascia is relaxed, and the fingers may be pressed deeply into the femoral division of the fossa; as a rule, the pulsations of the popliteal artery can be felt. Deep to the **semitendinosus** is the **semimembranosus**, which is still fleshy in its lower part, and bulges into the space to overlap the upper part of the popliteal artery. Between

the semimembranosus and the medial head of the gastrocnemius there is the most important **bursa** in the popliteal region; it not infrequently becomes distended with fluid and then presents usually a more or less sausage-shaped outline; sometimes the bursa communicates with the cavity of the knee joint.

To map out the line of the **popliteal vessels** and the **medial popliteal nerve**, a line is drawn from a point a little medial to the upper angle of the fossa to a point midway between the condyles of the femur, and thence along the middle of the fossa to the level of the lower part of the tubercle of the tibia. The medial popliteal nerve lies immediately under cover of the deep fascia; the artery is separated from the popliteal surface of the femur by a quantity of fat. The popliteal **lymph-glands** lie near the vessels.

FRONT OF THIGH

Between the front of the thigh and the abdomen is the *groove of the groin* in which the **inguinal ligament** can be felt as a tense band stretching from the

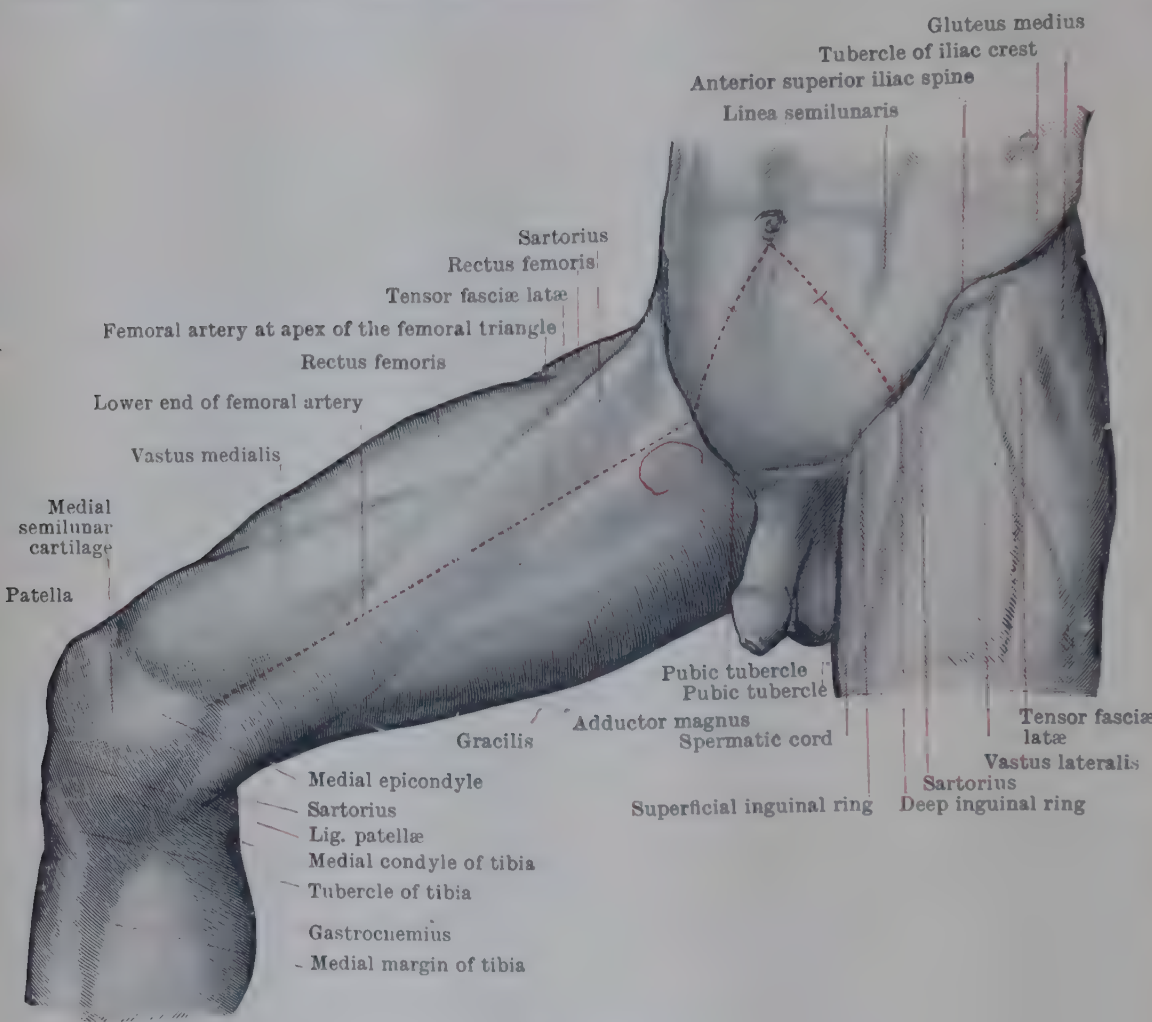

FIG. 1243.—THE THIGH AND GROIN.

anterior superior iliac spine to the pubic tubercle. The **anterior superior spine** looks directly forwards. To make comparative measurements of the two lower limbs a tape is stretched from that spine to the tip of the malleolus, taking care that the pelvis is horizontal, and the limbs are in corresponding positions. The **pubic tubercle**, in a man, is felt about 2·5 cm. lateral to the upper margin of the pubic symphysis, and, in a woman, rather farther from the symphysis—at the upper and lateral part of the mons pubis. Between the tubercle and the symphysis is the **pubic crest**, the two crests together forming a rounded, bony ridge. A line drawn from the pubic tubercle horizontally across the front of the thigh crosses the front of the hip joint at the level of the lower part of the head of the femur. The cord-like **tendon** of the **adductor longus** is readily felt, and a point abou t2·5 cm. below

the pubic tubercle is selected for performing the operation of subcutaneous tenotomy of the tendon.

The centre of the **saphenous opening** is situated 3·8 cm. below and lateral to the pubic tubercle; the opening overlies the medial (hernial) and intermediate (venous) compartments of the femoral sheath; behind the lateral border of the opening is the arterial compartment of the sheath; crossing over the lower border is the terminal part of the long saphenous vein. A femoral hernia makes its way into the thigh behind the upper edge of the opening. The course of the **long saphenous vein** in the thigh is indicated by a line drawn from the adductor tubercle of the femur to the lower part of the saphenous opening.

The **horizontal chain** of superficial **inguinal lymph-glands** can usually be felt a little below the line of the inguinal ligament; when the glands are inflamed the surgeon should not neglect to examine the buttocks and anus as well as the external genitals. The **vertical chain** lies in close relation to the upper end of the long saphenous vein. *Deeper* glands also are met with, behind the cribriform fascia close to the medial side of the femoral vein; and there is generally one in the femoral canal. To clear out the glands in the groin, an incision is made parallel to the whole length of the inguinal ligament and a finger's breadth below it.

To map out the course of the **femoral artery**, the thigh being slightly flexed and rotated laterally, a line is drawn from the mid-inguinal point to the adductor tubercle; rather less than the upper third of the line corresponds to the femoral artery in the femoral triangle, while rather more than its middle third corresponds to the artery as it lies in the subsartorial canal. The seat of election for ligature of the vessel is at the apex of the femoral triangle. To compress the femoral artery, pressure is directed backwards against the ilio-pubic eminence, and not against the head of the femur; in the subsartorial canal, the artery is pressed laterally against the medial surface of the shaft of the femur.

On the lateral side of the thigh the **fascia lata** is thick and strong, but is only loosely attached to the vastus lateralis; hence the tendency of abscesses to travel downwards under cover of it towards the knee. The **sartorius** is the most important muscular landmark of the thigh, and is thrown into prominence when the thigh is held unsupported, flexed, and slightly rotated laterally. In the upper third of the thigh it is the lateral boundary of the femoral triangle; in the middle third it is superficial to the subsartorial canal; and in the lower third it is in front of the medial hamstrings. Lateral and adjacent to the upper part of the sartorius is the prominence of the **tensor fasciæ latæ**, which, as it passes to its insertion, diverges from the sartorius; in the angle between the two the tendon of the rectus femoris may be felt as it overlies the lower part of the front of the capsule of the hip joint.

The medial side of the lower half of the **shaft of the femur** may be conveniently exposed through the vastus medialis where it comes to the surface between the sartorius and rectus muscles; the incision is made along a line that begins at a point midway between the medial border of the patella and the adductor tubercle and extends towards the anterior superior iliac spine.

The front of the **hip joint** may be reached through an incision from the anterior superior iliac spine downwards along either the medial or the lateral border of the sartorius; in the former case the deeper part of the dissection passes between the iliacus and the medial border of the rectus femoris, while in the latter case the joint is reached lateral to the rectus tendon, between it and the anterior borders of the gluteus medius and minimus muscles. The *ascending branch* of the **lateral circumflex artery** of the thigh crosses the capsule parallel to the trochanteric line and immediately above it. The **ilio-psoas** crosses the anterior and the medial part of the capsule; between the psoas and the joint-capsule there is a **bursa** which frequently communicates with the joint through the thin part of the capsule medial to the ilio-femoral ligament; it is by way of that communication that a psoas abscess occasionally gives rise to secondary tubercular disease of the hip joint. One of the commonest situations to meet with an abscess in hip joint disease is in the fatty areolar tissue under cover of the tensor fasciæ latæ; or the pus may pass below and medial to the neck of the femur and thence along the course of the medial circumflex artery to the back of the thigh. *To tap the hip joint*, the puncture is made in the interval between the sartorius and the tensor fasciæ latæ, 5 to 7 cm. below the anterior superior iliac spine; if the instrument is then pushed upwards, medially and backwards behind the tendon of the rectus femoris, it will pass through the capsule a little above the trochanteric line. Regarded from the point of view of **dislocation**, the regions of the acetabular notch and

of the lower part of the capsule are the weak points in the joint; it follows that abduction favours dislocation by bringing the head of the femur into relation with those two weak areas.

When particularly free access to the hip joint is required, as in the open reduction of a congenital dislocation, an angled incision may be employed. The upper limb of the incision runs parallel to the anterior third of the iliac crest and a finger's breadth below it; the vertical or lower limb passes in the plane between the sartorius and the tensor fasciæ latæ to a point below the level of the greater trochanter.

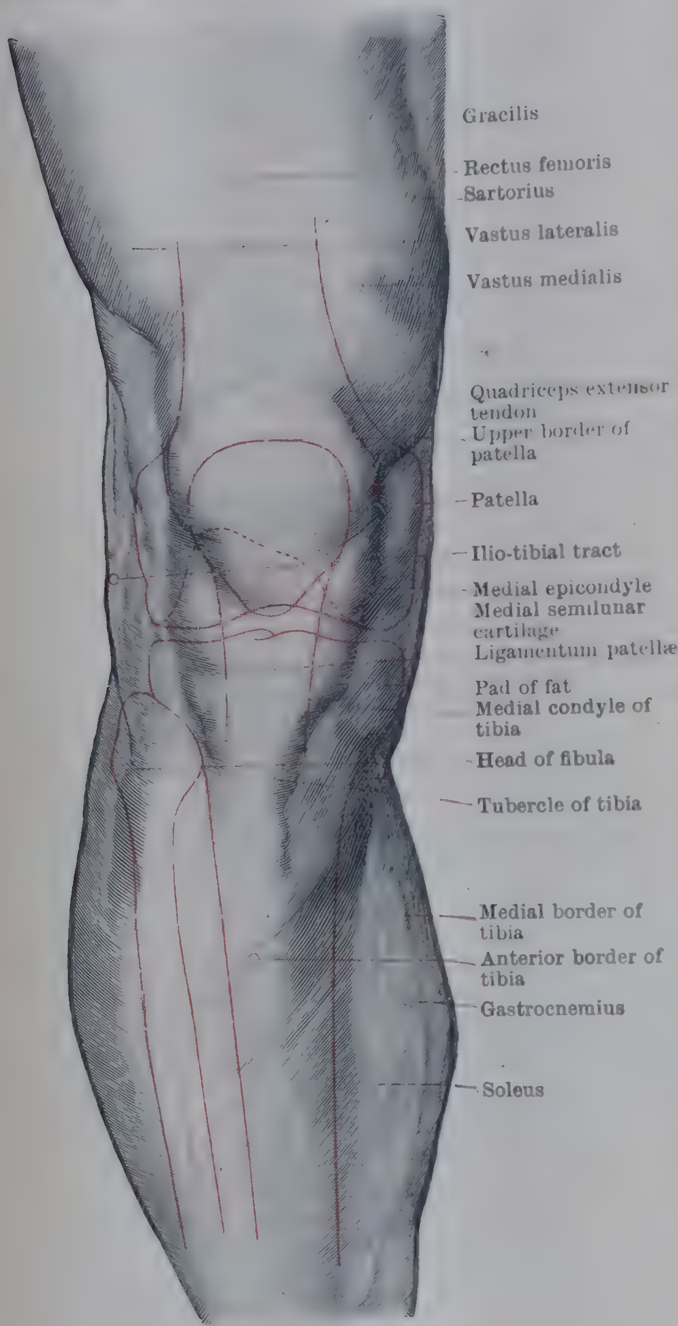

Fig. 1244.—Front of Knee.

THE KNEE

With the knee extended and the quadriceps relaxed, the **patella** can be readily outlined and moved from side to side on the femoral condyles. When the quadriceps is contracted its tendon springs forwards and is felt as a tense band above the patella; and the **ligamentum patellæ**, which has become tense and prominent, may be traced to the tubercle of the tibia. In front of the lower part of the patella and of the upper part of the ligamentum patellæ is the **prepatellar bursa**, into which effusion takes place in the condition known as housemaid's knee. Deep to and on each side of the ligamentum patellæ there is a well-circumscribed pad of fat, palpation of which gives rise to a feeling closely resembling true fluctuation. In extension, only the distal pair of articular facets of the patella are in contact with the patellar surface of the femur (Pl. XXXIV, Fig. 1, p. 371). In semiflexion the middle pair of facets rests on the femur; in that position the medial margin of the medial condyle of the femur, the upper border of the medial condyle of the tibia, and the lower part of the patella are all distinctly visible, and together bound a triangular depression which overlies the line of the joint and contains the anterior part of the **medial semilunar cartilage**; in that triangle the surgeon searches for a displaced or thickened medial cartilage, for a loose body, and for "lipping" of the edge of the articular cartilage in chronic osteo-arthritis. A similar but less well-defined triangle may be felt immediately lateral to the lower edge of the patella. When the quadriceps is thrown into sudden or violent contraction, as in preventing oneself from falling backwards, the patella may be transversely fractured at the moment of partial flexion. In full flexion almost the whole of the patellar surface of the condyles is exposed to palpation, covered, however, by the stretched quadriceps tendon.

The upper part of the medial surface of the medial condyle of the femur is overlapped by the fleshy prominence made by the lower part of the **vastus medialis.** Leading upwards from the medial condyle there is a slight furrow that corresponds to the interval between the lower part of the vastus medialis and the sartorius; at the bottom of the furrow the **tendon of the adductor magnus** can readily be felt

as a tense cord and can be followed to its insertion into the **adductor tubercle** ; the tubercle, situated at the junction of the medial supracondylar line with the upper and posterior part of the medial condyle, marks the level of the **epiphysial cartilage** (Pl. XXIV, p. 297). Anteriorly and posteriorly the epiphysial cartilage lies immediately above the highest part of the articular cartilage.

Disease of the lower part of the shaft of the femur generally invades the popliteal surface of the femur and the popliteal fossa rather than the cavity of the knee joint. In *Macewen's operation for knock-knee*, the incision through which the osteotome is introduced is carried down to the bone through the vastus medialis a little above the medial condyle—keeping a finger's breadth above the patellar surface to avoid injury to the epiphysial cartilage, and the same distance in front of the adductor tendon to avoid injury to the descending genicular vessels.

Below the medial condyle of the femur, the **medial condyle of the tibia** is readily felt, though it is crossed by the tendons of the sartorius, gracilis, and semitendinosus passing to their insertions. Between these tendons and the medial head of the gastrocnemius there is a groove which winds downwards and forwards from the popliteal fossa; an incision along that groove will expose the **long saphenous vein**, the **saphenous nerve** and the saphenous artery.

On the lateral side of the knee is the **ilio-tibial tract**, which, after crossing and obscuring the line of the joint, is attached to the **lateral condyle of the tibia.** By semiflexion of the knee the posterior border of the tract is thrown into relief, and a well-marked furrow intervenes between it and the tendon of the biceps ; the lower part of the shaft of the femur and its popliteal surface may be reached through an incision along that furrow. Under cover of the ilio-tibial tract, as it crosses the line of the joint, are the **lateral semilunar cartilage**, the **lower lateral genicular artery**, and the **lateral ligament of the knee**. The **head of the fibula** and the **tendon of the biceps** passing to be inserted into it become distinctly visible when the knee is semiflexed ; the head of the fibula lies on a level with the tubercle of the tibia, 3·8 cm. behind and a little below the most prominent part of the lateral condyle of the tibia. The termination of the **lateral popliteal nerve** is immediately below the head of the fibula, and is liable to be contused from blows and in fractures of the neck of the fibula.

At the lower part of the knee joint, anteriorly, the **synovial membrane** extends downwards as far as the level of the upper border of the tibia ; posteriorly, it dips downwards for a short distance behind the upper end of the tibia to form a small cul-de-sac, the close relation of which to the popliteal artery must be borne in mind in the operation of excision of the knee. At the upper part, anteriorly, the synovial membrane extends upwards under cover of the quadriceps in the form of a pouch which reaches a level nearly 5 cm. above the articular surface of the femur ; posteriorly, there is no extension of the synovial cavity above the condyles. At the sides of the knee the synovial membrane covers the anterior third of the superficial surface of each condyle.

In **effusion into the knee joint** the hollows become obliterated, the patella is floated up, and fluctuation may be obtained above, below, and on each side of the patella.

In **arthrectomy** of the knee for tuberculous disease, the extra-synovial fat facilitates the separation of the suprapatellar pouch from the lower and anterior part of the shaft of the femur ; to expose the **pouches behind the condyles,** the cruciate ligaments are divided.

THE LEG

The medial surface of the **tibia** is subcutaneous throughout ; hence, the seat of a fracture of the shaft is, as a rule, easily felt, and the lower end of the upper fragment is apt to perforate the skin. The skin over the lower half of this surface is the commonest seat of varicose and callous ulcers, which are frequently prevented from healing by adhesion of the floor of the ulcer to the periosteum.

The **shaft of the fibula** is on a plane behind that of the tibia, and, with the exception of the triangular subcutaneous surface, is deeply placed among the muscles. To examine the fibula, the surgeon stands on the opposite side of

the patient and manipulates the bone along the line of the intermuscular septum between the peronei and the muscles of the calf.

The greater fullness of the antero-lateral surface of the leg, as compared with its medial surface, is due to the presence of the **extensor** and **peroneal groups of muscles**. When those groups are thrown into action, the individual muscles are mapped out on the surface by the grooves that correspond to their intermuscular septa. The **posterior peroneal septum** is opposite a well-marked furrow which extends from the back of the head of the fibula to the hollow behind the lateral malleolus. In front of it are two **peroneal muscles**—the *longus* giving rise to a prominence in the upper half of the leg, and the *brevis* prominent in the lower half. Behind the septum there is a prominence formed by the lateral border of the **soleus**, which projects beyond the border of the **gastrocnemius**.

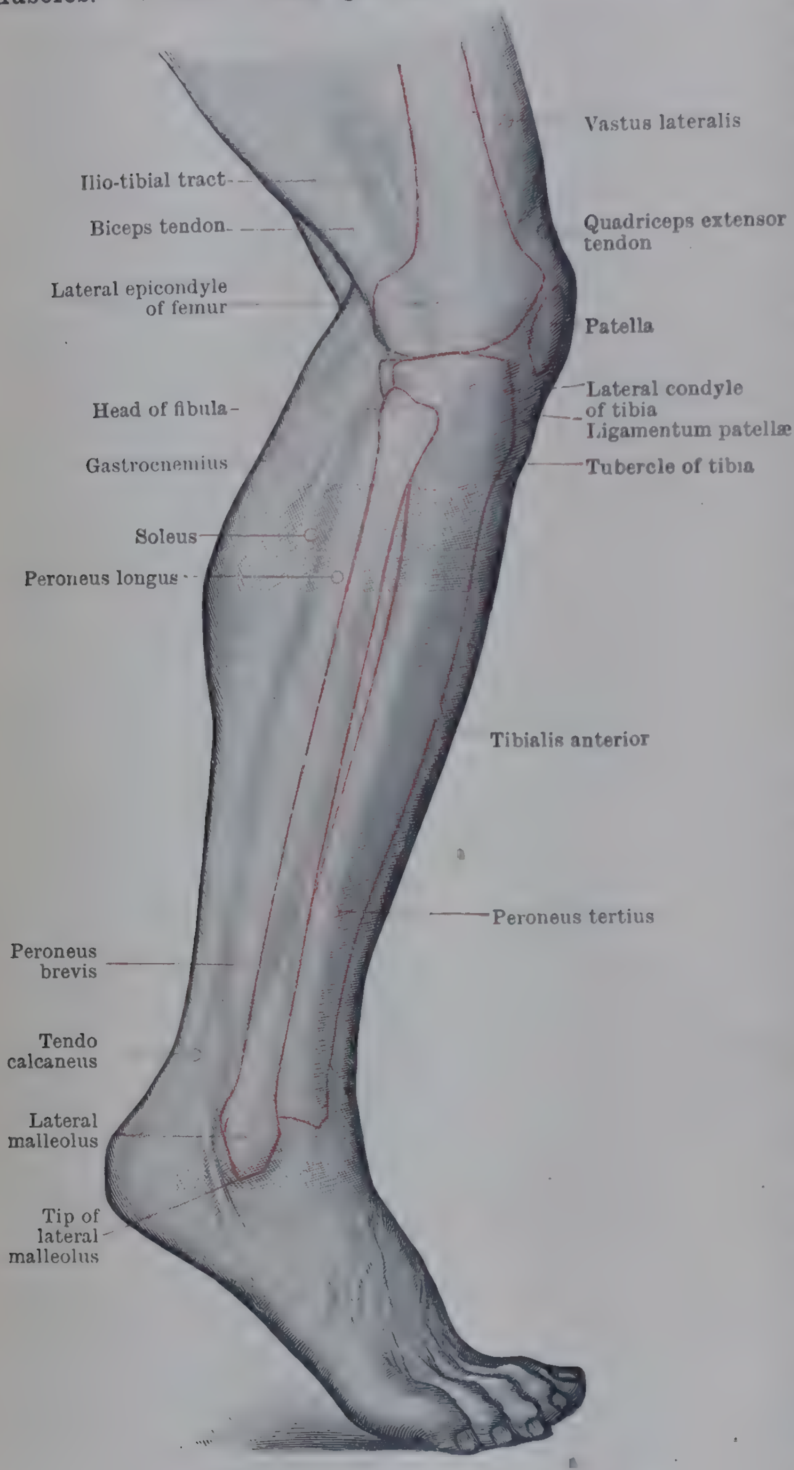

Fig. 1245.—Lateral Side of Knee and Leg.

It is along the line of the posterior peroneal intermuscular septum that incisions should be made to expose the fibula; to avoid the musculo-cutaneous nerve, however, the incision is not carried higher than 2·5 cm. below the head of the fibula.

The furrow between the extensors and the two peronei marks the **anterior peroneal septum**: it is much less distinct than the furrow of the posterior septum, and runs from the anterior border of the head of the fibula to the anterior border of the lateral malleolus; the **cutaneous portion of the musculo-cutaneous nerve** corresponds to the lower half of the furrow. At the junction of the middle and lower thirds of the leg the extensor muscles incline medially over the front of the tibia.

The **anterior tibial artery** reaches the front of the interosseous membrane 2·5 cm. below the head of the fibula; in the upper two-thirds of its course it lies on the interosseous membrane; in its lower third it winds on to the front of the tibia to terminate at a point opposite the ankle joint midway between the two malleoli. *Incisions to expose the vessel* should strike the lateral border of the tibialis anterior, which corresponds to a line drawn from a point midway between the lateral condyle of the tibia and the head of the fibula to the termination of the vessel.

When the muscles of the calf are thrown into action, a groove is seen between the two heads of the **gastrocnemius**, the fleshy fibres of which extend a little below the middle of the leg. The fleshy fibres of the **soleus** extend to the junction of the middle and lower thirds of the leg and project beyond the margins of the gastrocnemius. The narrowest part of the **tendo calcaneus** is opposite the bases of the malleoli, and it is there that the tendon is divided in the operation of tenotomy. The **short saphenous vein**, which lies a little to the lateral side of the tendon, gradually reaches the middle of the calf, along which it runs upwards to the middle of the popliteal fossa. The **long saphenous vein** and the **saphenous nerve** lie along the medial margin of the tibia, except in the lower part of the leg, where they course obliquely over the medial surface of the tibia.

The **posterior tibial** and **peroneal arteries** are exposed through an incision beginning to the medial side of the tendo calcaneus and extending upwards between the two heads of the gastrocnemius. The incision is deepened in the median plane, to divide the gastrocnemius, soleus, and tendo calcaneus into two halves, separation of which exposes the vessels and the posterior tibial nerve on the lateral aspect of the posterior tibial artery.

FOOT AND ANKLE

The tip of the **lateral malleolus** is 0·5 cm. lower than the tip of the **medial malleolus** (Pl. XXV, Fig. 1, p. 304). Above the lateral malleolus is the triangular subcutaneous surface of the fibula, the apex of which corresponds to the distal end of the anterior peroneal septum.

The **line of the ankle joint** can be felt on each side of the extensor tendons, and, when the foot is extended, the anterior part of the upper surface of the body of the **talus** forms a visible prominence below the anterior edge of the distal end of

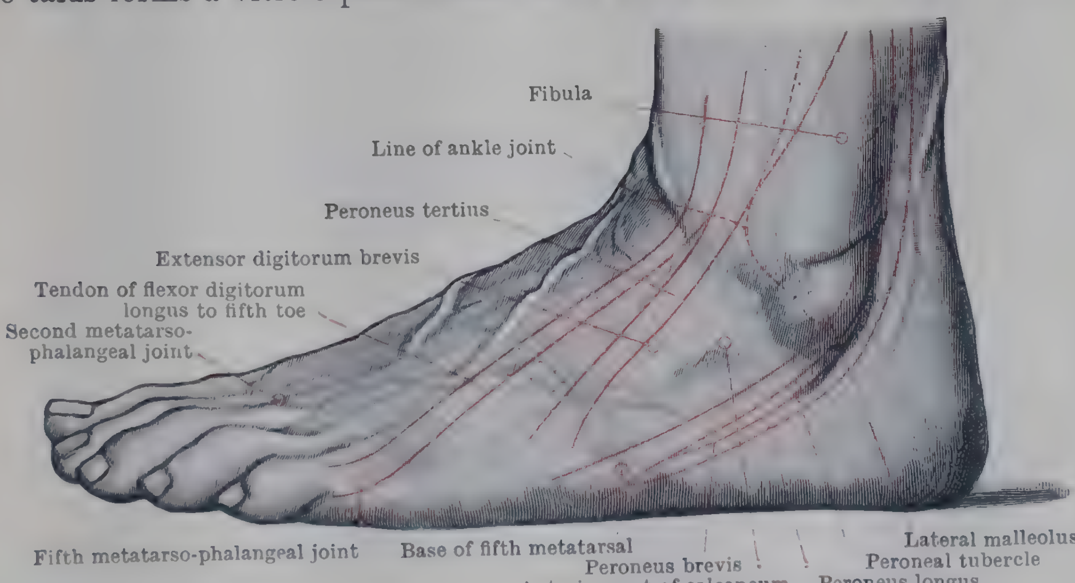

Fig. 1246.—Lateral Side of Foot and Ankle.

the tibia. The posterior surface of the talus is small, but it may be felt below and behind the medial malleolus at the anterior part of the hollow between it and the heel. In *effusions into the ankle joint*, the hollows in front of and behind the malleoli are obliterated, and the extensor tendons are raised from the front of the joint.

A finger's breadth below the tip of the medial malleolus is the **sustentaculum tali**; 3 cm. in front of the sustentaculum is the **tuberosity of the navicular bone** which is generally visible and always distinctly palpable. The **talo-calcanean joint** is immediately above the sustentaculum; and immediately above the joint the **tendon of the tibialis posterior** may be made visible as it extends from behind the tip of the medial malleolus to the tuberosity of the navicular. Three centimetres in front of the tuberosity of the navicular is the **joint between the medial cuneiform and the first metatarsal**; the ridge at the base of the first metatarsal furnishes a good guide to the joint. The first **metatarso-phalangeal joint** is a little in front of the middle of the ball of the big toe.

The **base of the fifth metatarsal bone** makes a prominence on the lateral border of the foot about midway between the point of the heel and the root of the little toe. A finger's breadth vertically below the tip of the lateral malleolus is the **peroneal tubercle** of the calcaneum, and midway between the two is the **talo-calcanean joint**; the peroneal tubercle is, when present, a trustworthy guide to the level at which the **two peroneal tendons** cross the lateral surface of the calcaneum. The anterior part of the **calcaneum** is felt in the triangular interval between the tendons of the peroneus brevis and tertius. The **calcaneo-cuboid joint** is barely a finger's breadth behind the base of the fifth metatarsal (Pls. XXV, Fig. 2, p. 304, and XXVII, p. 320). On the dorsum of the foot the tarsal joints are obscured by the extensor tendons. The **synovial membrane** of the **ankle joint** is prolonged on to the neck of the talus.

The **line of the tarso-metatarsal joints** extends nearly 2·5 cm. farther forwards on the medial border of the foot than on the lateral border; and it takes a zigzag course on account of the second metatarsal bone extending backwards between the medial and lateral cuneiform bones. The joint between the second metatarsal and intermediate cuneiform is nearly 1·5 cm. behind that between the first metatarsal

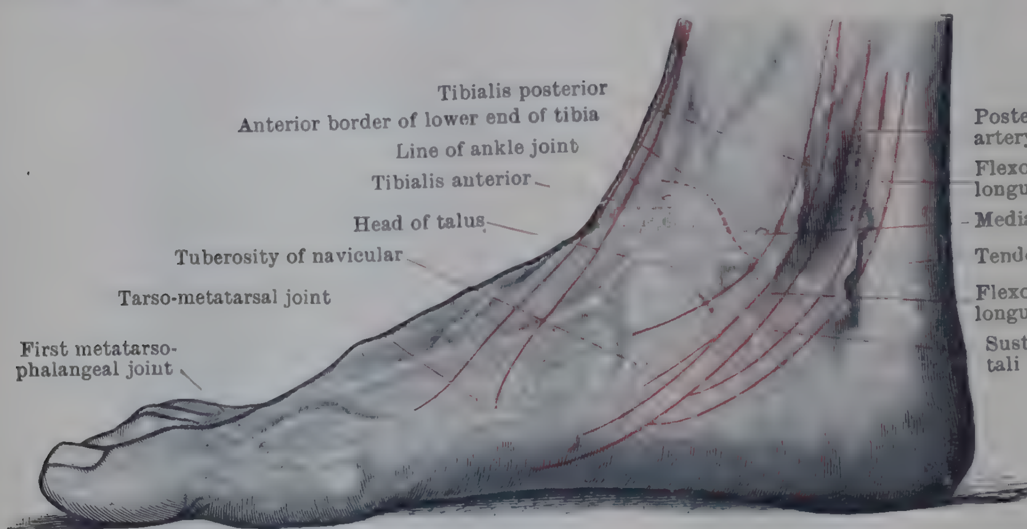

FIG. 1247.—MEDIAL SIDE OF FOOT AND ANKLE.

and medial cuneiform, and 0·5 cm. behind that between the third metatarsal and the lateral cuneiform.

The **metatarso-phalangeal joints** are 2·5 cm. behind the web of the toes. When a toe is disarticulated, the plantar ligament of the joint is detached from the phalanx, but left otherwise uninjured, for the bands of the deep transverse ligament of the sole are attached to its margins.

The **tendon** of the **tibialis posterior** may be felt, and, when the foot is inverted, seen, as it extends from behind the tip of the medial malleolus to the tuberosity of the navicular; it crosses the deltoid ligament and the talus immediately above the sustentaculum tali.

In the commonest form of club-foot — *talipes equino-varus* — the tuberosity of the navicular is approximated to the medial malleolus, and tenotomy of the tibialis posterior should be performed, therefore, through a puncture a little below the tip of the medial malleolus; after dividing the tendon, the knife is carried down to the bone in order to divide the **plantar calcaneo-navicular ligament** and to open the **talo-navicular joint**—a procedure called for before the foot can be brought into good position.

The following tendons—named from medial to lateral side—cross the front of the ankle joint: the **tibialis anterior** (the largest and most prominent), the **extensor hallucis longus**, the **extensor digitorum longus**, and the **peroneus tertius**. The **extensor digitorum brevis** makes the fleshy pad that overlies the dorsal surface of the calcaneo-cuboid joint. When the foot is everted, the tendon of the **peroneus brevis** may be seen extending from the tip of the lateral malleolus to the **base of the fifth metatarsal bone**; immediately below it is the tendon of the **peroneus longus**, which,

as it winds round the cuboid, is obscured by the fleshy fibres of the abductor digiti minimi muscle. The **abductor hallucis muscle**, although described along with the sole, forms a fleshy pad along the medial border of the foot below the sustentaculum tali.

An incision from the tuberosity of the navicular to the middle of the medial border of the heel will expose the various tendons, vessels, and nerves as they pass from the medial malleolus into the sole, deep to the abductor hallucis.

The **dorsalis pedis artery** may be mapped out on the surface by a line drawn from a point opposite the ankle joint midway between the two malleoli to the posterior end of the first interosseous space. The **long saphenous vein** and the

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<tr><th>L 2</th><th>L 3</th><th>L 4</th><th>L 5</th><th>S 1</th><th>S 2</th></tr>
<tr><td colspan="2">Sartorius</td><td></td><td></td><td></td><td></td></tr>
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<tr><td></td><td></td><td></td><td colspan="2">Extensor hallucis longus</td><td></td></tr>
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<tr><td></td><td></td><td></td><td colspan="2">Peroneus brevis</td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="3">Gluteus maximus</td></tr>
<tr><td></td><td></td><td></td><td colspan="3">Pir. & quadrat. fem.</td></tr>
<tr><td></td><td></td><td></td><td colspan="3">Semitendinosus</td></tr>
<tr><td></td><td></td><td></td><td colspan="3">Semimembranosus</td></tr>
<tr><td></td><td></td><td></td><td colspan="3">Biceps femoris</td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="2">Gastroc. & Sol.</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>Flex. dig.</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>Flex. hall.</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>Interossei</td></tr>
</table>

TABLE II.—SEGMENTAL INNERVATION OF MUSCLES OF LOWER LIMB.

saphenous nerve lie between the anterior border of the medial malleolus and the tendon of the tibialis anterior; the **short saphenous vein** and the **sural nerve** take the same course as the tendon of the peroneus brevis.

The **medial plantar vessels** and **nerve** lie along the **medial intermuscular septum**, which corresponds to a line drawn from the medial tubercle of the calcaneum to the interval between the first and second toes. The **lateral plantar vessels** and **nerve** may be exposed by an incision along the **lateral intermuscular septum**, which runs in a line drawn from the middle of the lower surface of the heel to the fourth toe. To map out the course of the **plantar arch**, a line is drawn across the sole from the medial side of the base of the fifth metatarsal bone to the posterior end of the first interosseous space.

Lumbo-Sacral Plexus.—The segmental innervation of the muscles of the lower limb is shown in Table II. For the cutaneous distribution of the nerves of the lumbo sacral plexus, see Fig. 941, p. 1096, and for the dermatomes of the lower limb, Fig. 942, p. 1097.

RADIOGRAPHIC ANATOMY

X-RAYS, since their discovery by Röntgen in 1895, have become of increasing importance in Medicine. Their possible value in diagnosis and treatment was soon recognized; and improvement in the design of apparatus has been so rapid that even the most extravagant early claims have been exceeded.

While it is true that X-rays are the product of complex electrical disturbances, it is not always appreciated that a knowledge of higher physics and of intricate electrical machinery is not the most essential factor in their application to medical problems. The purely technical aspects of the nature and production of X-rays are the province of the physicists and the electrical engineers; and even the actual processes of radiography—the preparation of radiographic films—are now usually left to the non-medical technician or radiographer. The radiologist, who is a qualified medical man, is concerned mainly with the interpretation of the radiograph and he requires to have only sufficient knowledge of the technical factors and processes to enable him to interpret it correctly. He is primarily concerned, therefore, with what he *sees* in the radiograph, which implies a thorough knowledge of anatomy and, when disease is present, of pathology.

Appropriate treatment can be applied, as a rule, only after the exact extent and nature of a disease have been ascertained. By ordinary methods of examination such information is difficult to secure if the diseased structures and organs lie at some depth in the body. It can often be obtained, however, by X-ray examination. In order that the treatment should be not only appropriate but also successful it is very important that the necessary information should be obtained while the disease is still in an early stage; for, in advanced stages, destruction may be so marked or the process so widespread that cure is usually impossible. X-ray examination may play an important part in the early recognition of disease, and there are few conditions in which it is not of some value and many in which it has become the most important single means of examination. But in the early stages of disease there is very little departure from the normal: it follows that the radiologist must be very familiar with the radiographic picture of the healthy body so that he will not overlook very slight changes and will not fail to assist the clinician at the only stage at which the disease may be curable. The more familiar he is with the normal anatomical appearances, the less likely he is to make such an error.

The interpretation of a radiograph is, however, by no means a simple matter. It is well known that it may be difficult to recognize even familiar objects viewed from an unusual angle or in an unusual manner; and distortion may easily cause a normal structure to appear abnormal. In a radiograph, the various structures through which the X-ray beam has passed are visible as areas of blackening of different density. The images all lie in the plane of the film and they may be so superimposed and so foreshortened that at first it is difficult to recognize them.

In order to interpret radiographs correctly, the observer must first be familiar with the parts as examined by ordinary means. He must know also the essential points in the process of radiography including the projections commonly employed.

In addition to the recognition of normal anatomical structures and of changes due to disease in its early stages, X-ray examination with a *fluorescent screen* provides a means of observing the form and movement of organs during life. Such a study enhances the observer's knowledge of anatomy and adds greatly to its interest. To the student it is of special value, for in the dissecting room he is apt to think only of the structure of the organs and of their shape and appearance as found in the cadaver. He has difficulty in appreciating that many of the parts he is dissecting are very different in their appearance during life and he thus often fails to correlate structure and function. For example, his conception of the stomach as a flaccid, inert bag is immediately rectified when he is able to observe directly the alterations in shape which it undergoes as it fills and empties and the peristaltic movement of its walls. Visualization of the movements of the ribs and

diaphragm during respiration, of the constant beating of the heart and of the movements of the joints cannot fail to add to his interest and make him appreciate anatomy in a new light.

For the assistance of the student a brief account of the production of X-rays and of the technique of radiography will now be given. For further information on the subject, which is obviously outside the scope of this Appendix, he must consult one of the many special books now available.

NATURE AND PROPERTIES OF X-RAYS

X-rays form part of the electro-magnetic spectrum, of which the longest wave-lengths are known as wireless waves. Wireless waves are usually measured in metres but, as we proceed down the scale of wave-lengths through the bands of visible light and ultra-violet light, we come to X-rays whose wave-lengths are of the order of a hundred-millionth part of a centimetre.

An X-ray tube consists of a high-vacuum glass cylinder into the ends of which two metal electrodes project (Fig. 1248). X-rays are produced by bombardment of the positive electrode or anode by electrons. The speed of the electrons when they strike the anode is very great and approaches the speed of light (which travels at 186,000 miles per second). Each electron carries a negative charge; and radiating lines of force extend out from it as from any other charged body. When the electrons

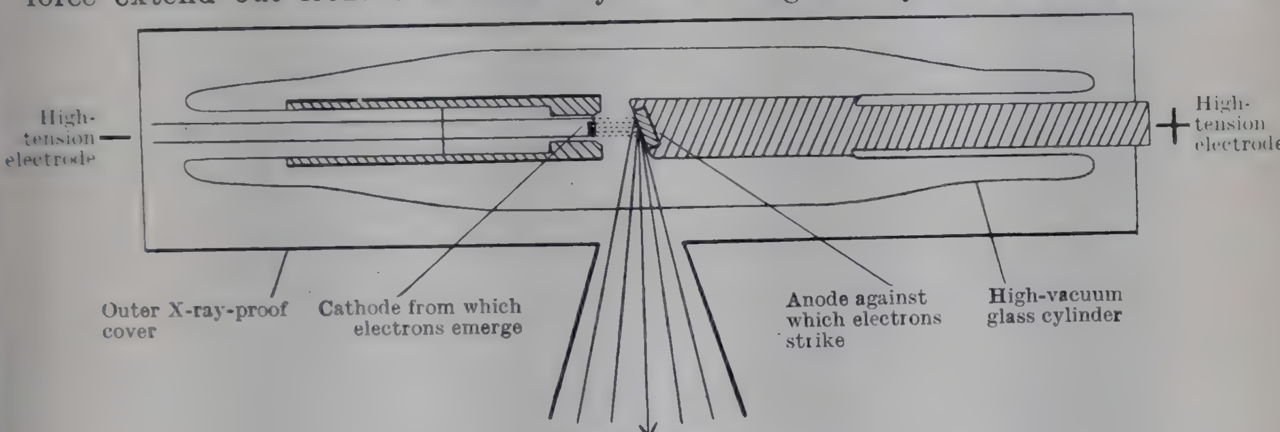

Fig. 1248.—Diagram of X-Ray Tube.

strike the anode they are brought violently to rest, and the collision causes vibrations to pass along the lines of force in a manner similar to the vibrations that pass along a tightly stretched rope struck at one point. These vibrations along the lines of force constitute X-rays. The higher the speed of the electron at the time of its impact, the more violent are the vibrations in the lines of force and the shorter the wave-length of the X-ray produced. Now, the speed of the electron, as it passes from the negative electrode or cathode to the anode, is determined by the voltage applied to the tube, so that the higher the voltage the shorter is the wave-length of the beam produced. Normally, voltages of the order of 40,000 to 100,000 volts are used in diagnostic radiography.

In addition to the control of the wave-length by the voltage, one may control the *amount* of X-rays by varying the amount of current (measured in ampères) that passes through the tube. It has been found that the output of X-rays is directly proportional to the current. The current used, however, is quite small and is usually only a fraction of an ampère.

When Röntgen discovered the new rays he called them *x*-rays to indicate that they were an unknown quantity. They still retain that name, though a great deal is now known about them and about their properties. The chief properties of X-rays are as follows:—

(1) They have the power of penetrating matter.
(2) They can blacken a photographic film.
(3) They produce fluorescence in certain substances.
(4) They have a special biological action.

Penetration of Matter.—One of the most useful properties of X-rays is their power of penetrating solid matter; and the shorter the wave-length the greater is the power of penetration. In their passage through matter, the rays are absorbed and the amount of absorption is dependent on the atomic number of the absorbing substance and its density. Hence, if the X-ray beam is made to pass through a limb, it will be absorbed to a different degree by the soft tissues and by the bones, because the bones not only are denser but also contain calcium, which is of higher atomic number than the carbon, hydrogen, oxygen, and nitrogen of the soft parts.

Effect on Photographic Film.—X-rays, like light-rays, have the power of blackening a photographic film; and the amount of blackening produced is dependent on the amount of X-rays and the time during which they act. If, then, a photographic film is placed on the opposite side of the limb from the tube, there will be less blackening produced where the rays have been absorbed by the bones. But the rays that pass through the less absorptive soft parts will retain much of their original intensity and will blacken the film to a considerable degree and so cause the white shadows of the bones to stand out (Pl. XVIII, p. 273). The radiographic film, like the ordinary photographic film, requires to be developed and fixed before the image can be examined and these processes are carried out in the ordinary way in the dark-room. The completed film is called **a radiograph.**

Fluorescence Effect.—The third property of X-rays is their power of producing fluorescence in certain metallic salts. The salts commonly employed in X-ray work are zinc sulphide, calcium tungstate, and barium platino-cyanide. *Fluoroscopic examination* is carried out by means of a glass screen coated with either zinc sulphide or barium platino-cyanide. The screen, like the film, is placed on the opposite side of the patient from the tube and, when the current is switched on, fluorescence occurs. The brightness of the fluorescence at any point on the screen, like the blackening of the film, is dependent on the intensity of the beam; where absorption occurs, there is diminished intensity and hence less fluorescence. The fluorescent images, like the radiographic images, are sharp in their definition, and the various structures through which the beam is passing can be readily recognized. Although the detail is not so good as in a radiograph, screen-examination has the great advantage that it permits the observer to study the movement, and, to some extent, the function of the part examined. Fluorescence is used also for another purpose. If an X-ray film is placed between two pieces of cardboard coated with calcium tungstate, it has been found that the exposure can be reduced by 10 to 20 times because the fluorescence produced by the calcium tungstate actually causes greater blackening than that produced directly by the X-rays. "Screened films" are always used, therefore, when the exposure must be of short duration.

Biological Action.—Within recent years, the biological properties of X-rays have become of great importance in the treatment of malignant disease. A full explanation cannot be given here, but it may suffice to state that the rays have the remarkable property of destroying cancer-cells without necessarily destroying the normal healthy cells; and a patient treated by X-rays may thus be cured of malignant disease without operative removal of the affected part. Where organs essential to life are involved, this means of treatment is obviously of the greatest value. In excessive dosage the rays will destroy all living tissue—normal as well as abnormal—and the treatment of cancer requires to be very carefully controlled so that just the right amount of radiation is given. When the whole body is exposed at intervals over a prolonged period, even small doses of X-rays are dangerous. Severe anæmia may occur and may prove fatal. It is therefore of the utmost importance that radiologists, radiographers, and all those concerned in the manufacture of X-ray apparatus should take every precaution to prevent themselves from being exposed to the rays. Nowadays, the dangers are well-known and preventive measures can be taken so that health need not be impaired or endangered.

RADIOGRAPHY

In the actual taking of a radiograph the various factors are selected to produce the clearest possible image. When the thick parts of the body are examined, considerable absorption of the X-ray beam takes place and a more penetrating ray must therefore be used. This is obtained by the use of higher voltages on the tube. When thinner parts are examined, the voltage is reduced because there is less absorption and too penetrating a beam produces a radiograph of poor contrast. In stout patients, contrast may be made still greater by the use of a special lead-grid called a Potter-Bucky diaphragm. In radiography, we speak of a "Bucky radiograph" when this device has been used. The radiographic images are merely the shadows of the structures through which the X-ray beam has passed; and it need hardly be said that there is no question of focusing the beam by means of a lens as in ordinary photography. But, in order that the definition of the shadows may be as sharp as possible, it is important that the rays should all come from the smallest possible source; for, if the source is large, there will be a "penumbra effect"—*i.e.*, a blurring of the margins of the shadows. In modern tubes, the source or "focal spot" on the anode is only a few millimetres square and is often of the order of one square millimetre. When moving objects are examined, it is important also that the radiograph should be taken in the shortest possible time in order that blurring of the margins of the shadows by movement may be avoided. The higher the output of X-rays from the tube, the shorter will be the exposure-time required. With the high currents now available, radiographs of the chest may be taken in $\frac{1}{25}$th of a second or less, and this speed is sufficient to give a sharp definition to the outline of the heart in spite of its constant movement.

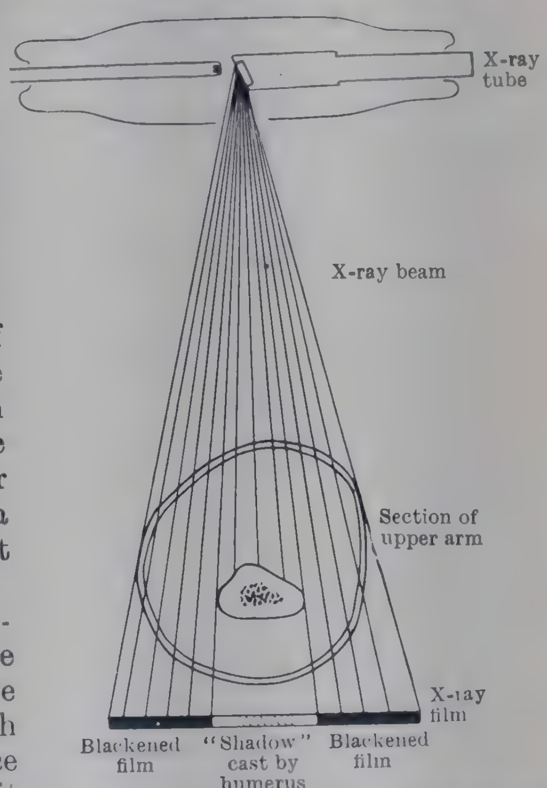

FIG. 1249.—DIAGRAM SHOWING THE ARRANGEMENT OF THE X-RAY TUBE, THE OBJECT AND THE FILM IN RADIOGRAPHY.

Note the enlargement due to divergence of the rays.

There is still another point to be considered. The greater the distance of the tube from the object to be examined, the more closely will the size of the shadow approach that of the object. Increased tube-distance will thus diminish distortion and render it possible to ascertain more accurately the relative size of the objects examined. A tube film-distance of about two metres is usually employed when it is desired to measure the size of the heart, but in ordinary work a distance of 70 to 100 centimetres is generally sufficient. Whatever distance is employed it is obvious that the shadows of the parts nearest the film will always suffer least distortion (Fig. 1249). The film is placed, therefore, on that side of the patient which is nearest to the structure or organ to be examined. Thus, the film is placed in front of the patient (an "anterior film") if the gall-bladder is to be examined, and behind the patient (a "posterior film") when the kidney is being investigated.

In the examination of certain areas (for example the skull, vertebral column, and thorax), stereoscopic examination is of great value. Stereoscopic radiographs may be obtained by two exposures of the same part on two separate films but with the position of the tube altered by a short distance. The patient must maintain exactly the same position, and the usual displacement of the tube is 6 cm. The radiographs are viewed in a stereoscope which, by means of mirrors or prisms, brings the images on the two radiographs together so that they fuse and can be seen in stereoscopic relief.

The foregoing is but a brief outline of the subject, but it may serve to indicate how a radiograph is produced and the possible scope of X-rays in the study of parts not readily capable of examination by ordinary means. It will be appreciated that the shadows in a radiograph, produced by the passage of a beam of X-rays through a part of the body, are similar to those shadows which a beam of ordinary light produces when it passes through some material that is not uniformly transparent. The sharpness of definition and the contrast in the shadows of the radiograph can be controlled by the voltage employed, the length of time of the exposure, the size of the focal spot, the use of a Potter-Bucky diaphragm, and other technical devices with which modern X-ray plants are provided.

It may have been noted that no mention has been made of the production of positive images or "printing". Radiographs are all examined as "negatives", not only because this saves time and expense, but also because the detail is always better in the original "negative" than in the most carefully produced "positive". With the exception of those that illustrate injected blood-vessels (Pls. LXXXI-LXXXVII), all the radiographs in the Plates of this text-book are reproduced as "negatives", and the student must note that the shadows of dense parts in the path of the X-ray beam appear white while the easily penetrated parts appear black. In a well-taken radiograph there should be all degrees of density ranging from the whitest parts to the blackest areas and not merely extremes of black and white, for this latter state of affairs shows that the radiographer has not selected the various factors so as to bring out as clearly as possible slight variations in density of the tissues.

INTERPRETATION OF RADIOGRAPHS

When the shadows in a radiograph come to be interpreted it must be clearly understood that, if all the tissues through which the beam passes are of the same density, there will be uniform absorption of the beam by these tissues and the radiograph will be uniformly blackened. One tissue or part can be distinguished from another only if the adjacent tissues are of a greater or lesser density. The absolute density of the part is of no importance. This point may perhaps be made clear by the following examples.

The heart is clearly visible in a radiograph of the chest, but the uterus, which is of approximately equal density, can be seen only rarely when the pelvis is examined. The heart is, of course, surrounded by air-filled lung which is much less dense, but the uterus is surrounded by tissues of density equal to that of itself. If, however, the parts of the lungs adjacent to the heart become solid as the result of disease, the heart can no longer be distinguished from the lung. For the same reason, in a radiograph of a joint, the articular cartilage cannot be seen, because the cartilage is equal in density to the soft parts and therefore casts a shadow of the same density; it becomes evident, however, if air is injected into the joint (Pl. XXXV, p. 382) or after the release of vapour on "cracking" a metacarpo-phalangeal joint (Roston & Haines, 1947). The blood is equal in density to the soft tissues because the amount of iron it contains is so small that it does not influence absorption; thus, normal blood-vessels cannot be seen in a radiograph.

With the exception of the skeleton and the air-filled lungs the tissues of the body are all approximately of equal density. With good technique, however, slight difference of density can be made out between some of the soft tissues. Thus, the kidney can be distinguished because the perirenal fat does not absorb the rays to quite the same extent. The outlines of muscles can be distinguished occasionally in a radiograph of the limbs because of the presence of fat and loose areolar tissue between the muscles. The margin of the psoas major can often be seen because the muscle is denser than the coils of intestine lateral to it (Pls. LXIX, p. 744, LXXI, Fig. 1, p. 745). Radiographs, especially lateral views, of the neck demonstrate the trachea because the air it contains absorbs less radiation than the surrounding tissue (Pls. LXI, p. 696, LXV, p. 704); and, for the same reason, gas

in the intestines may be seen. The air-bubble of the stomach can be seen when the patient is in the erect position but the liquid contents are not visible because they are of the same density as the adjacent parts. In the head, in addition to the bones, the air-sinuses are clearly seen; but the outlines of the ventricles of the brain are not visible until the cerebro-spinal fluid has been replaced by air or oxygen.

SPECIAL METHODS OF EXAMINATION

The examples given in the preceding paragraphs serve to indicate the limitations of X-ray examination and at the same time they indicate why special methods must be adopted in the examination of some organs. These special methods depend on the employment of **contrast-media** of different kinds. Contrast-media are divided into two main groups:—(1) Those which increase the density of the part and depend on the use of solutions or suspensions of salts of high atomic number. (2) Those which diminish density and in which air or oxygen is used. Some details will now be given of the actual techniques employed in the examination of particular organs and in the use of these contrast-media.

Alimentary Canal.—In the examination of the alimentary canal by X-rays a watery suspension of barium sulphate known as a *barium-meal* is employed. The salt is insoluble and therefore non-toxic; and barium, having a high atomic number, absorbs X-rays almost completely.

Examination of the œsophagus, stomach, and small intestine is usually carried out in the morning, the patient having taken neither solid nor liquid food since the evening before. The examination is mainly by fluoroscopy or "screening"; but radiographs may be taken for record purposes. Screening not only has the advantage of permitting the observer to see the passage of the barium and the peristaltic movements but also allows of palpation of the stomach and small intestine while they are visible on the screen.

The "barium-meal" is given to the patient standing erect behind the fluorescent screen in a completely darkened room. The tube is switched on and the patient is instructed to drink two mouthfuls of barium. The rapid passage of the barium down the **œsophagus** can be observed very clearly, especially if the patient is rotated to the left so that the shadow of the heart does not obscure the field (Pl. L, p. 593). (A "barium-paste" is sometimes used as it passes down the œsophagus more slowly.) The screen is then lowered and the patient is rotated again to face the observer. The barium is carefully watched as it enters the **stomach** and by suitable palpation it may be massaged or spread over the mucous membrane, to which it adheres. The thin coat of barium demonstrates the folds of mucous membrane as they pass from the fundus towards the pylorus (Pl. LI, p. 608). More barium is then given until the stomach is filled, when its outline and peristaltic movements may be observed (Pl. LVI, p. 621). In a few minutes—sometimes immediately—barium enters the first part of the duodenum, forming the "duodenal cap" (p. 621); and its subsequent passage through the duodenum and the rest of the small intestine may be studied at varying intervals according to the type of investigation being made.

The **large intestine** is examined best by a **barium-enema**. A "meal" may give some information, particularly in the cæcal region (Pl. LVII, p. 648), but it has the disadvantage that the passage of the barium is so slow that it cannot readily be detected on the screen and recourse must be had to multiple radiographs. Even with multiple radiographs certain parts may not be seen filled with barium. The barium-enema (Pl. LVIII, p. 648) is given through a special nozzle inserted in the rectum and connected by a length of rubber-tubing to a container for barium. The patient is examined in the supine position with the fluorescent screen above him and the X-ray tube under the couch on which he lies. The passage of barium from the rectum to the cæcum can be closely followed and, with the exception of the flexures and the pelvic colon, all parts of the large intestine are accessible to palpation.

Air also may be employed in the examination of the colon in conjunction with

barium. A barium-enema is given in the ordinary way and then the patient is allowed to evacuate the excess of barium. Some barium remains adherent to the mucous membrane and, when air is blown in, the walls of the intestine are separated and are rendered more clearly visible. This procedure is known as a "double-contrast enema" (Pl. LIX, p. 649).

The **appendix** can be examined either by the use of a "meal" or by an enema. Not infrequently the appendix is retrocæcal and the cæcum must be first displaced before the shadow of the appendix can be demonstrated.

Gall-Bladder.—The gall-bladder is not normally visible, but advantage has been taken of the fact that *phenol-phthalein* is excreted by the liver when taken by the mouth or injected into a vein. Phenol-phthalein itself is not opaque to X-rays, but, when iodine is combined in the molecule, the iodine, being of high atomic number, renders the compound capable of absorbing rays to a considerable extent. In practice, sodium tetra-iodo-phenol-phthalein (S.T.I.P.P.) is employed. Purification of the salt has made administration by the mouth almost free from unpleasant effects, and this route, in preference to intravenous injection, is now almost universally employed.

The shadow of the gall-bladder takes some time to appear because the salt is only very slowly excreted by the liver. It passes to the gall-bladder with the bile, and there it becomes concentrated. The best shadow is obtained usually about 14 to 16 hours after the salt has been swallowed. The patient is therefore told to take the salt dissolved in a glass of water in the evening of the day before examination. Radiographs are made next morning with the patient in the prone position, and if the gall-bladder is normal it can be clearly seen. It is important that the patient should not take any food from the time he has swallowed the salt until the completion of the examination, because food, and particularly fatty food, causes the gall-bladder to contract and expel its contents. Indeed, a "fatty meal" may be given to complete the investigation. The degree of contraction of the walls of the gall-bladder can be studied and the shadow of the salt may even be seen as it passes down the cystic duct and the bile-duct. Maximum contraction is observed usually about an hour after the fatty meal (Pl. LX, p. 649).

Urinary Organs.—There are two methods of investigating the renal tract. A complex iodine salt may be injected intravenously and radiographs then made as the salt is being excreted by the kidneys. This method is known as *excretion urography* or *descending pyelography*, and it has the advantage that the kidneys also are increased in density as the salt passes through their tubules (Pl. LXXI, Fig. **1**, p. 745). The disadvantage of the method is that the shadow cast by the ureters is less dense than in the second method of examination. The technique is simple. Twenty c.cm. of a solution of the salt are injected into a vein, and radiographs are taken almost immediately with the patient supine. The injection does not upset the patient and the whole examination can be completed in a short time.

In the second method, an instrument—the cystoscope—is passed along the anæsthetised urethra into the bladder. The cystoscope permits inspection of the interior of the bladder and, through the instrument, flexible hollow tubes (catheters) are inserted into the ureteral orifices and passed up the ureters to the kidneys. A solution of sodium iodide is then injected and, because of the greater concentration of iodine in this solution, very clear radiographs may be obtained of the calyces and of the whole length of the ureters (Pl. LXX, p. 744). This second method is known as *retrograde pyelography* and it is to be preferred in most cases because of the better detail that is obtained, and also because the walls of the bladder may be inspected at the same time. The kidney-substance is not increased in density as with the first method, but this is not of great importance, for in most radiographs the renal outlines are normally visible.

The outline of the **urinary bladder** may be rendered visible by both methods of examination (Pl. LXXI, Fig. **2**, p. 745).

The **male urethra** is usually examined by retrograde injection of sodium iodide.

Nervous System.—Air is the contrast-medium usually employed, as substances opaque to X-rays are not free from danger.

Air is passed into the ventricles of the brain after the withdrawal of cerebro-spinal fluid, and the ventricles then absorb radiation to a less extent than the surrounding brain and so can be seen in the radiograph (Pls. LXXIV, p. 945; LXXVI, p. 961.

The air may be injected through a long needle inserted directly into the lateral ventricles after small apertures have been drilled in the posterior portions of the parietal bones. This method is called *ventriculography* and it is the one usually employed. About 20 c.cm. of air are injected, and, by altering the position of the patient's head, the different parts of the lateral ventricles become filled with air. Thus, if the patient lies with the right side of the head on the table, the air will pass into the left lateral ventricle; with the face directed upwards the anterior horns of both ventricles can be seen, and, with the face downwards, the posterior horns are filled. The third ventricle and the aqueduct of the mid-brain are only occasionally visible with the usual quantities of air injected. The walls of the third ventricle and of the aqueduct are only so slightly separated that surface tension interferes with their being filled with air.

Air may be injected also into the vertebral canal in the lumbar region. The cerebro-spinal fluid is withdrawn from the subarachnoid space and is replaced by a slightly smaller volume of air. The air rapidly passes up the vertebral canal in the subarachnoid space and enters the ventricular system through the foramina in the roof of the fourth ventricle. As a rule some air escapes over the surface of the brain and outlines the sulci. This method is known as *encephalography* (Pl. LXXV, p. 960).

In the examination of the spinal subarachnoid space an *iodised oil* may be used. The usual preparation is a 40 per cent solution of iodine in poppy-seed oil ("lipiodol") and the iodine-content is sufficient to make the preparation opaque to X-rays. The injection is made between the spines of the fourth and fifth lumbar vertebræ. Its density when used in this strength is greater than that of the cerebro-spinal fluid, so that, when the patient is in the erect position, the oil collects in the lower lumbar and sacral portions of the vertebral canal. It is possible, by means of a tilting table on which the patient is placed, to make the oil flow towards the thoracic region or even as high as the neck. The passage of the oil is controlled by observation on the fluorescent screen. The oil, if left in the sub-arachnoid space, often becomes irritant and it should be removed by aspiration on completion of the examination.

Vascular System.—**Blood-vessels** may be made opaque to X-rays by the injection of salts of a high atomic number (Pls. LXXX-LXXXVII). Sodium iodide may be used but, as it may cause damage to the intima of the vessels and to the blood, only a dilute solution may be used, and, in consequence, the definition in the radiograph is poor. A colloidal suspension of *thorium dioxide* ("thorotrast"), on the other hand, markedly increases the density of the blood, so that the vessel and its branches become clearly visible. But this substance is radioactive—and therefore not free from danger—and organic iodine compounds are now usually employed.

Arteries are more commonly injected than veins, and the radiograph must be taken just before the injection is completed. If there is delay, the contrast-medium may have left the arteries and passed almost entirely into the veins. The internal carotid artery (or the common carotid, which is more accessible) and the vertebral artery are injected by the neuro-surgeon to display the condition of the cerebral vessels (Pl. LXXX, p. 1287).

Respiratory System.—As indicated on p. 721, it is exceedingly difficult to see the bronchi in an ordinary radiograph. If, however, their walls are coated with iodised oil they can be clearly demonstrated (Pls. LXII, LXIII, p. 696). The oil is usually injected into the bronchi through a rubber tube passed *via* the nasal cavity, the pharynx, larynx, and trachea after these parts have been anæsthetised. The examination is best conducted with the aid of the fluorescent screen and a tilting table. If the patient is placed in the correct position, it is possible to outline either the right or the left bronchus and, indeed, it is often possible to fill only the bronchus to the lobe it is desired to examine. This selective method of examination has great advantages as it may be difficult to disentangle the

shadows when all the bronchi are outlined. It is important that the examination should be conducted with great care and gentleness, for if the patient should cough, the alveoli become filled and obscure the bronchi.

Injection of "lipiodol" by means of a needle passed through the skin of the neck and the crico-thyroid ligament does not permit selective filling of the bronchi but this may be the only possible method with children.

Radiography of the bronchi after the injection of iodised oil has been largely superseded, except in special cases, by bronchoscopy, since it has been found that direct inspection of the interior of the trachea and bronchi through a bronchoscope is much more reliable and gives information of greater value.

Female Genital Organs.—Iodised oil may be used also in radiography of the uterus and the uterine tube. The cervix is dilated and the oil is injected directly into the uterus through a metal tube. If slight pressure is used some of the oil passes into the tubes and may reach the peritoneal cavity (Pl. LXXII, p. 745).

Other Uses of Iodised Oil.—Iodised oil may be injected into the **paranasal air-sinuses** and into the ducts of the salivary glands (Pl. XLIX, p. 592); and it may be used also to outline inflammatory sinuses and fistulæ.

Other Uses of Air or Oxygen.—Air may be injected into the peritoneal cavity by means of a needle passed through the linea alba immediately below the umbilicus. By the use of large quantities of air the **liver** and **spleen** may be demonstrated when the patient is in the erect position, and, if the patient is inverted, the pelvic organs can be seen. The method has fallen into disfavour because it is not free from risk, and also because it does not give any indication of the nature of the disease process even when enlargement and irregularity of outline of these organs have been demonstrated.

While the renal outlines can usually be seen in the ordinary radiograph, the suprarenal glands cannot be demonstrated unless a contrast-agent is used. Air may be injected into the perirenal fat through a needle inserted from behind about the level of the third lumbar transverse process. The air tends to collect between the kidney and its fat and passes upwards around the suprarenal gland and between it and the kidney. The **suprarenal gland** is thus outlined as well as the **kidney** (Pl. LXIX, p. 744), but the method is rarely used except for the demonstration of the gland, as the examination of the kidney by pyelography gives information of greater value than the mere outlining of that organ.

As already mentioned (p. 1554), air may be introduced into the synovial cavity of a joint, by which means the articular cartilage becomes apparent, and, in the case of the knee joint, the shadows of the semilunar cartilages may be seen (Pl. XXXV, p. 382).

Thorium Dioxide in Examination of Liver and Spleen.—This method is mentioned only to complete the list of the uses of contrast-agents. As already stated, thorium is a radio-active salt and for that reason is dangerous. In animals it has been found that thorium dioxide which has been injected intravenously collects in the reticulo-endothelial system of the liver and spleen and that these organs are increased in density and are thus more clearly visible in a radiograph. In Man, the method is never justifiable, because in time the liver and spleen become severely damaged by the radio-activity of the salt, and there may also be destruction of the bone-marrow and even the production of malignant tumours.

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